GROWTH, CAPITAL AND NEW TECHNOLOGIES

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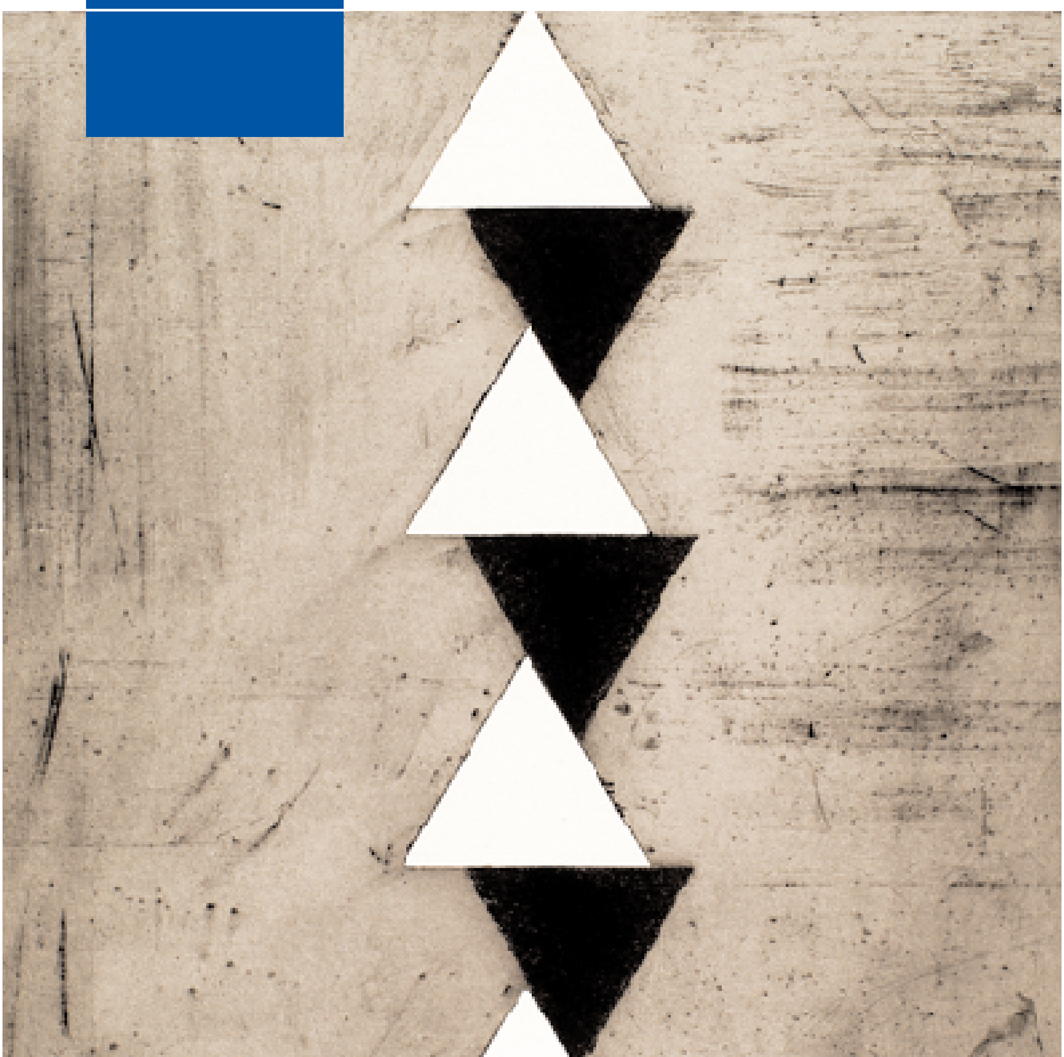

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Introduction

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DURING the 1990s, the United States experienced an upsurge in economic growth. Despite the fact that some of this acceleration was of a purely cyclical nature, more long-term structural explanations were also proposed, in particular the role of information and communication (ICT) capital and the production of ICT assets. The contrast between the U.S.'s growth record and the much more modest progress of the European Union (EU) was sometimes interpreted as being the result of the EU's backwardness in the use and production of assets related to new technologies. If there has indeed existed such a gap and if it explains differential growth performances, this has important political consequences from the point of view of designing strategies for economic growth, such as those set out by the EU at the Lisbon and Barcelona summits.

However, the economic profession is still far from generally accepting that ICT investment and production have been the main driving forces behind the U.S.'s economic growth. It is also unclear whether the explanation for the EU's relatively poor record during recent years can be found in the actual or assumed gap in ICT investment and use. Furthermore, the lack of reliable and comparable data, in particular of estimates of capital stock series and ICT capital for a number of EU countries, has hampered any assessment of the growth contribution of technology-related assets.

Growth, capital measurement and new technologies are the main topics addressed in this book, which is the result of the contributions presented and discussed in an international seminar organized by the BBVA Foundation and the Ivie (Valencian Institute of Economic Research) in Valencia, Spain, on 25–26 November 2002. All the papers presented there have been updated for this edition.

The objective of the seminar, and therefore of the book, was to discuss the main features of the economic growth process from an international perspective. One aspect received special attention: the role played by capital accumulation in general, and by ICT capital in particular. To develop this subject, the book deals with both measurement and analytical aspects of investment and capital, especially regarding ICT. The papers focus on capital services measures since they are thought most suitable for productivity analysis and for analyzing the contribution of ICT capital to growth. The book also focuses on the EU and the U.S. because their comparison has given rise to much debate.

Analysis of the sources of growth has received much attention not only from researchers but also from policy makers and the media. The seminal article by Solow (1957) proposed the *Growth Accounting Approach* as a framework for quantifying the contributions of technical progress, labor and capital to aggregate growth. Since then, an extensive amount of theoretical and empirical evidence has been provided, extending Solow's initial methodological framework in different directions, as well as testing whether his conclusions could be generalized to other economies besides the U.S.

Solow's main result was in a sense disappointing because it ranked technical progress as the driving force of economic growth and relegated the virtues of frugality—i.e. saving and capital accumulation—to a much more modest place. The professional responses to this conclusion have moved in many different directions, and a great deal of research has been aimed at *rescuing* the role of capital accumulation in economic growth.

One important line of research has centred on the problems posed by the measurement of capital input. Questions of data availability aside, Solow's hypothesis has been tested using what is now considered to be an inappropriate measure of capital input. The traditional measure of the net capital stock, widely produced by statistical offices as a measure of *wealth*, reflects the market value of capital goods, but is not normally the best measure to assess their contribution to production. The latter is best captured by measures of the productive stock and *capital services* as developed by Jorgenson and Griliches (1967). The two measures of capital produce different results and may lead to different conclusions about the role of capital in production. The present book devotes some space to the measurement issues that arise when capital's contribution to production is analyzed.

In the following pages we set out the main contributions of the book made by the different authors around eight topics.

1. Methodological issues

Measurement problems are central to this book. Schreyer and Dupont's paper, in Chapter 1, restates the concepts of capital measurement. It presents capital services measures and describes estimation methods, along with a number of salient theoretical and practical issues. Most of these issues concern the treatment of technical change, depreciation and obsolescence in capital services measures. One of its main conclusions is that methodology matters. The reason is that productivity analysis, central to the assessment of growth patterns, relies on the availability of statistical series on the prices and quantities of capital services that enter the production process. But capital services estimates are sensitive to the choice of assumptions about age-efficiency functions, retirement patterns, assumed average service lives and rates of return. The use of appropriate investment deflators may also significantly impact on results, in particular when they concern fast-evolving high-technology products with large relative price changes.

A main feature of the methodology outlined is that it provides consistent estimates of gross, net (wealth) capital stock and capital services. The paper also discusses the various assumptions that typically flow into capital services estimates such as: (i) the form of the age-efficiency profile (the authors opt for a hyperbolic form); (ii) the pattern for the retirement distribution of assets (the authors choose a normal distribution); (iii) the selection of the rate of return (an exogenous approach is put forward);

and (iv) the question of methodological differences between countries in the construction of investment price series, in particular for ICT capital goods, that may impact on the analytical results (a *harmonized* deflator is used across countries). Based on these choices, Schreyer and Dupont develop a set of consistently constructed capital service data at the international level.

There is need for such data because, to date, only a small number of countries have produced time series of capital services as part of their official statistics. The capital services series developed by the OECD (Organisation for Economic Co-operation and Development) Secretariat complements these national data by making them comparable at the international level and by extending them to a broader number of countries. Results for a sample of eight OECD countries—Australia, Canada, France, Germany, Italy, Japan, United Kingdom and United States—are shown in the paper.

Mas, Pérez and Uriel's paper, in Chapter 2, presents the capital stock estimates for the Spanish economy, thus expanding the OECD database presented in Chapter 1. These estimates are built up from much more detailed information on assets than the OECD set: seventeen asset types, three of which are ICT assets and six are different types of infrastructure. The methodology closely follows the one used by the OECD. The paper also presents various results to test the sensitivity of the capital services estimates with regard to the assumptions made. The main conclusion is that the estimates are very sensitive to the choice of asset lives, but are fairly robust regarding the choice of retirement patterns or age-efficiency profiles.

Van Ark and Timmer's, as well as Vijselaar's and Melka and Nayman's papers follow the methodology developed by Jorgenson (1995), which is based on somewhat different assumptions: (i) geometric age-price and age-efficiency functions that imply; (ii) absence of an explicit retirement function; and (iii) an endogenous rate of return. They also use *harmonized* ICT deflators. As Mas et al. illustrate, the changes in the first two assumptions, with respect to the ones underlining the OECD and Spanish estimates, have few practical consequences on the estimated capital services growth rates in the long run, but they do matter for shorter time spans. Thus again, methodology matters.

Whether an endogenous or an exogenous rate of return should be adopted has been a long lasting debate with no definitive answer as yet. Schreyer and Dupont discuss the pros and cons of each alternative, favoring the exogenous approach, which is also the one adopted by the Spanish estimates. Conversely, the papers presented in Chapters 5, 6, 8 and 9 rely on the endogenous approach to determine the internal rate of return. It is important to bear this difference in mind since the growth accounting exercises provide rather different results depending on which of the two approaches is adopted. As long as this debate remains unsettled, the precise quantification of the sources of growth will remain an open question.

2. Productivity and technology in the long run

Although ICT capital accumulation was already important by the beginning of the 1980s, these new technologies started to show their impact on U.S. economic growth only in the mid-1990s. This observation led to Robert Solow's famous remark that "computers could be seen everywhere except in the productivity statistics." Albers' paper in Chapter 3 concludes, however, that Solow's paradox is not a true paradox when placed in historical context.

After reviewing historical experiences in the UK and the U.S. (the 1716–1913 period for the UK and 1800–1989 for the U.S.), he concludes that aggregate productivity growth rates remained very low in the early stages of industrialisation, and increased only later in a very gradual process. Sudden jumps or discontinuities have been the exception and not the norm and, as a rule, cannot be easily attributed to technological factors. In other words, at first sight the long-term record does not support the assertion that overall productivity growth should necessarily accelerate markedly in response to the introduction of new technologies. There tends to be a significant lag between technological breakthroughs and their economic impact. Because the long-term positive impact is spread over time and often difficult to discern, the lasting gains of innovation are often not widely acknowledged.

However, Albers points to some important differences between ICT and innovations from earlier technological episodes. First, the speed of diffusion of ICT seemed to be much faster, and its direct economic impact larger in comparison to earlier general purpose technologies such as steam and electricity. Second, relative price declines of ICT goods have been extremely rapid, inducing much faster substitution of investment in cutting-edge technologies for older equipment. Third, the contribution of ICT to productivity growth seems to be larger than that of previous general purpose technologies. Finally, the sectoral composition of technology diffusion and investment is quite different. ICT investment can be found throughout knowledge-intensive service industries, whereas steam and electric power were much more narrowly confined to the mining, manufacturing and transport sectors.

As he concludes in his final remarks, "there is no compelling reason to be disappointed that the ICT *revolution* has not led to a clear surge in overall productivity growth throughout a wide range of advanced economies. Economic history suggests that it would be naïve to expect otherwise."

Pilat's paper in Chapter 4 shares the same view. He argues that the diffusion of ICT in OECD countries has been relatively rapid compared to some other technologies, although technological diffusion typically takes considerable time. Technological diffusion often follows an s-shaped curve, with slow diffusion when a technology is new and expensive, rapid diffusion once the technology is well established and prices fall, and slow diffusion once the market is saturated. As an illustration of the international differences he mentions that by 2000, Japan and the EU area had a share of ICT in total investment similar to that of the U.S. in 1980.

3. The effects of ICT on economic growth

The effects of ICT on economic growth run through three channels. First, the accumulation of ICT capital plays a similar role to other forms of capital accumulation, contributing to capital deepening and thus to overall productivity growth. From this perspective, it makes little difference whether investment is in ICT assets or in other forms of capital. Second, the ICT producing sectors have experienced rapid technical progress that has allowed them to produce goods of better quality at lower prices. In consequence, the improvements in labor productivity and TFP (total factor productivity) should be higher in the ICT producing sectors than in non-producing ones. Third, greater use of ICT may help firms to benefit from externalities or spillover effects between firms and industries and so benefit the more intensive ICT users. The positive effect of ICT on those last sectors can be reinforced if technical progress is embodied in the new forms of capital. Whichever of the aforementioned effects is at work, the conclusion is that the composition between ICT and non-ICT capital matters. This observation goes further than the simple capital deepening argument, which explains higher productivity gains in the ICT intensive users sectors by a higher overall propensity to invest in capital goods.

4. The ICT producing sector

Several studies have shown that rapid technological development in the ICT producing industries played a major role in the revival of TFP growth, in the U.S. As Pilat points out in Chapter 4, having an ICT producing sector can be important for growth, since ICT production has been characterised by rapid technological progress and very strong demand. Fast growth in this sector leads to a large contribution to economic growth, employment and exports. However, ICT production is a heterogeneous industry and there is significant variation in the types of ICT goods that are being produced in different OECD countries. Some countries only produce peripheral equipment, which is characterised by much slower technological progress and, consequently, by much less change in prices and productivity growth.

Furthermore, the presence of a large ICT producing industry is not a necessary condition for a country to benefit from ICT driven growth: many benefits from productivity gains in ICT producing industries accrue to countries that import these industries' products and to domestic users, due to terms-of-trade effects and an increased consumer surplus.

At the same time, Pilat also provides some reasons why an ICT producing sector can be important for ICT diffusion, thereby fostering economic growth. In the first place, it may help firms that wish to use ICT, since proximity with producing firms might have advantages when developing ICT applications for specific purposes. In the second place, a strong ICT producing sector should also help generate the skills and competences needed to benefit from ICT use. It could also lead to spin-offs, as in the case of Silicon Valley or other high technology clusters. Having an ICT sector can thus support ICT diffusion, although some studies have shown that it is not a prerequisite for benefiting from the technology.

In Chapter 5, Van Ark and Timmer provide some estimates of the contribution of ICT producing industries to aggregate TFP growth in the EU and the U.S. Their estimates can only be considered as preliminary results, since, as they argue, reliable TFP estimates for ICT producing sectors are not available for many EU countries. Due to this lack of empirical evidence, they make the strong assumption that TFP growth rates in the IT producing industries in the EU are the same as in their U.S. counterparts. EU specificities are taken into account by applying EU weights to these sectoral measures of productivity growth and examining the impact on aggregate GDP (gross domestic product) and productivity growth. Their preliminary results show that the contribution of ICT producing industries to TFP growth is higher in the U.S. than in the EU and that the difference increased during the second half of the 1990s. According to their estimates, for the period 1995–2000 about one third of the gap of 0.58 percentage points in aggregate TFP growth between the EU and the U.S. was due to the U.S.'s lead in the production of ICT.

Vijselaar's paper in Chapter 6 provides additional evidence for the euro area. According to his results, even though labor productivity growth in the ICT producing manufacturing sectors was clearly above average in the euro area, both higher productivity growth rates and the larger size of the ICT producing manufacturing sectors imply that the contribution to overall labor productivity growth from these sectors has been more important in the U.S. According to this author, developments in ICT producing sectors thus explain part of the observed differences in labor productivity growth between the euro area and the U.S.

Hernando and Núñez in Chapter 8 present similar results for Spain. In contrast to the other studies presented in this book, they rely on firm level data provided by the Central Balance Sheet Office of the Bank of Spain. According to their results, ICT producing sectors have experienced higher ICT capital growth rates and higher ICT contributions to value-added growth than other economic sectors. This is especially the case for the second half of the sample period (1996–2000). Besides, value-added growth rates in these sectors have been significantly higher than those of the rest of the economy. They conclude that ICT producing sectors have contributed positively to output growth, although given the modest share of ICT value-added in Spain (around 5.2%) this contribution has remained small. In terms of TFP, ICT manufacturing and ICT communications have experienced much higher growth rates than other sectors. These growth rates accelerated in the second half of the nineties, in contrast to the slowdown in TFP growth in the whole market economy.

5. Europe vs. U.S. growth performance

Several papers in this book propose complementary explanations for the different performances of many European countries and the U.S. in the second half of the nineties. While the U.S. experienced an acceleration of labor productivity growth in the second half of the 1990s, this was not the case for most European countries.

The first explanation of these phenomena has already been mentioned in the previous section: the greater importance and better performance of the ICT producing industry. However, this does not seem to be the main reason. Van Ark and Timmer's paper shows that faster GDP and labor productivity growth in the U.S. vis-à-vis the EU-12 in the latter half of the 1990s is linked to more investment in ICT. Although the growth rates of U.S. and EU IT investment have been comparable, levels of IT investment in the former remain much higher than in the latter, explaining the correspondingly higher contribution of ICT capital to output and labor productivity growth. Vijselaar for the euro area countries, Melka and Nayman for France, and Hernando and Núñez for Spain highlight the same result.

However, Van Ark and Timmer, as well as Vijselaar, agree on attributing the weaker performance of European countries to two factors: (i) the strong deceleration of non-ICT capital deepening; and (ii) the drop of TFP growth in the non-ICT producing industries in the EU countries, in contrast with the acceleration in the U.S. A similar result is found by Melka and Nayman. According to them, capital deepening decelerated in France, Germany and the United Kingdom in spite of the rising contribution of ICT. This increase was accompanied by a sharp decrease in the contribution of non-ICT capital deepening (non-residential structures and to a lesser extent other non-ICT equipment).

Van Ark and Timmer argue that point (ii) above is closely related to the lack of spillover effects in the EU as a consequence of the following combined factors: lower levels of IT investment, an insufficient degree of organisational innovations accompanying ICT, and structural impediments. They argue that restrictive rules and procedures on working hours and employment protection in Europe limit flexibility in organizing the workplace and hiring and firing workers. In addition, restrictions on labor and product markets might have limited the opportunities to allocate IT to its most productive uses in Europe, in particular in services industries, which are among the biggest IT investors.

Vijselaar shares the view that the differences between the EU and the U.S. may be explained by differences in the regulatory framework, but also by problems with the measurement of output in the services sector. The *Slifman/Corrado* type of simulation that he proposes provides evidence in this regard, but he concludes that it is unlikely that measurement issues explain all the differences.

6. ICT impact on structural change

Wolff's paper in Chapter 7 argues that ICT has had additional effects on the economy. Based on regression analysis, he presents evidence that the degree of computerisation has had a significant effect on changes in industry input coefficients and other dimensions of structural change. These include occupational restructuring and changes in the composition of intermediate inputs, as well as changes in the overall dispersion of the size distribution of establishments within manufacturing.

From his point of view, the diffusion of IT appears to have *shaken up* the U.S. economy beginning in the 1970s. However, this was a technological revolution that showed up more strongly in measures of structural change than in terms of productivity. The strongest results of the effects of IT on productivity growth were found in the late 1990s, while Wolff's results seem to indicate that it had strong effects on changes in occupational composition and input structure dating from the early 1970s.

The two sets of results—no evidence that computer investment is positively linked to TFP growth until the middle of the 1990s, plus strong and positive association of computerisation with structural change—might reflect the high adjustment costs associated with the introduction of new technologies. The results are also consistent with an alternative interpretation of its role in modern industry. Wolff's argument is that a substantial amount of new technology may be used for product differentiation rather than productivity enhancement. Computers allow for greater diversification of products, which in turn permits greater price discrimination and the ability to extract a large portion of consumer surplus. Greater product diversity might increase a firm's profits, though not necessarily its productivity.

7. The impact of ICT at the firm level

Pilat remarks in Chapter 4 that the strongest evidence for the economic impacts of ICT use emerges from firm-level studies. The main results stemming from these studies are the following. First and most important, the use of ICT does not guarantee success. As he points out, many of the firms that improved performance thanks to their use of ICT were already experiencing a better performance than the average firm. Second, those technology users that were using communications technologies or combining technologies from several different technology classes increased their relative productivity the most. In turn, gains in relative productivity were accompanied by gains in market share. Third, some ICTs may be more important for firm performance than others. Computer networks may be particularly important, as they allow a firm to outsource certain activities, to work more closely with customers and suppliers and to better integrate activities throughout the value chain. These technologies are often associated with network or spillover effects. Fourth, the studies that he reviews show that the benefits of ICT appear to depend on sector-specific effects and are not found in equal measure in all sectors.

Finally, Pilat summarises the following factors that affect the impact of ICT at the firm level: (i) many empirical studies suggest that ICT primarily affects firms in which skills have been improved and organisational changes have been introduced; (ii) studies typically find that the greatest benefits from ICT are realised when ICT investment is combined with other organisational changes, such as new strategies, new business processes and practices and new organizational structures; (iii) company size affects the impact of ICT, increasing with the size of firms and plants; and (iv) ICT use is closely linked to innovation in general, and notably to process innovation. The links between ICT and innovation go in both directions. On the one hand, firms that have innovated in the past are more likely to have the abilities required to implement ICT and make changes that are needed to benefit from ICT. On the other hand, ICT can help firms to strengthen innovation, as it helps to foster networking and informal learning between firms that is often the key to innovation in services.

8. Growth and convergence

The volume closes with De la Fuente's contribution on the empirical results and theoretical implications of the neoclassical convergence hypothesis. Both his focus and methodology lend an additional perspective to the rest of the papers presented at the conference. While these concentrate on growth performance as such, he asks whether poor countries or regions have grown faster than rich ones. His emphasis thus moves from the identification of the sources of growth to the existence of convergence/divergence among economies, the theoretical foundations of the convergence mechanisms, and the available empirical evidence. ICT capital accumulation is not in the centre of his analysis, but most of the topics he addresses are closely related to the main subjects discussed here.

De la Fuente's paper points to the need to consider other forms of capital in order to reconcile the empirical results of the convergence literature with the standard neoclassical model. The only departure from the traditional assumptions required for explaining the empirical evidence is a broadening of the traditional physical capital concept to include at least two additional elements: technological and human capital.

One possible way of measuring these assets is to accumulate educational investment in the case of human capital, and R&D (research and development) expenditures in the case of technological capital. Formally, this can be done in a similar way as for traditional physical assets, as explained in Schreyer and Dupont and Mas et al. This avenue is currently being explored by the international community of national accountants who are considering a capitalization of R&D. The main problems to be addressed are the specification of the average service lives and the age-efficiency profiles needed to produce capital services estimates. A second alternative, adopted in the Melka and Nayman paper, is to introduce a labor quality index constructed under the assumption that wages reflect true marginal productivities of the different kinds of labor.

One interesting result of De la Fuente's paper is that about 30% of relative productivity differentials among a set of OECD countries can be attributed to TFP. His conclusion is the clear need for additional work on the dynamics and determinants of the level of technical efficiency, which seems to be gaining importance over time as a source of labor productivity disparities. This last point has been well documented in some of the papers presented in this volume, where differences in TFP performance have played an important role in the disparities in output growth between the U.S. and the European Union since the middle of the nineties.

9. Concluding remarks

The present collection of papers aims to improve our understanding of the drivers of economic growth and productivity performance in the 1990s, and specifically the role of ICT. Along with similar work (e.g., OECD 2004) the studies show that knowledge of the effects of ICT has significantly improved from what it was only a few years ago.

Although knowledge has advanced, several key issues remain poorly analyzed. For example, evidence on firm dynamics and the conditions under which new firms are created is still scarce and could usefully complement industry-level and aggregate statistics on productivity growth. There is also room for the development of improved measures of labor and capital input at the industry level, and advancement on tricky measures of output in ICT related service industries such as banking, insurance, health and business services.

Work at the national and at the international level has started, and can go a long way as in the case of Spain, where private sponsorship has helped to develop a complete set of new capital services data that usefully complements official statistics. Such partnerships could well be a model for future developments in specific statistical areas, and it is hoped that the present volume helps to identify the most promising analytical avenues.

References

JORGENSON, Dale W. *Productivity*. Vols. 1 and 2. Cambridge, MA: MIT Press, 1995.

JORGENSON, Dale W. and Zvi GRILICHES. "The Explanation of Productivity Change." *Review of Economic Studies* 34, no. 3 (July 1967): 249–80.

OECD. *The Economic Impact of ICT: Measurement, Evidence and Implications*. Paris: Organisation for Economic Co-operation and Development, 2004.

SOLOW, Robert. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39, no. 3 (1957): 312–20.

1. OECD Capital Services Estimates: Methodology and a First Set of Results[1]

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WHEN it comes to measuring capital, two dimensions need distinguishing: capital as storage of wealth, measured by the wealth or net stock and its evolution, and capital as a means of production, measured by the productive stock and its rate of change, the flow of capital services. Capital service measures constitute the conceptually correct measure for purposes of productivity and production analysis. This document presents in some detail the concepts underlying capital services measures and shows how they can be measured empirically. The various assumptions that flow into the measurement of capital stocks and capital services are outlined and discussed. Specifications are provided on how the OECD (Organisation for Economic Co-operation and Development) goes about measuring a set of capital services with a view to constructing an internationally consistent tool for productivity comparisons. Sensitivity analysis shows that methodological choices matter and need careful consideration. Despite some difficulties, the implementation of capital services measures not only offers a tool for productivity measurement but also leads to a consistent entity of measures of the gross stock, the net stock, prices and quantities of capital services and depreciation that are useful for research and analysis.

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1.1. Introduction

Measures of productivity are central to the assessment of growth patterns. Measures of multi-factor (total factor) productivity or of capital productivity rely on the availability of statistical series on the prices and quantities of capital services that enter the production process. Two OECD manuals, *Measuring Productivity* (2001a) and *Measuring Capital* (2001b) have described the concept and measurement of capital services and their relation to the better-known measures of gross and net capital stocks. Both manuals are very clear in their recommendation that volume indices of capital services are the appropriate measure of capital input for activity and production analysis. Unfortunately, to date only a small number of countries produce time series of capital services as part of their official statistics.[2] This document reports on an initiative by the OECD Secretariat to develop a set of capital service measures for a broader number of countries. The paper also raises a number of theoretical and practical issues that emerge in the context of capital measurement. Most of these issues concern the treatment of technical change, depreciation and obsolescence in capital service measures.

The following general conclusions have so far emerged from this work:

- Computation of capital services measures does not, in general, require a larger set of data or information than the computation of gross and net capital stock series. Indeed, the different capital measures are and should be based on the same statistical information.
- The capital services approach not only offers a tool for productivity measurement but also leads to a consistent entity of measures of the gross stock, the net stock, prices and volumes of capital services, and consumption of fixed capital. There is sometimes a dissociation of capital services

[2] This is the case for Australia (Australian Bureau of Statistics [ABS]), the United States (Bureau of Labor Statistics [BLS]) and Canada. Results for Spain are presented in the next chapter (Mas, Pérez, and Uriel 2006) and recently, work has been taken up in the United Kingdom.

measures for productivity analysis from depreciation and net stock measures in the national accounts. Where possible, these measures should be consistent and derived from the same model, as spelled out in the present paper.

- Methodology matters. Capital services estimates are sensitive to the choice of deflators, in particular for fast-evolving, high-technology products. But assumptions about age-efficiency functions and the choice of the rate of returns also play a role. There is no best way to deal with some of these issues but it is obvious that more and better empirical information could settle a number of outstanding issues in capital service measurement.
- The present calculations raise questions about the level of detail at which OECD member countries publish investment data. In particular, there is an issue about the level of asset detail. From the perspective of capital services measurement, the separate recognition of certain investment goods (e.g. IT [Information Technology] equipment) with large relative price changes would be desirable.
- Open questions remain, though. They are of a conceptual nature (e.g., some questions regarding the treatment of obsolescence) and of an empirical nature (e.g., the form of age-efficiency functions, the choice of service lives, or the comparability of price indices). Some of these issues may merit a specific international effort to advance in a co-ordinated manner, others will require new empirical studies at the national level to put capital measures on a more solid empirical footing.

1.2. Framework

Capital services measures are based on the economic theory of production and have been described in OECD (2001a, 2001b). The present framework offers a more complete treatment, in particular with regard to measurement of depreciation, obsolescence and expectations. It builds on the work by Jorgenson (1995), Hulten (1991), Triplett (1996, 1998), Hill (2000) and Diewert (2001).

In a production process, labor, capital and intermediate inputs are combined to produce one or several outputs. Conceptually, there are many facets of capital input that bear a direct analogy to measures of labor input (Table 1.1). Capital goods that are purchased or rented by a firm are seen as carriers of capital services that constitute the actual input in the production process. Similarly, employees hired for a certain period can be seen as carriers of stocks of human capital and therefore repositories of labor services. Differences between labor and capital arise because producers usually own capital goods. When the capital good *delivers* services to its owner, no market transaction is recorded. The measurement of these implicit transactions —whose quantities are the services drawn from the capital stock during a period and whose prices are the user costs or rental prices of capital—is one of the challenges of capital measurement for the productivity analyst. We also note that there has been a long-standing academic debate about the fundamental nature of capital and its role in production. One approach, also adopted in this paper, is centred on prices and volumes of capital services. Another approach considers as fundamental the services not of the capital good, but of *waiting*, i.e., the act of foregoing today's consumption in favor of building up capital goods and future consumption (see Rymes 1971 for a discussion).

TABLE 1.1: **Labor and capital inputs**

Stock measures	**Labor input** **Human capital**	**Capital input** **Physical capital**
Services to production from input factors:		
Quantity	Labor services, measured as total person hours worked	Capital services, measured for example as total machine hours (typically, assumed to be in fixed proportion to capital stock)
Prices	Compensation per hour	User cost of capital per unit of capital service
Differentiation	By industry and by type of labor input	By industry and by type of capital asset
Factor cost or factor income	Compensation per hour multiplied by total hours	User costs multiplied by productive capital services
Aggregation weights	Industry-specific and labor quality-specific shares in total compensation	Industry-specific and asset specific shares of user costs of capital

1.2.1. Capital measures for a single homogenous asset

Capital services and the productive stock

For any given type of asset, there is a flow of productive services from the cumulative stock of past investments. This flow of productive services is called *capital services* of an asset type and is the appropriate measure of capital input for production and productivity analysis. Conceptually, capital services reflect a quantity, or physical concept, not to be confused with the value, or price concept of capital. To illustrate this, take the example of an office building. Service flows of an office building are the protection against weather, and the comfort and storage services that the building provides to personnel during a given period.

The price of capital services is measured as their rental price. If there were complete markets for capital services, rental prices could be directly observed. In the case of the office building, rental prices do indeed exist and are observable in the market. This is not the case for many other capital goods that are owned and for which rental prices have to be imputed. The implicit rent that capital good owners *pay* themselves gives rise to the terminology user costs of capital. Frequently, no conceptual distinction is made between rental prices and user costs. However, this requires that several added hypotheses (e.g., existence of complete and fully functioning markets for all types and vintages of capital goods) hold. For the purpose at hand, the distinction will be made: we define rental prices as market prices for the use of capital assets, where market transactions actually take place. User costs of capital are the costs of using capital assets that arise for the owner-producer. A more extensive discussion of user costs can be found below.

Of course, the price for capital services will vary as a function of the age of the capital good. Typically, the user cost for an older piece of capital is lower than the user cost for a new capital good, reflecting the differences in productive efficiency of the two items. Total payments for capital services are then the product of the user costs for each asset and the quantity of capital services for each asset and vintage. Some notation is needed here for clarity. Call $uk^i_{t,s}$ the price of capital services that are derived from an *s*-year old capital good of type *i* in year *t*, and call $K^i_{t,s}$ the quantity of capital services associated with an *s*-year old asset. Total payments for capital services are given by expression (1.1). They are expressed in current prices but for convenience we assume that these current price payments can be broken up into a price component uk^i_t and a quantity component K^i_t.

$$uk^i_t K^i_t = uk^i_{t,0}K^i_{t,0} + uk^i_{t,1}K^i_{t,1} + uk^i_{t,2}K^i_{t,2} + uk^i_{t,3}K^i_{t,3} + \ldots \quad (1.1)$$

Typically, neither the flow of capital services nor its market prices are directly observable. The assumption is thus made that the flow of capital services from an *s*-year old asset is in proportion to the volume of investment of that asset *s* years ago. Let λ^i_t be the proportionality factor by which capital service flows and vintage investment are linked. The quantity of investment of asset *i* in year *t*, I^i_t, is either measured in physical units if a truly homogenous asset can be observed, or is obtained as the deflated value of current price investment. For this and other purposes, let q^i_t be the price index for an *s*-year old asset of type *i* prevailing in year *t*.

Further, a retirement pattern is needed that describes how assets are withdrawn from service (scrapped, discarded). Typically, a retirement pattern is a distribution around the expected or mean service life. Each truck in a fleet of identical vehicles of the same age has the same expected service life. In practice, some of the trucks will be retired or scrapped before the expected service life, others later. This phenomenon is described by the retirement pattern. For the present purpose, we use a function F_s to describe the retirement pattern. F_s is non-negative and falling as *s*, the age of an asset, increases. For a new asset with $s = 0$, F_0 takes a value of one.

It is also assumed that the investment goods purchased and installed in period *t* give rise to a flow of capital services in the following period. In the absence of specific empirical information about the length of lags between purchases of investment goods and their actual use in the production process, this seems like a reasonable and simple assumption that is maintained for all types of assets. The flow of capital services is then approximated by:

$$K^i_{t,s} = \lambda^i_t F^i_s I^i_{t-s-1} \quad (1.2)$$

Combining expressions (1.2) and (1.1) yields:

$$uk_t^i K_t^i = uk_{t,0}^i \lambda_t^i F_0^i I_{t-1}^i + uk_{t,1}^i \lambda_t^i F_1^i I_{t-2}^i + \\ + uk_{t,2}^i \lambda_t^i F_2^i I_{t-3}^i + uk_{t,3}^i \lambda_t^i F_3^i I_{t-4}^i + \ldots \quad (1.3)$$

$\lambda_t^i uk_{t,s}^i F_s^i I_{t-s-1}^i$ represents the value of capital services in period *t*, derived from investment *s* periods ago. $uk_{t,s}^i$ has been defined as the price of one unit of capital services. More frequently, user cost expressions are defined in terms of the cost of using one unit of vintage investment. We call the so defined user cost term $u_{t,s}^i$ and compute it as $u_{t,s}^i = \lambda_t^i uk_{t,s}^i$. (1.3) is then re-written as:

$$uk_t^i K_t^i = u_{t,0}^i F_0^i I_{t-1}^i + u_{t,1}^i F_1^i I_{t-2}^i + u_{t,2}^i F_2^i I_{t-3}^i + u_{t,3}^i F_3^i I_{t-4}^i + \ldots \quad (1.4)$$

Next, a behavioral relationship has to be introduced (Hulten 1991): a rational, cost-minimising producer will choose a vintage composition such that the relative productivity of different vintages is equal to the relative user costs of the two vintages. The relative marginal productivity of two vintages of the same type of assets is captured by the *age-efficiency function*. This reflects the loss in productive capacity of a capital good over time or the rate at which the physical contributions of a capital good to production decline over time, as a result of wear and tear and technical obsolescence. For the purpose at hand, the age-efficiency function is called h_s^i, with non-negative values that decline with rising age *s*: $h_s^i = 1$ for a new capital good ($s = 0$) and $h_s^i = 0$ for a capital good that has reached its maximum service life ($s = T$). In this general formulation, no other assumptions are made concerning the shape of h_s^i. For the empirical implementation, it will be assumed that the age-efficiency function is hyperbolically shaped. In a functioning market, the following relationship holds: $\left(h_s^i / h_0^i\right) = \left(u_{t,s}^i / u_{t,0}^i\right)$ or $u_{t,s}^i = u_{t,0}^i h_s^i / h_0^i$. When this term is inserted into (1.4), one obtains:

$$uk_t^i K_t^i = u_{t,0}^i \left(F_0^i I_{t-1}^i + h_1^i F_1^i I_{t-2}^i + \right. \\ \left. + h_2^i F_2^i I_{t-3}^i + h_3^i F_3^i I_{t-4}^i + h_4^i F_4^i I_{t-5}^i + \ldots\right) \quad (1.5)$$

BOX 1.1: How restrictive are age-efficiency functions?

It is common procedure, and also adopted in the present case, to assume that the relative user costs of different vintages of capital can be represented by a time-invariant age-efficiency function. This assumption has been challenged on the grounds that it is overly restrictive when it comes to capturing the effects of obsolescence of capital goods. To understand this point, it is useful to recall that in a well functioning market and with a rational producer, user costs of a particular vintage of capital will just equal the marginal revenues from employing this vintage in production. Thus, the assumption that relative user costs are captured by a time-invariant age-efficiency function implies that the ratio of marginal productivities of two vintages does not change over time.

This view has been challenged, for example by Harper (2002) who points out that cyclical effects and obsolescence typically affect different vintages in a disproportional way. For example, the introduction of a new computer model may have little impact on the marginal productivity of a one-year old model already in use, but it may lead to discarding a five-year old model, thereby reducing its marginal productivity to zero. This is possible when quantities of computing power associated with different models are not perfect substitutes, e.g., because they require different combinations with labor, as is the case in Harper's model. Such an event implies disproportionate implications for marginal productivities and user costs of different vintages and is incompatible with a constant age-efficiency function.

Harper proposes a *machine model* with vintage-specific production functions. Machines are aggregated to *M-capital*, using the property that the rents per unit of *M-capital correspond* to the price of output which is therefore identical across machines. This solves the aggregation problem but implies deflation of the value of capital services with a single deflator, the price of output, which does not really give rise to a meaningful volume measure of capital (for a more extensive discussion of Harper, see Diewert 2002).

Another issue[1] concerns the effects of enterprise demography and firm-specific investment on average age-efficiency functions. When firms exit, their productive capital often suffers a *sudden death* as firm-specific assets are not directly or only at significant cost, re-usable by other firms. As churning rates of enterprises are important, this form of obsolescence may affect the overall, average length of service lives and/or the form of the age-efficiency and age-price curve.

Thus, there is no easy way to reconcile current measurement approaches for capital with a more general treatment of obsolescence and other forces that may affect marginal productivity of vintages in a differential way. More research and a good empirical understanding of the effects of obsolescence will be needed in this area.

[1] This point was raised by John Baldwin (Statistics Canada) in a recent workshop on productivity measurement. Empirical studies carried out by Statistics Canada provide evidence for such an effect.

With expression (1.5), one is close to an operational expression for estimating a price and quantity component of capital services. As a last step, we define the productive stock of asset i at the end of period t–1 as:

$$S_{t-1}^{i} = F_0^i I_{t-1}^i + h_1^i F_1^i I_{t-2}^i + h_2^i F_2^i I_{t-3}^i + h_3^i F_3^i I_{t-4}^i + h_4^i F_4^i I_{t-5}^i + \ldots \quad (1.6)$$

The importance of measuring the productive stock in productivity analysis derives from the fact that it offers a practical tool to estimate flows of capital services—were the latter directly observable, there would be no need to measure capital stocks. Given information or assumptions about the age-efficiency function h_s^i, about the retirement pattern F_s^i and about the volume of vintage investment $I_{t,s}^i$, (1.6) is an expression of the perpetual inventory method that yields a measure of the productive stock of asset *i*. The productive stock of asset *i* is the sum of all vintage investment in this type of asset, corrected for the probability of retirement, and corrected for its loss in productive capacity, so that S_t is expressed in *new equivalent* units of year *t*. Such additive aggregation across vintages (Hulten 1991) implies perfect substitutability between investment goods of different vintages.[3] Inserting (1.6) into (1.5) yields:

$$uk_t^i K_t^i / u_{t,0}^i = F_0^i I_{t-1}^i + h_1^i F_1^i I_{t-2}^i + h_2^i F_2^i I_{t-3}^i + \\ + h_3^i F_3^i I_{t-4}^i + h_4^i F_4^i I_{t-5}^i + \ldots = S_{t-1}^i \quad (1.7)$$

From (1.7), it is apparent that the productive stock of asset *i* at the end of period *t* in *new equivalent* units is equal to the deflated value of capital services, where the price index for deflation of $uk_t^i K_t^i$ is the user cost for a new asset in year *t*, $u_{t,0}^i$. Put differently, the value of capital services at current prices is equal to the volume of the productive stock in *new equivalent* units, valued at user costs of a new capital good:

$$uk_t^i K_t^i = u_{t,0}^i S_{t-1}^i \quad (1.8)$$

For our empirical purpose of measuring the rate of change of the volume of capital services flowing from asset *i*, we simply form an index of the productive stock: S_t^i / S_{t-1}^i. This may seem straightforward but a number of qualifications are in place, spelled out in Box 1.2. Furthermore, for the aggregation procedure of capital service flows across assets we refer to the section on aggregation in this document.

[3] Diewert (2001) showed how less restrictive forms of aggregation can be used to construct volume indices across vintages. However, for the case of time-invariant age-efficiency functions and constant proportionality factors λ, results are identical and the more restrictive additive formulation has been kept here for simplicity of exposition.

BOX 1.2: What are the quantities in the value of capital services?

Expression (1.8) provides a breakdown of the nominal value of capital services into a price and into a volume component: the latter is the productive stock in *new equivalent* units and in prices of a (fixed) base year. The former is the user cost for a new asset. While this seems like a natural way to go about things, there is no compelling reason to do so. An alternative way of presenting the value of capital services is to consider not the user cost per unit of investment, but the user cost per unit of capital services. In the present notation, this would amount to expressing the price component as $uk^i_{t,0}$ and the quantity component as $\lambda^i_t S^i_{t-1}$.

This switch has no consequences for the *rate of change* of the volume of capital services as long as the proportionality factor λ^i_t is time invariant: $\dfrac{S^i_t}{S^i_{t-1}} = \dfrac{\lambda^i S^i_t}{\lambda^i S^i_{t-1}}$ for $\lambda^i_t = \lambda^i_{t-1} = \lambda^i$. However, if one maintains the more general formulation with a time-variant proportionality factor, the price-volume split will yield different results, as the volume index of capital services would be given by $\dfrac{\lambda^i_t S^i_t}{\lambda^i_{t-1} S^i_{t-1}}$. One obvious interpretation of $\dfrac{\lambda^i_t}{\lambda^i_{t-1}}$ is the rate of capital (or capacity) utilisation, so that the so computed capital input flow would be corrected for cyclical variations. Of course it is difficult to value $\dfrac{\lambda^i_t}{\lambda^i_{t-1}}$ empirically, and this is the principal reason why λ^i is either taken as time-invariant or simply relegated to the price component of the capital services expression.

But recognition of the fact that variations in the flow of capital services per unit of investment *should* be measured can be helpful. For example, an index of capital productivity would read as:

$$\textit{True}\text{ index of capital productivity} = \frac{\dfrac{Q_t}{Q_{t-1}}}{\left(\dfrac{\lambda^i_t}{\lambda^i_{t-1}}\right)\left(\dfrac{S^i_t}{S^i_{t-1}}\right)}$$

Without knowledge about $\dfrac{\lambda^i_t}{\lambda^i_{t-1}}$ we would measure capital productivity as:

$$\textit{Apparent}\text{ index of capital productivity} = \frac{\dfrac{Q_t}{Q_{t-1}}}{\dfrac{S^i_t}{S^i_{t-1}}}$$

A straightforward comparison of the two expressions shows that

$$\textit{Apparent}\text{ index of capital productivity} = (\textit{True}\text{ index of capital productivity})\left(\frac{\lambda^i_t}{\lambda^i_{t-1}}\right)$$

We are thus reminded that our empirical measure of capital productivity corresponds only to the true one if there are no variations in the intensity of the service flow. Otherwise, the empirical capital input measure will miss out on changes in $\frac{\lambda_t^i}{\lambda_{t-1}^i}$ —and under- or over-estimate true capital input and true capital productivity.

Similar observations can be made for multi-factor productivity measures that often show pro-cyclical variations. The present set-up shows that such variations could be explained by capital input measures where variations in $\frac{\lambda_t^i}{\lambda_{t-1}^i}$ have been assumed away.

1.2.2. The wealth (net) and the gross capital stock

Whereas the productive stock is designed to capture the productive capacity of capital goods, and by implication the flow of capital services, the wealth (net) stock measures the market value of capital assets. Conceptually, the more familiar *net capital stock* is synonymous to the wealth capital stock. *Wealth stock* is sometimes considered a more precise terminology, however, because there are other forms of *net* stock, in particular the productive stock which is the gross stock *net* of efficiency declines in productive assets.

The wealth (net) stock at prices of period t is called $q_t^i W_t^i$ and defined as in (1.9).

$$q_t^i W_t^i = q_{t,0}^i F_0^i I_t^i + q_{t,1}^i F_1^i I_{t-1}^i + q_{t,2}^i F_2^i I_{t-2}^i + q_{t,3}^i F_3^i I_{t-3}^i + \dots \quad (1.9)$$

Before moving on to the computation of user costs, a parenthesis is opened regarding the gross capital stock—a statistic frequently available in OECD countries. The *gross capital stock* is the cumulative flow of investments, corrected for the retirement pattern. It constitutes an intermediate step in the calculation of the productive stock that takes account of the withdrawal of assets but does not correct the assets in operation for their loss of productive capacity. Alternatively, gross capital stocks can be considered a special case of the productive stock, where the age-efficiency profile follows a pattern where an asset's productive capacity remains fully intact until the end of its service life (sometimes called *one-hoss-shay*).[4]

[4] More formally, a gross capital stock of asset i in year t based on the perpetual inventory method is calculated as the sum

$$F_0^i I_{t-1}^i + F_1^i I_{t-2}^i + F_2^i I_{t-3}^i + F_3^i I_{t-4}^i + F_4^i I_{t-5}^i + \dots$$

1.2.3. User costs

A fundamental relation in capital theory (Jorgenson 1963) states that the market price of an asset equals the discounted value of the rentals that the asset is expected to generate in the future. In the absence of complete markets, the same relation can be adopted for the user-owner of capital goods by stating that the value of an asset equals the discounted marginal revenues from using the asset in production in the future. Expectations are formed under the information set Ω_t available at the beginning of period *t*. We adopt the convention that the marginal revenues (the rentals if there is a market transaction) generated by an asset arise at the end of each period and are discounted with the nominal rate *r*. The discount rate applies equally to all expected rentals, but it may change over time as the information set changes. Marginal revenues of an *s*-year old asset are equal to its user costs, and called $u^i_{t,s}$ as before. $q^i_{t,s}$ is the purchase price of capital good *i* with age *s*, prevailing throughout period *t*. Note that all variables depend on the information set Ω_t. For notational simplicity, this is not explicitly stated but should be kept in mind.

$$q^i_{t,s}\big|_{\Omega t} = u^i_{t+1,s}(1+r_t)^{-1} + u^i_{t+2,s+1}(1+r_{t+1})^{-2} + \\ + u^i_{t+3,s+2}(1+r_{t+2})^{-3} + u^i_{t+4,s+3}(1+r_{t+3})^{-4} + \ldots \quad (1.10)$$

A simplification is introduced here: we assume that the discount rate *r* that applies to different future time periods is constant for every information set Ω_t: $r_{t+s} = r_t = r(\Omega_t)$ for all $s = 0,1,\ldots,T$. Expression (1.10) can be *solved* for u^i_t by shifting it by one period while keeping the information set Ω at period *t*, as in (1.11). This expression is then subtracted from (1.10) after multiplication by $(1+r)$. The result can be found in (1.12).

$$q^i_{t+1,s+1}\big|_{\Omega t} = u^i_{t+2,s+1}(1+r)^{-1} + u^i_{t+3,s+2}(1+r)^{-2} + \\ + u^i_{t+4,s+3}(1+r)^{-3} + u^i_{t+5,s+4}(1+r)^{-4} + \ldots \quad (1.11)$$

$$u^i_{t+1,s}\big|_{\Omega t} = q^i_{t,s}(1+r) - q^i_{t+1,s+1} \quad (1.12)$$

As a final step, we shift the information set to the beginning of period t–1 and express the user costs of capital in period t for an s year-old asset u^i_{t+1} as:

$$u^i_{t,s}\Big|_{\Omega t-1} = q^i_{t-1,s}(1+r) - q^i_{t,s+1} \qquad (1.13)$$

BOX 1.3: Use of expected variables: a contradiction with the national accounts?

The variables on the right hand side of (1.14) are expected variables, given the information available at the beginning of period t–1. These expectations govern the rental price $u^i_{t,s}\big|_{\Omega t-1}$. The System of National Accounts, to which capital stock data should tie into, is based on ex-post prices observed in the context of actual transactions. Would the use of user cost expressions such as the one above then be in contradiction with the principles of national accounts?

In our view, the answer is *no*. Note that the presence of expectations does not make $u^i_{t,s}\big|_{\Omega t-1}$ less *real*: transactions are concluded at this price, even if with hindsight (ex-post) the expectations underlying it may turn out to be wrong. This is most apparent when one thinks of a case where capital goods are actually rented: the observed rental price characterises the transaction and is the relevant market price, typically dependent on expectations on the side of the lessor and the lessee. Nobody would challenge using such observed prices in the national accounts. If rental prices are not observable, values have to be imputed, and equation (1.14) indicates how this can be done on the basis of economic theory. Imputations are numerous in the national accounts, and in this sense, the imputation of user costs would not constitute an exception.

Thus, it is not the presence of expected variable as such that is at issue. The real question from a capital and productivity measurement viewpoint is whether the realised but unobserved marginal productivity of fixed assets is better approximated by an ex-ante or by an ex-post measure of user costs? This question is discussed in Box 1.4.

(1.13) constitutes a computable expression for user costs of capital, if a set of market prices for vintage investment goods and a discount rate are available. Vintage prices are observable, although not for all assets, and empirical studies are rare and often outdated. It will thus often be necessary to compute sets of vintage prices, by invoking economic theory and a few additional assumptions. Before doing so, we transform (1.13) into a form frequently used in empirical work. To this end, define the (expected) rate of depreciation of asset i as $d^i_{t,s} \equiv 1 - q^i_{t,s+1} / q^i_{t,s}$ and the (expected) rate of price change of the same asset as $\zeta^i_t \equiv q^i_{t,s} / q^i_{t-1,s} - 1$. With these notations, the user cost term becomes:

$$u^i_{t,s}\big|_{\Omega t-1} = q^i_{t-1,s}\left(r + d^i_{t,s} - \zeta^{\,i}_t + d^i_{t,s}\zeta^{\,i}_t\right) \qquad (1.14)$$

(1.14) has, for example, been discussed by Hulten (1991) and shows that the user cost of capital for an *s*-year old asset is the product of the purchase price of this asset $q^i_{t-1,s}$ multiplied by the gross rate of return on this asset where the gross rate of return is the sum of the discount rate (or net rate of return), plus the rate of depreciation d^i_t minus the rate of asset price change $\zeta^{\,i}_t$ plus an interaction term of depreciation and asset price change $d^i_t\zeta^{\,i}_t$.

In the present set-up, rental contracts are concluded at the beginning of period *t*–1. The price specified in these rental contracts is the user cost, payable at the end of period *t*–1 (or at the beginning of the period *t*). When capital goods are owned and used in production by the same unit, the user cost term is implicit but the economic rationale remains the same: an asset will be used in production up to the point where its marginal revenues correspond to the expression on the right hand side of (1.14).

BOX 1.4: User costs: ex-ante or ex-post?

The distinction between expected or ex-ante user costs has been discussed by Berndt and Fuss (1986) Harper, Berndt and Wood (1989), Diewert (2001) and by Berndt (1991) in his discussion of Hulten (1991). In Box 1.3, it was concluded that the importance of the distinction between ex-ante and ex-post measures lies in their capacity to approximate the realised marginal productivity of capital assets. On this matter, Berndt (1991) points out that: "…if one wants to use a measure of capital to calculate actual multifactor productivity growth, then theory tells us quite clearly that we should weight the various traditionally measured capital inputs by their *realised* marginal products, not their *expected* marginal products. This means that in choosing capital service price weights, one should employ shadow values or ex-post rates of return, and not the ex-ante rates of return that are appropriate in the investment context."

While we concur with Berndt's statement that for purposes of productivity measurement, realised marginal products are the appropriate weights, we wish to point out that this does not necessarily imply that ex-post rates of return are always the preferred approximation to realised marginal productivity. Suppose that a capital asset is rented by a producer at a given, pre-agreed rental price to be paid by the end of the period. Independent of the ex-post rental price the lessee of the asset will use it in his production process as planned. Then, the marginal productivity of the asset in the production process would best be approximated by the ex-ante rental price which is the price at which the rental transaction took place.

Take another case of an owner/producer and suppose that there has been investment at the beginning of the period in line with the ex-ante user cost. Now let there be a change in market conditions that lead to a modification of expectations and of user costs. If capital is fully flexible and can be adjusted continuously, it will be done so in line with the new user cost term. But the user cost term remains one governed by expectations, even though expectations may have changed. Only when capital cannot be adjusted, the ex-post user cost term would furnish the preferred approximation to the realised marginal productivity of an asset. This is the case that Berndt (1991) and Berndt and Fuss (1986) have in mind and it relies on quasi-fixity of capital in the production process. In other words, there is no general conclusion that ex-post user cost measures should always be preferred to ex-ante one for purposes of measuring and aggregating capital input.

There is another conceptual difficulty with ex-post user costs: the computation of the realised rates of return is commonly done by choosing a rate of return so that the ensuing user cost and total value of capital services just exhausts the measured gross operating surplus available from the national accounts. This computation relies, however, on the assumption that there be *only one* ex-post rate of return across all assets. While equalisation of rates of return across assets is a natural assumption in an ex-ante context, it is much harder to justify in an ex-post context, and a state of disequilibrium. We would be imposing an equilibrium condition to implement an (ex-post) measure that was specifically chosen on the grounds that it captures the nature of a situation of disequilibrium.

Diewert (2001) also points out that while the ex-post measure (of the nominal rate of return) is widely used in empirical research, it is subject to measurement error and it may not reflect the economic conditions facing producers at the beginning of the period.

Note a practical argument against the ex-post rate: its calculation requires information on the level of the productive capital stock at current prices (or alternatively on the wealth stock at current prices). But levels of capital stocks tend to be less reliable statistics than their rates of change, in particular when long historical investment series have to be estimated. This problem does not arise when user costs and nominal rates of return are of an ex-ante nature and therefore exogenous variables. On the other hand, ex-post rates of return are of interest as such, and straightforward to compute. In sum then, there is no clear conclusion on this matter. For the present work, however, we gave preference to an ex-ante approach—mainly because it allows us to develop capital service measures independently from measures of labor compensation, gross operating surplus and mixed income in the national accounts.

1.2.4. Depreciation

Depreciation measures the loss in *value* of a capital good as it ages. This definition follows the productivity literature and associates depreciation with the wealth or net capital stock. It has to be distinguished from *decay* or *efficiency decline* that reflects the loss of productive services that can be drawn from a capital good. Efficiency decline or decay is associated with the productive capital stock. Patterns of depreciation pertain to the age-price profile of an asset, and patterns of decay to its age-efficiency profile.

The loss in value of a capital good as it ages is shown in its age-price profile or the pattern of relative prices for different vintages of the same (homogenous) capital good.[5] How steeply the price of a capital good falls as it ages depends on several factors, including the rate of loss of productive capacity and the remaining service life. Obsolescence is another source for the loss of value of an old asset because a newly introduced asset of the same class contains improvements in productiveness or efficiency (Triplett 1998). The market value of a five-year old truck is much lower than that of a new one, because the older truck has suffered from wear and tear and because its remaining service life is five years less than that of the new vehicle.

The age-price profile and age-efficiency profile of a specific type of capital good are not necessarily identical, but they are related. Thus, they cannot be defined independently of each other. A one-year old truck may have lost 20% of its market value but it has not necessarily lost 20% of its capacity to ship goods from one place to another. Indeed, the trucking services of a one-year old vehicle are probably nearly identical to those of a new one. Nonetheless, a change in service life or a different rate of efficiency loss will necessarily influence the value of existing assets. This illustrates the link between the age-price and age-efficiency patterns.

How does one compute the rate of depreciation $d^i_{t,s}$? In those cases where a set of vintage prices is available, the answer is straightforward: $d^i_{t,s} = 1 - q^i_{t,s+1} / q^i_{t,s}$ by definition. More often than not, however, the set of vintage prices is incomplete. In fact, most of the time, only time series of new asset prices $q^i_{t,0}$ are readily available. In this case, use has to be made of the asset price equilibrium condition (1.10) to derive consistent estimates of the age-price profile. More precisely, the price of an $s + 1$ year old asset relative to an asset that is s years old can be presented as:

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[5] Depreciation is understood here to measure the value loss due to ageing for a capital good conditional on its survival. Thus, the effects of retirement are not reflected in this measure—they are picked up as a volume change (retirement effect) in the wealth stock. It is also possible to have a different set-up where both the combined value loss due to the ageing of existing assets and the value loss due to retirement of assets enter the depreciation term.

$$\frac{q^i_{t,s+1}}{q^i_{t,s}}\Big|_{\Omega t} = \frac{\sum_{\tau=0} u^i_{t+\tau+1,s+\tau+1}(1+r)^{-(\tau+1)}}{\sum_{\tau=0} u^i_{t+\tau+1,s+\tau}(1+r)^{-(\tau+1)}} \qquad (1.15)$$

The vintage price ratio in (1.15) depends on expected user costs, and the discount rate prevailing at *t*, given the information available at the beginning of period *t*. To progress in this general case, one has to formulate expectations about future user costs of capital. Suppose that, given the information set Ω_t, users-owners expect user costs to change at a rate of ξ^i percent per period. In this case, one has $u^i_{t+\tau,s} = u^i_{t,s}\left(1+\xi^i\right)^\tau$. Note that although this has not been explicitly marked, ξ^i is dependent on the information set and may thus change over time. Then:

$$\frac{q^i_{t,s+1}}{q^i_{t,s}}\Big|_{\Omega t} = \frac{\sum_{\tau=0} u^i_{t,s+\tau+1}(1+\xi^i)^{\tau+1}(1+r)^{-(\tau+1)}}{\sum_{\tau=0} u^i_{t,s+\tau}(1+\xi^i)^{\tau+1}(1+r)^{-(\tau+1)}} \qquad (1.16)$$

Next, invoke behavioral equation $\left(h^i_s / h^i_0\right) = \left(u^i_{t,s} / u^i_{t,0}\right)$, which links the ratio of user costs to the age-efficiency profile. We use it to present the numerator and denominator in (1.16) in terms of the user costs for new capital goods in period *t* only:

$$\frac{q^i_{t,s+1}}{q^i_{t,s}}\Big|_{\Omega t} = \frac{\sum_{\tau=0} u^i_{t,0}h^i_{s+\tau+1}(1+\xi^i)^{\tau+1}(1+r)^{-(\tau+1)}}{\sum_{\tau=0} u^i_{t,0}h^i_{s+\tau}(1+\xi^i)^{\tau+1}(1+r)^{-(\tau+1)}} \qquad (1.17)$$

$u^i_{t,0}$ cancels out of expression (1.17) and one is left with the computable expression for vintage prices below. It depends on the age-efficiency profile, the discount rate and the expected rate of change of the asset price.

$$\frac{q^i_{t,s+1}}{q^i_{t,s}}\Big|_{\Omega t} = \frac{\sum_{\tau=0} h^i_{s+\tau+1}\left[\dfrac{(1+r)}{(1+\xi^i)}\right]^{-(\tau+1)}}{\sum_{\tau=0} h^i_{s+\tau}\left[\dfrac{(1+r)}{(1+\xi^i)}\right]^{-(\tau+1)}} \qquad (1.18)$$

1.2.5. More on expected price changes

Some further remarks are called for regarding equation (1.18). First, in the special case where the age-efficiency profile is geometric, and declines at a constant rate δ^i independent of time t and vintage s, the expression simplifies to an age-price profile that is also geometric. Suppose that $h^i_{s+\tau} = h^i_\tau(1-\delta^i)^s$. This yields

$$\frac{q^i_{t,s+1}}{q^i_{t,s}}\Big|_{\Omega t} = \frac{\sum_{\tau=0} h^i_\tau \left(1-\delta^i\right)^{s+1}\left[\frac{(1+r)}{(1+\xi^i)}\right]^{-(\tau+1)}}{\sum_{\tau=0} h^i_\tau \left(1-\delta^i\right)^{s}\left[\frac{(1+r)}{(1+\xi^i)}\right]^{-(\tau+1)}} = \left(1-\delta^i\right).$$ Age-price and age-efficiency profiles coincide and significantly simplify computations. Geometric rates have been widely used in empirical research, in particular by Jorgenson (1995) and many of his co-authors. However, geometric rates have also been criticised for several reasons (see OECD 2001b for a discussion) and the general approach that does not rely on geometric rates is further pursued in this paper.

The second remark about expression (1.18) concerns the term $\frac{(1+r)}{(1+\xi^i)}$. It is easy to see that a nominal discount rate divided by a rate of price change represents a real interest rate, albeit a somewhat special one, obtained not by applying a general price index but by applying an asset-specific price index. Of course, we could also say that the expression $\frac{(1+r)}{(1+\xi^i)}$ is the ratio of a real interest rate $\frac{(1+r)}{(1+p)}$ divided by a relative price change $\frac{(1+\xi^i)}{(1+p)}$ where p is some overall expected price index such as the GDP (Gross Domestic Product) deflator or the consumer price index.

OECD (2001b) uses a special case where $\frac{(1+r)}{(1+\xi^i)}$ is taken as constant, at 1.04. This is justified on the grounds that a 4% rate is a reasonable order of magnitude for a long-term real interest rate. For this reasoning to hold, however, the expected relative price change $\frac{(1+\xi^i)}{(1+p)}$ between user costs and some overall price index have to be assumed away so that the 4% rate applies to the term

$\frac{(1+r)}{(1+p)}$. For this term it presents a plausible value, independent of the specific asset under consideration.

The present work also uses a constant, but country-specific figure for the expected real interest rate $\frac{(1+r)}{(1+p)}$. In addition, we also formulate an empirical measure for the expected relative price change $\frac{(1+\xi^i)}{(1+p)}$. Together with values for the age-efficiency function, and based on the relationship (1.18), this provides us with a set of vintage asset prices for every time period under consideration.

A look at the user cost expression (1.14) recalls that all variables are based on an information set available at the beginning of period *t–1*, and this includes the rate of change of the purchase price of asset *i*, ζ_t^i. Thus, ζ_t^i is also an expected variable. This is apparent from its definition as $\zeta_t^i = \frac{q_{t,0}^i}{q_{t-1,0}^i - 1}$ which includes $q_{t,0}^i$, a variable not yet known with certainty at the beginning of period *t*–1. A consistent set-up for the user cost expression has to take into account the nature of ζ_t^i as an expected variable, in line with the expected variables underlying the estimate for the depreciation rate $d_{t,0}^i$ and the nominal discount rate *r*.

There is a direct link between the expected change in the purchase price of an asset, ζ_t^i, and the expected rate of change of its user costs, ξ^i, if one imposes consistency of these two terms in a situation of balanced growth. Suppose that ζ_t^i, ξ^i and *r* are constant and on some equilibrium path: $\zeta_t^i = \zeta^{i*}$, $\xi^i = \xi^{i*}$ and *r* = *r**. By definition, $\frac{q_{t,s}^i}{q_{t-1,s}^i} = 1 + \zeta^{i*}$ and $\frac{u_{t,s}^i}{u_{t-1,s}^i} = 1 + \xi^{i*}$. But from (1.10) we also find that in this situation, $\frac{q_{t,s}^i}{q_{t-1,s}^i} = \frac{u_{t,s}^i}{u_{t-1,s}^i}$. Consequently, the long-run rate of asset price change has to be the same as the long-run rate of change of the user cost term, or $\zeta^{i*} = \xi^i$. We use this relation to simplify our empirical measurement of expected variables and set $\xi^i = \zeta^i$.

Yet another remark is in place here. In equation (1.8), it was shown that the value of capital services could also be presented as the productive capital stock multiplied by the user cost term for a *new* asset: $uk_t^i K_t^i = u_{t,0}^i S_{t-1}^i$. For the empirical calculations of capital services, only the productive stock S_{t-1}^i is needed as the quantity measure and the user cost expression $u_{t,0}^i$ as the price measure. From (1.14) it follows that $u_{t,0}^i = q_{t-1,0}^i \left(r + d_{t,0}^i - \zeta_t^i + d_{t,0}^i \zeta_t^i\right)$. Only the depreciation rate for a new asset enters the user cost term and all that is needed here is $d_{t,0}^i = \dfrac{q_{t,s}^i}{q_{r,0}^0 - 1}$.

1.3. Aggregation across different assets

Because many different types of capital goods are used in production, an aggregate measure of the capital stock or of capital services must be constructed. For net (wealth) stocks at current prices this is a straightforward matter of summing estimates for different types of assets. In so doing, market prices serve as aggregation weights. The situation is different in productivity analysis. Typically, each type of asset is associated with a specific flow of capital services and proportionality is assumed between capital services and capital stocks at the level of individual assets. This ratio is not the same, however, for different kinds of assets, so that the aggregate stock and the flows covering different kinds of assets must diverge. A single measure cannot serve both purposes except when there is only one single homogenous capital good (Hill 1999).

Jorgenson (1963) and Jorgenson and Griliches (1967) were the first to develop aggregate capital service measures that take the heterogeneity of assets into account. They defined the flow of quantities of capital services individually for each type of asset, and then applied asset-specific user costs as weights to aggregate across services from the different types of assets. User costs are prices for capital services and, under competitive markets and equilibrium conditions, these prices reflect the marginal productivity of the different assets. User cost weights thus provide a means to effectively incorporate differences in the productive contribution of heterogeneous investments as the composition of investment and capital changes.

An aggregate measure of the wealth (net) capital *stock*, on the other hand, uses *market prices* of individual assets to weight its components. Consequently, the difference between an aggregate index of capital services and an aggregate index of a capital stock can be seen in the sets of weights—the former is based on user costs, the latter on the market prices of the assets. In statistical practice, aggregate capital stock is often computed by summing up the stocks of individual assets, each measured at prices of a given base year. Over time, the quantity index of the capital stock will represent a Laspeyres-type index of aggregate capital, with market prices of a base year as weights.

1.3.1. Volume index of total capital services

To start out, define the total value of capital services as:

$$uk_t K_t = u_t S_{t-1} = \sum_{i=1} u_t^i S_{t-1}^i \tag{1.19}$$

where the productive stock per asset S_t^i and its associated user costs u_t^i as well as the flow of capital services from asset *i*, K_t^i, and its associated price uk_t^i have been defined and discussed earlier. In the total value of capital services, there is a quantity component that consists of the productive stocks of different assets S_t^i and a price component, the user costs. Thus, there is a price vector $\boldsymbol{u}_t \equiv [u_t^1, u_t^2, u_t^3, \ldots]$ and a quantity vector $\boldsymbol{S}_t \equiv [S_t^1, S_t^2, S_t^3, \ldots]$. The change in the value of capital services over time $\frac{u_t S_t}{u_{t-1} S_{t-1}}$ has the following index number decomposition:

$$\frac{u_t S_{t-1}}{u_{t-1} S_{t-2}} = U(\boldsymbol{u}_t, \boldsymbol{u}_{t-1}, \boldsymbol{S}_{t-1}, \boldsymbol{S}_{t-2})\, S(\boldsymbol{u}_t, \boldsymbol{u}_{t-1}, \boldsymbol{S}_{t-1}, \boldsymbol{S}_{t-2}) \tag{1.20}$$

where U and S are price and quantity indices respectively. For empirical implementation, we choose a Törnqvist index number and the volume index of depreciation of asset i is given by:

$$\ln \frac{S_t}{S_{t-1}} = \sum_{i=1} 0.5\left[v_{t+1}^i + v_t^i\right] \ln \frac{S_t^i}{S_{t-1}^i} \text{ with } v_t^i \equiv \frac{u_t^i S_{t-1}^i}{u_t S_{t-1}} \tag{1.21}$$

The price index for capital services is defined implicitly as

$$\frac{U_t}{U_{t-1}} = \left(\frac{\dfrac{u_t S_{t-1}}{u_{t-1} S_{t-2}}}{\dfrac{S_{t-1}}{S_{t-2}}} \right).$$

1.3.2. Net (wealth) stock

The total wealth stock at current prices is computed by simple addition of the wealth stocks of individual assets, i.e., as $q_t W_t = \sum_{i=1} q_t^i W_t^i$. Proceeding the same way as for capital services, a volume index of the next stock can also be derived by identifying a price vector $\boldsymbol{q}_t \equiv [q_t^1, q_t^2, q_t^3, \ldots]$ and a quantity vector $\boldsymbol{W}_t \equiv [W_t^1, W_t^2, W_t^3, \ldots]$ so that the total value change of the wealth stock $\dfrac{q_t W_t}{q_{t-1} W_{t-1}}$ can be decomposed into a price and a volume component:

$$\frac{q_t W_t}{q_{t-1} W_{t-1}} = Q(\boldsymbol{q}_t, \boldsymbol{q}_{t-1}, \boldsymbol{W}_t, \boldsymbol{W}_{t-1})\ W(\boldsymbol{q}_t, \boldsymbol{q}_{t-1}, \boldsymbol{W}_t, \boldsymbol{W}_{t-1}) \qquad (1.22)$$

where Q and W are price and quantity indices respectively. For empirical implementation, a Törnqvist index number can be used and the volume index of the wealth stock is:

$$\ln \frac{W_t}{W_{t-1}} = \sum_{i=1} 0.5 \left[v_t^{W,i} + v_{t-1}^{W,i} \right] \ln \frac{W_t^i}{W_{t-1}^i} \quad \text{with} \quad v_t^{w,i} \equiv \frac{q_t^i W_t^i}{q_t W_t} \qquad (1.23)$$

BOX 1.5: International comparability of price indices

Price indices are key in measuring volume investment, capital services and user costs. Accurate price indices should be constant quality deflators that reflect price changes for a given performance of ICT (Information and Communication Technologies) investment goods. Thus, observed price changes of *computer boxes* have to be quality-adjusted for comparison of different vintages. Wyckoff (1995) was one of the first to point out that the large differences that could be observed between computer price indices in OECD countries were likely much more a reflection of differences in statistical methodology than true differences in price changes. In particular, those countries that employ hedonic methods to construct ICT deflators tend to register a larger drop in ICT prices than countries that do not. Schreyer (2000) used a set of *harmonized* deflators to control for some of the differences in methodology. We follow this approach and assume that the ratios between ICT and non-ICT asset prices evolve in a similar manner across countries, using the United States as the benchmark. Although no claim is made that the *harmonized* deflator is necessarily the correct price index for a given country, we feel that the possible error due to using a harmonized price index is smaller than the bias arising from comparing capital services based on national deflators. For completeness and transparency, both sets of results are presented.

Note the difficulty with the harmonized deflator. From an accounting perspective, adjusting the price index for investment goods for any country implies an adjustment of the volume index of output. In most cases, such an adjustment would increase the measured rate of volume output change. At the same time, effects on the economy-wide rate of GDP growth appear to be contained (see Schreyer 2001, for a discussion).

BOX 1.6: Wealth and capital services in the presence of technical change—a numerical example

The choice of aggregation weights becomes crucial when prices and quantities of different types of capital goods evolve at very different rates. This is, for example, the case when there is relatively rapid quality change of one type asset compared to others. Aggregation of assets by way of purchase prices will generate a serious bias in the capital input measures because purchase prices will inadequately approximate the marginal productivity of assets which constitute the appropriate weights for aggregation of capital services. User costs are designed to measure the marginal productivity of assets, and the difference between purchase prices (*q*) and user costs (*uc*) is the gross rate of return (*GRR*) that an asset must yield per year: marginal productivity (marginal revenue) = *uc* = *q*GRR*. The gross rate of return itself is composed of the net rate of return, the rate of depreciation and rate of revaluation or asset price change. Rapid negative price changes or large rates of depreciation therefore imply large gross rates of return and user costs. Thus, an aggregation based on user cost weights will give more weight to assets with relatively large *GRR*s as opposed to an aggregation based on purchase prices, *q*.

Consider the following example with two assets, A and B. In period $t = 0$, the purchase price of both assets equals unit but declines by 30% in the case of A and rises by 10% in the case of B. Given the quantities of investment and the (geometric) rates of depreciation, a capital stock in period $t = 1$ can easily be calculated. In the present case, wealth and productive stock coincide at the level of individual assets. Assume a net rate of return of 5%. The total user cost is then computed as 0.55 for Asset A and 0.15 for Asset B. This gives rise to a share of Asset A in total user costs in period $t = 0$ of 79% and a share of Asset B of 21%—quite different from the 50% share for each asset when weights are based on purchase prices. Finally, construct a simple Laspeyres quantity index of capital services and the wealth stock and it is easy to see that the former rises much faster than the latter.

		Asset A	Asset B
Purchase price	t = 0	1	1
	t = 1	0.70	1.10
Quantity of investment	t = 0	10	10
	t = 1	15	8
Productive stock/Wealth stock	t = 0	10	10
	t = 1	23	16
User costs	Net rate of return	0.05	0.05
	Depreciation	0.20	0.20
	Revaluation	–0.30	0.10
	Total	0.55	0.15
Weights t = 0	User cost based	0.79	0.21
	Purchase price based	0.50	0.50
Laspeyres quantity index	User cost based	2.15	
	Purchase price based	1.95	

1.4. Results

The following section presents a first set of capital service measures[6] for the G-7 countries and Australia. These should be considered as a preliminary, and further tests have to be carried out before data is used in production and productivity analysis. Nonetheless, this first set of results gives rise to several points of discussion. To start with, Table 1.2 shows the volume changes of capital services by type of asset or by type of product. One notes that at the level of *individual* assets, the rate of change of capital services is just equal to the evolution of the productive stock. The aggregate index of capital services (Table 1.2) corresponds to a weighted average of the each asset's index of capital services where nominal shares in total user costs constitute the relevant weights.

Rates of change of deflators can be found in Table 1.4. To account for some of the methodological differences between countries' deflators for ICT products, the results presented here are based on *harmonized* deflators (see Box 1.5).

A first way of assessing the set of capital services measures produced here is to compare them with similar data published at the national level. Today, this possibility for comparison exists only for a very few countries. Those are Australia (ABS publishes capital services data as part of its annual national accounts), the United States (capital services series are published by the Bureau of Labor Statistics as part of its multifactor productivity measurement programme) and the United Kingdom where work is underway at ONS (Office of National Statistics) and where a first set of capital services data has been published at the Bank of England (Oulton 2002). Statistics Canada has also compiled a set of capital services measures (Harchaoui and Tarkhani 2002) and the results for Spain (Mas, Pérez, and Uriel 2006) are presented in the next chapter.

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[6] Value and volume measures for depreciation as well as the wealth stock have also been computed in the present exercise but no results are presented in the present document to keep it focused on capital services.

TABLE 1.2: Volume index of capital services by type of asset
Compound annual percentage changes, total economy, based on *harmonized* deflators for ICT assets
(percentage)

	Year	Total	Products of agriculture, metal products and machinery			Transport equipment	Non-residential construction	Other products	
			Hardware	Communication equipment	Other			Software	Other
Australia	1990–95	1.0	19.9	2.5	–1.7	0.2	2.1	11.0	0.6
	1995–2000	1.8	30.2	6.3	–3.0	1.5	2.3	10.4	1.1
	1995–2002	1.8	27.6	6.0	–3.1	1.9	2.2	10.3	1.5
Canada	1990–95	3.4	16.8	6.6	1.7	2.1	3.6	11.3	n.a.
	1995–2000	4.3	36.2	9.3	2.0	4.0	3.3	12.1	n.a.
	1995–2002	4.3	32.6	8.9	1.8	4.1	3.3	10.5	n.a.
France	1990–95	2.2	14.8	4.5	2.7	2.1	1.9	6.5	3.7
	1995–2000	2.0	32.0	6.7	2.0	3.4	1.4	20.0	0.1
	1995–2002	1.9	27.6	6.2	1.8	3.6	1.2	14.6	0.5
Germany	1990–95	2.3	14.4	3.9	2.0	3.2	2.1	6.9	7.2
	1995–2000	2.1	29.7	3.7	1.2	2.4	1.6	10.4	7.7
	1995–2002	2.1	29.5	4.0	1.2	2.3	1.5	9.9	7.8
Italy	1990–95	2.3	8.3	3.7	2.8	1.3	2.1	0.7	2.7
	1995–2000	2.8	28.4	6.4	3.0	3.0	1.8	11.8	1.9
	1995–2001	2.9	28.5	6.3	3.1	3.3	1.8	11.5	2.1
Japan	1990–95	4.1	18.8	7.9	2.5	3.8	4.4	7.5	4.9
	1995–2000	3.5	30.6	11.0	1.5	2.0	3.2	15.6	1.0
	1995–2002	3.3	26.9	9.7	1.2	1.7	3.0	13.3	0.2
United Kingdom	1990–95	2.4	17.6	7.5	2.2	–0.4	2.5	13.7	n.a.
	1995–2000	3.7	33.5	15.6	4.0	1.3	2.1	12.8	n.a.
	1995–2001	3.8	32.5	14.9	4.1	1.4	2.1	11.3	n.a.
United States	1990–95	1.7	18.0	4.8	–1.2	2.1	2.0	12.5	–3.5
	1995–2000	3.2	31.4	8.4	–0.3	5.0	2.2	15.7	4.7
	1995–2002	3.1	28.2	8.3	–0.5	4.4	2.1	12.9	4.1

Source: OECD Productivity Database (September 2004).

TABLE 1.3: Volume index of capital services
All assets. Total economy, based on *harmonized* deflators for ICT assets
(1980 = 100)

	Australia	Canada	France	Germany	Italy	Japan	United Kingdom	United States
1980	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1981	102.8	109.5	102.6	103.2	105.5	106.4	102.1	104.1
1982	106.2	117.7	105.4	105.9	110.1	112.5	104.4	107.6
1983	108.8	125.3	108.1	108.7	114.5	118.0	106.8	111.2
1984	111.4	133.1	110.7	111.4	119.5	123.5	109.9	115.8
1985	114.4	141.6	113.5	114.4	124.3	129.4	113.4	120.6
1986	117.6	150.3	116.6	117.6	129.4	135.6	117.0	125.1
1987	120.7	159.9	120.0	120.9	134.9	142.5	121.3	129.4
1988	123.9	170.7	124.2	124.4	141.3	151.0	126.8	133.5
1989	127.4	181.6	129.1	128.5	147.8	161.0	132.8	138.1
1990	130.7	191.3	134.4	133.2	154.1	171.0	138.3	142.4
1991	133.2	200.0	139.3	138.3	159.6	181.4	142.8	146.0
1992	135.4	208.0	143.6	143.1	164.5	190.9	146.9	149.9
1993	137.5	215.6	146.9	146.6	167.3	199.1	151.1	153.9
1994	139.4	224.3	150.1	150.1	170.6	206.1	156.1	158.5
1995	142.0	233.4	153.2	153.5	175.0	214.0	162.3	164.4
1996	145.3	243.3	156.3	157.0	180.2	223.7	169.1	171.7
1997	149.8	256.9	159.5	160.8	186.1	234.2	176.9	181.1
1998	155.1	272.4	163.5	165.2	192.8	244.2	190.0	192.3
1999	158.6	289.1	168.5	170.1	200.6	253.9	201.8	204.5
2000	160.9	305.7	174.4	175.3	209.3	263.2	213.0	216.5
2001	163.3	320.8	179.9	179.6	217.7	271.0	223.2	225.5
2002	165.7	332.6	183.9	182.3	n.a.	275.4	n.a.	232.2

Source: OECD Productivity Database (September 2004).

A first comparison of our results for Australia and those published by the ABS[7] reveals two points. First, the time profile of the OECD series follows that of the ABS series fairly closely. At the same time, and this is the second observation, there appears to be a systematic downward bias (5.1% versus 3.7% per year between 1980 and 1999) of our measures with regard to the official statistics. This is, however, due to the fact that the ABS series relates to the business sector whereas our results concern the entire economy. When only private sector data are used in the OECD model, a capital service measure with similar rates of change to those of the official ABS time series is found. Other small sources of differences in methodology persist (e.g., ABS chooses an endogenous rate of net return to capital; the OECD series is based on an exogenous rate. ABS equates actual and expected price changes in their

[7] Series 5402.0. *Australian System of National Accounts.*

TABLE 1.4: Price indices of capital goods by type of asset

Compound annual percentage changes, total economy, based on *harmonized* ICT deflators

(percentage)

	Year	Products of agriculture, metal products and machinery			Transport equipment	Non-residential construction	Other products	
		Hardware	Communication equipment	Other			Software	Other
Australia	1990–95	–12.8	0.8	8.0	5.1	0.7	0.1	–1.6
	1995–2000	–22.9	–1.2	13.9	–0.1	2.6	1.6	6.5
	1995–2002	–18.4	–0.8	11.0	–0.2	2.3	2.6	6.2
Canada	1990–95	–15.4	–1.8	3.0	2.3	0.8	–2.5	n.a.
	1995–2000	–27.0	–5.3	2.0	1.7	2.6	–2.5	n.a.
	1995–2002	–21.1	–3.5	2.5	1.8	2.4	–0.2	n.a.
France	1990–95	–15.0	–1.4	0.3	0.5	1.5	–2.1	2.1
	1995–2000	–26.9	–5.3	0.8	–0.8	2.1	–2.5	1.1
	1995–2002	–21.4	–3.8	–2.8	–0.5	2.3	–0.5	2.2
Germany	1990–95	–13.4	0.2	1.7	2.6	3.8	–0.5	–0.2
	1995–2000	–27.7	–6.0	0.8	1.5	–0.4	–3.2	–1.9
	1995–2002	–22.1	–4.5	1.5	1.3	–0.3	–1.2	–1.5
Italy	1990–95	–9.4	4.2	2.8	5.3	4.5	3.5	4.0
	1995–2000	–26.0	–4.3	1.6	2.4	2.3	–1.5	2.0
	1995–2001	–24.2	–4.0	1.5	2.2	2.4	–0.9	1.6
Japan	1990–95	–15.9	–2.3	0.0	–0.6	0.7	–3.0	1.3
	1995–2000	–28.8	–7.1	–1.2	–0.7	–0.3	–4.3	–0.8
	1995–2002	–23.8	–6.2	–1.5	–0.8	–0.5	–2.9	–1.0
United Kingdom	1990–95	–15.5	–1.9	2.4	3.3	–1.7	–2.6	n.a.
	1995–2000	–27.6	–5.9	–3.2	1.4	4.6	–3.1	n.a.
	1995–2001	–25.5	–5.3	–2.6	0.8	4.5	–2.2	n.a.
United States	1990–95	–14.7	–1.2	4.8	2.5	2.5	–2.7	6.9
	1995–2000	–24.4	–3.5	5.2	0.6	3.3	–0.8	1.3
	1995–2002	–22.4	–3.4	4.7	0.4	3.0	–0.5	1.7

Source: OECD Productivity Database (September 2004).

user cost computations; OECD uses moving averages for price expectations etc.). Overall, however, the series fit closely when they relate to the same sector aggregate.

A second comparison relates to our capital services measures and those of the BLS. Over the entire period 1981–2000, U.S. capital input grew by 3.8% per year according to BLS, and by 3.7% according to OECD estimates. This small difference over the entire period hides more significant differences over sub-periods that tend to offset on average. The OECD capital services series tend to show a smoother profile than the official BLS results. Partly, this may be explained by the fact that the BLS series relates to the private sector whereas OECD data covers the entire economy.

The third comparison relates to the United Kingdom. Of the four comparisons, this is clearly the case where differences are largest. However, a good deal of the discrepancy between OECD measures and Oulton (2002) can be traced back to the fact that Oulton's estimates are based on United States price indices for ICT equipment goods, adjusted for exchange rate effects. Such exchange rate effects can be sizeable and have been discussed at greater length in Schreyer (2002). The OECD series here uses *harmonized* deflators: they are thus also based on U.S. data but not exchange rate adjusted. This adjustment for exchange rate movements between sterling and the U.S. dollar introduced larger amplitude to the resulting volume series. Again, this comparison points to the crucial importance of the choice of price indices in producing capital services and capital stock data. Work is also underway in the UK Office of National Statistics to produce and release a series of capital services measures.

The fourth comparison concerns Canada. On the face of it, the capital services series released by Statistics Canada feature a profile that is significantly different from the one obtained by OECD. However, several important methodological differences account for such discrepancy. First, the OECD series relate to the economy as a whole whereas Statistics Canada's data covers the private sector. Secondly, the Canadian series are based on a geometric age-efficiency profile whereas OECD employs a hyperbolic pattern. Third, Canada's user cost measures are based on an endogenous rate of return, those computed by OECD on an exogenous rate. Fourth, there are significant differences in the service lives employed—in particular the service life of buildings and construction assets is significantly shorter in the official series than in those computed by the OECD. A more detailed analysis can be found in Appendix 1.2 where it is also shown that after correction for the methodological differences, the OECD model tracks the official data quite closely: over the period 1982–2001, Statistics Canada evaluates capital services growth at 3.2% per year. The corresponding and comparable OECD result is at 3.3%.

The Canadian case clearly shows the trade-off between using symmetric and reproducible assumptions for all countries at the international level and thereby improving international comparability while foregoing potentially more accurate information for individual countries (such as service lives for Canadian assets). There is no short-term solution to this trade-off except careful documentation and explanation of differences in the release of data.

References

Berndt, Ernst R. "Comments on 'The Measurement of Capital' by Charles R. Hulten." In Ernst R. Berndt and Jack Triplett, eds. *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth (National Bureau of Economic Research Studies in Income and Wealth)*. Chicago and London: University of Chicago Press, 1991, 119–58.

Berndt, Ernst R., and Melvyn A. Fuss. "Productivity Measurement with Adjustments for Variations in Capacity Utilisation and Other Forms of Temporary Equilibria." *Journal of Econometrics* 33 (1986): 7–29.

Bureau of Labor Statistics (BLS). *Trends in Multifactor Productivity, 1948–81.* Bulletin 2178. Waschington, DC: U.S. Bureau of Labor Statistics, 1983.

Diewert, Erwin D. "Exact and superlative Index Numbers." *Journal of Econometrics* 4, no. 2 (1976): 115–45.

—. *Measuring the Price and Quantity of Capital Services under Alternative Assumptions.* Department of Economics Working Paper 01–24. Vancouver: University of British Columbia, 2001.

—. "Commentary on 'Technology and the Theory of Vintage Aggregation' by Michael Harper." Note for the NBER and CRIW Measurement Workshop, Cambridge, MA, 2002.

Fraumeni, Barbara M. "The Measurement of Depreciation in the U.S. National Income and Product Accounts." *Survey of Current Business,* July 1997.

Gellatly, Guy, Marc Tanguay, and Beiling Yan. "An Alternative Methodology for Estimating Economic Depreciation: New Results Using a Survival Model." In *Productivity Growth in Canada 2002.* Catalogue no. 15-204-XPE. Ottawa: Statistics Canada, Analytical Studies Branch, 2002.

Harchaoui, Tarek M., and Fauozi Tarkhani. "A Comprehensive Revision of Statistics Canada's Estimates of Capital Input for the Productivity Accounts." Methodological Note, Microeconomic Analysis Division, Statistics Canada, 2002. Also available online at http://www.cansim.ca/english/concepts/15-204/note.pdf.

Harper, Michael J. "Technology and the Theory of Vintage Aggregation." Paper prepared for the NBER/CRIW Summer Institute, July 2002.

Harper, Michael J., Ernst R. Berndt, and David O. Wood. "Rates of Return and Capital Aggregation Using Alternative Rental Prices." In D. W. Jorgenson and R. Landau, eds. *Technology and Capital Formation.* Cambridge, MA: MIT Press, 1989, 331–37.

Hill, Peter. "The Productive Capital Stock and the Quantity Index for Flows of Capital Services." Paper presented at the third meeting of the Canberra Group on Capital Stock Statistics, Washington, DC, 1999.

—. "Economic Depreciation and the SNA." Paper presented at the 26th Conference of the International Association for Research in Income and Wealth, Cracow, 2000.

HULTEN, Charles R. "The Measurement of Capital." In Ernst R. Berndt and Jack Triplett, eds. *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth (National Bureau of Economic Research Studies in Income and Wealth)*. Chicago and London: University of Chicago Press, 1991, 119–58.

—. "Issues in the Measurement of Depreciation: Introductory Remarks." *Economic Inquiry* 34 (1996): 10–23.

JORGENSON, Dale W. "Productivity and Economic Growth." In Ernst R. Berndt and Jack Triplett, eds. *Fifty Years of Economic Measurement: The Jubilee of the Conference on Research in Income and Wealth (National Bureau of Economic Research Studies in Income and Wealth)*. Chicago and London: University of Chicago Press, 1991, 19–119.

JORGENSON, Dale W. "Capital Theory and Investment Behaviour." *American Economic Review* 53 (1963): 247–59.

—. *Productivity*. Vols. 1 and 2. Cambridge, MA: MIT Press, 1995.

JORGENSON, Dale W., and Zvi GRILICHES. "The Explanation of Productivity Change." *Review of Economic Studies* 34, no. 3 (1967): 249–83.

MAS IVARS, Matilde, Francisco PÉREZ GARCÍA, and Ezequiel URIEL JIMÉNEZ. "Capital Stock in Spain 1964-2002. New Estimates." In Matilde Mas and Paul Schreyer, eds. *Growth, Capital and New Technologies.* Madrid: BBVA Foundation, 2006, 67-91.

OECD. *Measuring Productivity – OECD Manual: Measurement of Aggregate and Industry-Level Productivity Growth.* Paris: Organisation for Economic Co-operation and Development, 2001a.

—. *Measuring Capital – OECD Manual: Measurement of Capital Stocks, Consumption of Fixed Capital and Capital Services*. Paris: Organisation for Economic Co-operation and Development, 2001b.

OULTON, Nicholas. "ICT and productivity growth in the United Kingdom." Bank of England Working Paper. Londres, 2001 (later published in *Oxford Review of Economic Policy* 18, no. 3 [2002]: 363–79).

RYMES, Thomas K. *On Concepts of Capital and Technological Change.* Cambridge: Cambridge University Press, 1971.

SCHREYER, Paul. *The Contribution of Information and Communication Technology to Output Growth: A Study of the G7 Countries.* OECD Science, Technology and Industry Working Paper no. 2000/2. Paris: OECD Directorate for Science, Technology and Industry, 2000.

—. "Computer Price Indices and International Growth Comparisons." *Economics of Innovation and New Technology* 10 (2001): 339–76.

—. "Computer Price Indices and International Growth and Productivity Comparisons." *Review of Income and Wealth* 48, no. 1 (2002): 15–33.

TRIPLETT, Jack. "Depreciation in Production Analysis and in Income and Wealth Accounts: Resolution of an old Debate." *Economic Inquiry* 34 (1996): 93–115.

—. *A Dictionary of Usage for Capital Measurement Issues.* Presented at the Second Meeting of the OECD Canberra Group on Capital Stock Statistics, 1998.

WYCKOFF, Andrew W. "The Impact of Computer Prices on International Comparisons of Productivity." *Economics of Innovation and New Technology* 3, nos. 3–4 (1995): 277–93.

Appendix 1.1. Additional methodological remarks

Asset types

The estimation of capital service flows starts with identifying R different assets—for present purposes, these correspond to the asset breakdown current available from the OECD/Eurostat (Statistical Office of European Communities) National Accounts questionnaire, augmented by information on ICT assets where available. Only non-residential gross fixed capital formation is considered, and in particular, seven types of assets or products:

Type of product/asset	Collected in OECD/ Eurostat questionnaire
Products of agriculture, metal products and machinery	Yes
of which:	
IT Hardware	No
Communications equipment	No
Other	No
Transport equipment	Yes
Non-residential construction	Yes
Other products	Yes
of which:	
Software	No
Other	No

Investment series

For each type of asset, a time series of current-price investment expenditure and a time series of corresponding price indices is established, starting with the year 1960. For many countries, this involves a certain amount of estimates, in particular for the period 1960–80. Such estimates are typically based on national accounts data prior to the introduction of SNA93 (System of National Accounts 1993), or on relationships between different types of assets that are established for recent periods and projected backwards. For purposes of exposition of the methodology, call current price investment series for asset type i in year t IN_t^1 ($i = 1, 2,..., 7$) and the corresponding price index q_t^i. Price indices are normalised to the reference year 1995 where $q_t^i = 1$.

Productive capital stocks for each asset type

For each of the (supposedly) homogenous asset types, a productive stock S_t^i is constructed following equation (1.6):

$$S_t^i = \sum_{\tau=0}^{Ti} \frac{IN_{t-\tau}^i}{q_{t-\tau,0}^i} h_\tau^i F_\tau^i \qquad \text{(A.1.1)}$$

In this expression, the productive stock of asset i at the beginning of period t is the sum over all past investments in this asset, where current price investment in past periods, $IN_{t-\tau}^i$ is deflated with the purchase price index of new capital goods, $q_{t-\tau,0}^i$. Ti represents the maximum service life of asset type i.

Because past vintages of capital goods are less efficient than new ones, an *age efficiency function* h_τ^i has been applied. It describes the efficiency time profile of an asset, conditional on its survival and is defined as a hyperbolic[8] function of the form used by the United States Bureau of Labor Statistics (BLS 1983):

$$h_\tau^i = \frac{T-\tau}{T-\beta\tau}$$

Furthermore, capital goods of the same type purchased in the same year do not generally retire at the same moment. More likely, there is a retirement distribution around a mean service life. In the present calculations, a normal distribution with a standard deviation of 25% of the average service life is chosen to represent probability of retirement. The distribution was truncated at an assumed maximum service life of 1.5 times the average service life. The parameter F_τ^i is the cumulative value of this distribution, describing the probability of survival over the cohort's life span. The following average service lives are assumed for the different assets: 7 years for IT equipment, 15 years for communications equipment, other equipment and transport equipment, 60 years for non-residential structures, 3 years for software and 7 years for remaining other products. The parameter β in the age-efficiency function was set to 0.8.

Net rate of return

The present work uses a constant value *rr* for the expected real interest rate *rr*. The constant real rate is computed by taking a series of annual observed nominal rates (un-weighted average of interest rate with different maturities) and deflating them by the

[8] This is but one possible functional form of the age-efficiency profile. Often, a geometric form is chosen. For a discussion, see OECD (2001a, 2001b).

consumer price index. The resulting series of real interest rates is averaged over the period (1980–2000) to yield a constant value for *rr*. The expected nominal interest rate for every year is then computed as $r_t = rr\,(1 + p_t) - 1$ where p is the expected value of an overall deflator, the consumer price index.

To obtain a measure for p, the expected overall inflation, we construct a 5-year centred moving average of the rate of change of the consumer price index $\dfrac{MACPI_t = \sum_{s=1}^{5} CPI_{t-s}}{5}$ where CPI_t is the annual percentage change of the consumer price index. This yields the expected rate of overall price change and, by implication, the nominal net rate of return.

Rate of depreciation

The next variable to measure in the user cost of a new asset is the rate of depreciation. It is defined as the ratio of the purchase price of a one-year old asset over that of a new asset: $d_{t,0} = 1 - \dfrac{q^i_{t,1}}{q^i_{t,0}}$. To compute this ratio, as outlined in expression (1.16), one first needs to define the expected rate of change of nominal user costs, ξ^i, defined as $u^i_{t+\tau,0} = u^i_{t,0}\left(1+\xi^i\right)^{\tau}$. Empirically, ξ^i is measured as a 5-year centred moving average of rates of asset price change in the five years prior to *t*.

With the results for the expected asset price change and for the net rate of return, one gets an expression for $\dfrac{1+r}{1+\xi^i}$. Together with the age-efficiency profile, this is all that is needed to evaluate expression (1.18).

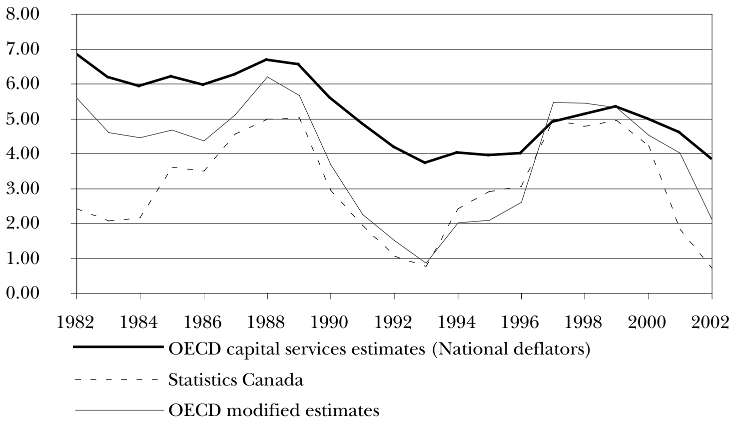
Appendix 1.2. Differences between capital services estimates by Statistics Canada and the OECD Statistics Directorate

The comparison of the OECD results for capital services for Canada and those produced by Statistics Canada reveals significant differences over the entire period 1982–2001 (Graph A.1.2.1). Canadian capital services estimates grew by 3.3% per year according to Statistics Canada and by 5.3% according to OECD estimates. However, methodology and scope for the two series are different, and inhibit direct comparison. The present note aims at explaining and quantifying the sources of discrepancy.

Overall effect

There are four main differences between the capital series computed by Statistics Canada and OECD (Table A.1.2.1): the sector coverage, the age-efficiency (or depreciation) profile, the average length of service lives of certain assets and the measurement of the nominal rate of return.[9] When the OECD

GRAPH A.1.2.1: **Capital services**
(percentage)



[9] The capital services estimates published by Statistics Canada includes land and inventories but Statistics Canada provides OECD Statistics Directorate with results excluding land and inventories and as a consequence, the comparison is limited to the other assumptions.

estimate is modified to emulate as closely as possible the methodological choices made by Statistics Canada, a new series results, also shown in Graph A.1.2.1. As it turns out, the profile of these *OECD modified estimates* is very similar to those from Statistics Canada. The main remaining difference concerns the early 1980s and in all probability reflects weak source data used by the OECD for its estimates.[10]

The cumulative effect of the modification of all these four assumptions is an average decrease of 1.89 percentage points per year over the period 1982–2001. Thus, the modified OECD series features capital services growth of 3.4% per year as compared with 3.3% of Statistics Canada's series.

De-composition of overall effect

In addition to assessing the combined effect of modifying the capital services methodology it is of interest to quantify the relative importance of individual effects, for example moving from a hyperbolic to a geometric age-efficiency profile. This raises an interesting methodological issue—that of choosing the order in which to evaluate partial effects. To stick with the above example, the effect of changing between age-efficiency profiles may be different when one set of service lives is used as opposed

TABLE A.1.2.1: **Methodological choices**

	OECD assumptions	**OECD modified assumptions**	**Statistics Canada**
Sector coverage	Total economy	Business sector	Business sector
Age-efficiency profile	Hyperbolic	Geometric	Geometric
Average service life[1] (years):			
• Transport equipment	15	7	7
• Non-residential buildings	60	30	30
Measurement of the nominal rate of return	Exogenous	Endogenous	Endogenous

[1] OECD service life assumptions reflect current practices in OECD countries. The service life data for Canada refers to the Tables 2.4 and 2.5 in Gellatly, Tanguay and Yan (2003).

[10] A good deal of the investment series for the period 1960–81 broken down by asset type that flow into capital services measures had to be estimated by OECD in the absence of available official series.

to another set. In other words, the partial effects of changing parameters one-by-one is in general path-dependent, i.e., it depends on the order by which effects are computed. Theory has little to recommend about a preferred ordering. One way to deal with this situation is to compute all possible paths and then average across partial effects. In the present case, with 4 sets of parameters to vary, there are 8 different paths, and assessing them all would have meant significant additional time spent on computations. The present simulations are therefore based on two of these paths only, and are reported in the Tables A.1.2.2 and A.1.2.3.

The first path (Table A.1.2.2) is defined by the following consecutive modifications: Sector (business sector instead of total economy); Measurement of the rate of return (endogenous instead of exogenous); Age efficiency profile (geometric instead of hyperbolic); Average service life (from 15 years to 7 for transport equipment and from 60 years to 30 for non-residential buildings). The size of the effects of each modification given a certain constellation of other parameters is shown in Tables A.1.2.2 and A.1.2.3. For example, moving from the OECD's assumptions on service lives to those used by Statistics Canada (the "age effect") reduces the measured capital service growth by 0.16 percentage points over the period 1985–2001 (Table A.1.2.2), whereas the age effect turns out to be 0.05 percentage points in Table A.1.2.3.

It is apparent from this table that each modification of assumptions generates a decrease of the capital services estimates over the entire period. Also, for the period as whole the effect of the change in profiles is the most important one. For sub-periods (e.g. 1995–2001) this is not necessarily the case.

An alternative path led to consider the following successive modifications: Sector; Measurement of the rate of return; Average service life; Age efficiency profile, where the two last modifications of assumptions are inverted compared with the first path (Table A.1.2.3).

TABLE A.1.2.2: **Simple effects of the following successive modifications of assumptions on the capital services estimates: Sector – Rate – Profile – Age**

Path 1	**Sector effect**			**Rate effect**		**Profile effect**		**Age effect**	
Sector	Total economy	**Business sector**		Business sector		Business sector		Business sector	
Age-efficiency profile	Hyperbolic	Hyperbolic		Hyperbolic		**Geometric**		Geometric	
Average service life	OECD estimates	OECD estimates	**Sector effect**	OECD estimates	**Rate effect**	OECD estimates	**Profile effect**	**Statistics Canada estimates**	**Age effect**
Measurement of the Rate of return	Exogenous	Exogenous		**Endogenous**		Endogenous		Endogenous	
1980–85	6.80%	6.69%	–0.11	6.26%	–0.42	5.21%	–1.05	5.41%	0.20
1985–90	6.24%	6.32%	0.09	5.42%	–0.90	4.35%	–1.07	4.20%	–0.15
1990–95	4.12%	3.79%	–0.34	3.39%	–0.39	2.13%	–1.26	1.41%	–0.72
1995–2001	4.89%	4.76%	–0.13	3.91%	–0.85	3.44%	–0.47	3.49%	0.05
1980–2001	5.51%	5.39%	–0.12	4.75%	–0.64	3.78%	–0.96	3.63%	–0.16

TABLE A.1.2.3: **Simple effects of the following successive modifications of assumptions on the capital services estimates: Sector – Rate – Age – Profile**

Path 2	**Sector effect**			**Rate effect**		**Age effect**		**Profile effect**	
Sector	Total economy	**Business sector**		Business sector		Business sector		Business sector	
Age-efficiency profile	Hyperbolic	Hyperbolic		Hyperbolic		Hyperbolic		**Geometric**	
Average service life	OECD estimates	OECD estimates	**Sector effect**	OECD estimates	**Rate effect**	**Statistics Canada estimates**	**Age effect**	Statistics Canada estimates	**Profile effect**
Measurement of the Rate of return	Exogenous	Exogenous		**Endogenous**		Endogenous		Endogenous	
1980–85	6.80%	6.69%	0.11	6.26%	–0.42	6.88%	0.62	5.41%	–1.47
1985–90	6.24%	6.32%	0.09	5.42%	–0.90	5.48%	0.05	4.20%	–1.28
1990–95	4.12%	3.79%	–0.34	3.39%	–0.39	2.80%	–0.59	1.41%	–1.39
1995–2001	4.89%	4.76%	–0.13	3.91%	–0.85	3.63%	–0.28	3.49%	–0.14
Average	5.51%	5.39%	–0.12	4.75%	–0.64	4.70%	–0.05	3.63%	–1.07

It is again apparent that the impact of the profile effect is more important than those of other assumptions. However, this effect is more important for the second path (Table A.1.2.3) than for the first. Secondly, the hierarchy of the simple effects is different between the two paths: for the first one, the age effect is more important than the sector effect, while in the second the situation between these two effects is inverted. To approximate the average impact of each modification we calculate an arithmetic average of the single effects for the two paths described above:[11] sector effect, –0.12 percentage points per year; rate effect, –0.64; age effect, –0.11; and profile effect, –1.02. The profile assumption has the most important effect, the rate effect is important and the age and sector effect are less significant. However, as could be seen above, only both assumptions together can explain the differences in the results from Statistics Canada and from the OECD.

Three principal conclusions arose from this analysis:

- First, the implementation of alternative methodological assumptions allows us to explain the differences between the capital services estimates from Statistics Canada and from the OECD Statistics Directorate.
- Second, the definition of different paths can be useful to evaluate the partial effects of each modification in the methodological assumptions. The order of these changes influences the distribution of the partial effects even if the global sensitivity of productivity estimates remains the same.
- Third, all the modifications of methodological modifications have a negative effect on the capital services estimates. The age-efficiency profile (hyperbolic or geometric) has the most important impact. However, the differences between estimates from Statistics Canada and those from the OECD can only be explained by a combination of options.

[11] This approximation should be more accurate with a larger number of paths considered.

2. Capital Stock in Spain, 1964–2002. New Estimates[1]

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THIS paper presents the methodology followed in a new estimation of capital stock for the Spanish economy, and some general results. The new series provide estimates of gross, wealth and productive capital stocks, and capital services for each asset type. A sensitivity analysis has been carried out in order to test the implications for the estimates of competing assumptions. The estimation considers seventeen asset types, of which three belong to new technologies (software, hardware and communication) and six types of infrastructure (road, water, railway, airport, port and urban infrastructure). The estimation has required disaggregating GFCF (Gross Fixed Capital Formation) by asset types, as well as the estimation of appropriate price deflators. The information refers to national totals for the period 1964–2002.

[1] This paper summarizes the methodology, and some preliminary results of the BBVA Foundation-Ivie (Valencian Institute of Economic Research) project "Estimación del Stock de Capital Riqueza y Capital Productivo." It forms part of the projects supported by the Spanish and Valencian governments (SEJ 2005-02776, Grupos 03/123). M. Mas gratefully acknowledges the financial support of the Spanish Ministry of Education, Culture and Sports, whose Mobility Programme (Grant PR2002-0287) has allowed her to stay at the OECD in Paris. The authors are indebted to Paul Schreyer, whose comments and suggestions have greatly contributed to the development of this project. They are also grateful to Vicent Cucarella, and Juan Carlos Robledo for their more than competent statistical and computational skills. Any errors remaining are ours alone.

2.1. Introduction

Since 1995 the BBVA Foundation and the Ivie have been providing the capital stock estimates for the Spanish economy, obtained following the previous OECD (Organisation for Economic Co-operation and Development) methodology (Ward 1976; OECD 1993). The BBVA Foundation has released the latest estimate, available at http://www.fbbva.es. It covers the period 1964–2000 for national totals, and 1964–98 for the 17 regions (*comunidades autónomas*) and 52 provinces in Spain. The methodology followed is the PIM (Perpetual Inventory Method). The details of the estimation procedure can be seen in Mas, Pérez and Uriel (2000, 2002).

One of the main features of the estimation procedure is the distinction made between private and public capital. The latter is broken down into roads, water infrastructure, urban structures and health and education infrastructure. Railways, motorways and harbour infrastructure are added, even though they are not strictly provided in Spain by public authorities. They can be assimilated with the former given the nature of the services they provide. Data availability, which goes back to 1845, allows us to start the public capital series in 1955.

The private capital stock series takes into account 23 sectors (dwelling, agriculture, fishing, energy, 13 industrial sectors, construction and 5 services sectors). The series start in 1964 even though the private GFCF series available was not long enough to apply the PIM. In order to overcome this limitation, our previous estimates used the study by the University of Deusto (1968), which provided the first estimation of Spain's capital stock for 1964 as a reference. Thus 1964 is the benchmark year for the private capital stock estimates.

The estimates provided so far did not explicitly consider the distinction between asset types, though this was taken into account implicitly.[2] However, the two OECD Manuals (2001a, 2001b) highlight the need for this kind of information in order to obtain the capital stock series in general, and the productive capital stock and capital services series in particular.

[2] For instance, in the estimation of health and education capital stock a distinction is made between structures and equipment since different service lives were assigned to each of these two types of assets.

The BBVA Foundation and the Ivie have recognised the need to revise the capital stock estimates provided so far, by starting a new joint project for the purpose of adjusting the Spanish estimates to the new international standards. The project will continue in the future and in common with the previous estimates, it includes the distinguishing features of disaggregation by sectors, and geographically by regions and provinces. To date, the information is available only for national totals and the period covered starts in 1964. With these references in mind, the structure of the paper is as follows. Section 2.2 presents the main methodological issues. Section 2.3 revises the process of estimation of GFCF and deflators by asset type, the raw material on which capital stock estimates are built. Section 2.4 presents some results while section 2.5 contains some final remarks.

2.2. Methodology: a short survey

The methodology on which the new Spanish capital stock estimates are based is well described in two OECD manuals (2001a, 2001b), so we will not go into detail. Interested readers may refer to the same for further information as well as to Schreyer and Dupont (2006) for capital theory fundamentals.

Three different versions of capital stock are estimated: gross, wealth and productive. The *gross* capital stock is the result of GFCF accumulation, after deducting withdrawals that have taken place during the period, but otherwise valuing capital goods at *as new* prices. The *wealth* capital stock is the market value of the assets on the assumption that it equals discounted future revenues that the asset is expected to generate. Thus, capital goods are valued at market prices. The *productive* capital stock at constant prices is a quantity concept that takes into account the loss of efficiency as the asset ages. This quantity concept can be combined with a price concept, the user's cost of capital, in order to obtain the *value of capital services* provided by an asset. The last two concepts are the relevant ones in productivity analysis.

Gross Capital Stock

The calculation of the gross capital stock at constant prices is given by equation (2.1):

$$KG_{j,t} = \sum_{\tau=0}^{T} IR_{j,t-\tau} \bullet F_{j,\tau} \tag{2.1}$$

where $KG_{j,t}$ is the Gross Capital Stock at constant prices of a τ-years old asset *j* at time *t*, and *IR* stands for investment (GFCF) at constant prices. Thus, $IR_{j,t} = IN_{j,t} / p_{j,t}$, where $IN_{j,t}$ is investment in nominal terms, and $p_{j,t}$ is the price of asset *j* (referred to a base year), $F_{j,\tau}$ represents the survival function, and *T* is the maximum service life of asset *j*. The Gross Capital Stock at current prices, $KG^C_{j,t}$ will be given by expression (2.2):

$$KG^C_{j,t} = KG_{j,t} \bullet p_{j,t} \tag{2.2}$$

In order to obtain the Gross Capital Stock estimates we need information about nominal GFCF by asset types, deflators (referred to a base year, 1995 in our case) for each type of asset, a survival function and the maximum service life of the asset. The first two sets of data, GFCF and price figures should come from National Accounts statistics. However, at least in the Spanish case, these are not available with the desired level of dis-aggregation. Therefore an effort has to be made in this direction as described in section 2.3.

The two remaining pieces of information needed for the estimation of KG_j, are the average service life of the asset, and the survival function. For these, assumptions must be made when empirical surveys are not available, as is the case of Spain.[3]

With regard to the survival/retirement function, the new Spanish estimates assume that it follows a Winfrey S-3 shape. The previous estimates were also constructed under this assumption. The choice of a specific survival function has practical consequences. A sensitivity analysis was carried out assuming four alternative survival functions: linear, delayed linear, simultaneous exit and Weibull. These were used to estimate Gross Capital Stock for software in Spain and then compared with the baseline case and the selected Winfrey S-3, both of which concern levels and

[3] In the U.S., the BEA (Bureau of Economic Analysis) has extensively used, in the determination of average service lives and the corresponding depreciation rates, research by Hulten and Wykoff (1980) and Wykoff (1989).

TABLE 2.1: Gross capital stock in software
Differences with respect to the Winfrey S-3 survival function and three years of average service life

a) Levels (percentage)

	1965	1974	1981	1988	1995	2002
Delayed linear	–13.44	–12.38	–13.27	–12.31	–14.92	–14.64
Simultaneous Exit	1.03	1.65	0.86	1.64	0.08	1.21
Linear	–18.77	–19.37	–18.68	–19.66	–17.51	–18.98
Weibull	–10.90	–10.74	–10.72	–10.84	–10.90	–11.66

b) Average annual growth rates (percentage points differences)

	1966–70	1971–78	1979–86	1987–94	1995–2002	1966–2002
Delayed linear	0.18	–0.15	0.35	–0.62	0.16	–0.03
Simultaneous Exit	0.03	–0.01	0.07	–0.12	0.09	0.01
Linear	–0.06	0.08	–0.22	0.37	–0.26	–0.02
Weibull	0.04	–0.02	0.06	–0.10	–0.08	–0.03

rates of growth.[4] Table 2.1 presents the results of this sensitivity analysis.

The above results highlight that the Gross Capital Stock level estimated for 2002 would have been 18.98% lower if a linear survival function had been used rather than the Winfrey S-3. Its average growth rate for the 1987–2001 period would also have been lower, with a difference of –0.02 percentage points per year. On the other hand, the use of a simultaneous exit function would have had almost no practical consequences in terms of levels, and its annual growth rate would have been 0.01 percentage points higher on average for the same period.

The selection of the average service life of an asset is a crucial decision. Table 2.6 provides information on the service lives used in the Spanish capital stock estimates. A sensitivity analysis was also carried out for software, considering three alternative service lives: two, four and five years, while maintaining Winfrey S-3 as the survival function. Table 2.2 presents the percentage differences between Gross Capital Stock estimated by the selected three year assumption, and any of the remaining three alternatives.

As can be seen, the selection of a given service life for an asset has very important implications. In the case of software the consideration of a five year service life instead of three, would translate into a Gross Capital Stock 49.50% higher, while its annual rate of growth would have been also higher: 0.06 percentage

[4] The growth rate of all the variables has been computed as Törnqvist indices.

TABLE 2.2: Gross capital stock in software
Differences with respect to the three years' service life assumption

a) Levels (percentage)						
	1967	**1974**	**1981**	**1988**	**1995**	**2002**
2 years	–28.49	–27.24	–27.92	–27.14	–30.54	–31.00
4 years	24.34	22.52	24.01	21.75	29.24	26.56
5 years	45.56	41.76	45.15	39.28	56.77	49.50

b) Average annual growth rates (percentage points differences)						
	1968–74	**1975–81**	**1982–88**	**1989–95**	**1996–2002**	**1968–2002**
2 years	0.30	–0.21	0.26	–0.74	–0.06	–0.09
4 years	–0.25	0.29	–0.42	0.94	–0.35	0.04
5 years	–0.45	0.54	–0.87	1.86	–0.77	0.06

points' difference on average for 1968–2002. However, this may be a very extreme situation since going from three to five years means almost doubling the asset service life, a situation that would hardly be considered with longer asset lives.

Once the Gross Capital Stock for each individual asset has been obtained, by applying equations (2.1) and (2.2), we can obtain the aggregate by simply adding up the individual figures at current and constant prices (base year 1995).

Capital Services and Productive Capital Stock

The relevant concept for productivity analysis is the volume of capital services that every individual asset provides to the production process. It is a quantity concept that should be measured in physical units for every homogenous asset. As it is not possible to work with such a high degree of dis-aggregation, the assumption is made that the volume of capital services provided by a specific asset is proportional to its Productive Capital Stock (valued at constant prices) (KP_j).[5] Its calculation is given by the following expression:

$$KP_{j,t} = \sum_{\tau=0}^{T} IR_{j,t-\tau} \bullet F_{j,\tau} \bullet h_{j,\tau} \tag{2.3}$$

Where $h_{j,\tau}$ is known as the *age-efficiency function* of a τ-year-old asset j. As before, Productive Capital Stock at current prices (KP_j^C) will be given by:

[5] The relationship between the *volume of capital services* concept and its operational measure, the productive capital stock of an asset, is carefully explained in Schreyer and Dupont (2006).

$$KP^{C}_{j,t} = KP_{j,t} \bullet p_{j,t} \tag{2.4}$$

In order to compute (2.3), an assumption must be made concerning the specification of the age-efficiency function, $h_{j,\tau}$. Among the different options available, the Spanish estimates apply a hyperbolic function of the following form to all assets:[6]

$$h_{\tau} = \frac{T-\tau}{T-\beta\tau} \tag{2.5}$$

The value of the β parameter has been set at 0.75 for dwellings and other constructions, and at 0.5 for equipment.

As mentioned, the use of a hyperbolic function and the value of the β parameter, is in each case only one of the possibilities available. Other functional forms for the age-efficiency profiles that have been used are constant efficiency, geometric and linear loss of efficiency. In order to test the implications of selecting the hyperbolic function for productive capital estimates, Table 2.3 presents the percentage differences of the estimated productive stocks obtained by using any of these three alternative functions compared to the baseline case (hyperbolic, Winfrey S-3 retirement function), as well as the percentage point differences in growth rates. It also considers the possibility of fixing a different value for β (0.75). The data again refer to software, assuming three years of service life.

TABLE 2.3: **Productive capital stock in software**
Differences with respect to the assumed hyperbolic age-efficiency (β = 0.5)

a) Levels (percentage)

	1964	**1975**	**1984**	**1993**	**2002**
Constant	13.86	13.61	12.95	15.42	14.97
Geometric	3.22	3.11	2.97	3.68	3.51
Linear	2.73	2.65	2.52	3.11	2.97
Hyperbolic beta = 0.75	5.86	5.77	5.49	6.47	6.32

b) Average annual rates of growth (percentage point differences)

	1965–74	**1975–81**	**1982–88**	**1989–95**	**1996–2002**	**1965–2002**
Constant	–0.070	0.066	–0.072	0.226	0.019	0.026
Geometric	–0.023	0.025	–0.028	0.080	–0.005	0.007
Linear	–0.019	0.021	–0.023	0.066	–0.004	0.006
Hyperbolic beta = 0.75	–0.030	0.026	–0.028	0.093	0.014	0.011

[6] This is also the one chosen by the OECD (2001b), ABS (Australian Bureau of Statistics), Schreyer (2000) and Schreyer and Dupont (2006).

Even though the selection of a given age-efficiency function has practical consequences, this is not as important as the ones generated by different assumed service lives (Table 2.2). The most noticeable difference appears when the constant age-efficiency function vs. the selected hyperbolic function ($\beta = 0.5$) is used. If a geometric function were used this would, for 2002, give rise to a productive capital stock 3.51% higher, and an annual growth rate 0.007 percentage points higher for the entire period 1965–2002.

Productive Capital Stock or Volume of Capital Services of an asset j is a quantity concept. In order to obtain its monetary counterpart it must be associated with a price concept. The relevant price for capital services is the user's cost of capital (Jorgenson 1963). The expression for the user's cost of asset j at time t ($\mu_{j,t}$) is given by (2.6).

$$\mu_{j,t} = p_{j,t}\left(r_t + \pi_t + d_{j,t} - \left(\frac{p_{j,t} - p_{j,t-1}}{p_{j,t-1}} \right) \right) \tag{2.6}$$

where $d_{j,t}$ is the depreciation rate, r_t the real rate of return and π_t the general rate of inflation. Thus, $r_t + \pi_t = i_t$ is the nominal rate of return which is assumed to be the same for all assets. π_t has been calculated as the three year centred moving average of the CPI (Consumer Price Index).

The method of estimation for $d_{j,t}$ is explained below. The internal rate of returns i_t, can be calculated endogenously or exogenously (see Diewert 1980). Spanish estimates follow the exogenous procedure assuming like the OECD (2001b) a constant real rate of return of 4% for the whole period.

Expressions (2.3) and (2.6) allow us to obtain the value of capital services ($CS_{j,t}$) provided by asset j at time t:

$$CS_{j,t} = \mu_{j,t} \bullet KP_{j,t-1} \tag{2.7}$$

As long as the value of capital services provided by a given asset is a nominal concept, expressed in current prices, it is possible to obtain the aggregate capital services (CS_t) of the economy by simply adding up all its components:

$$CS_t = \Sigma_j \, CS_{j,t} \tag{2.8}$$

On many occasions it is also of interest to have a measure of aggregate capital services in real terms. However, as the volume of capital services provided by an asset is a quantity concept, it does not make much sense to add up quantity figures in order to obtain the aggregate (the old pears and apples problem). However, what can be computed is the rate of change of the aggregate productive capital stock in real terms, or volume index of capital services. This is the relevant variable in productivity analysis.

The usual way (see Diewert 1987, for a discussion) to obtain the rate of change of the aggregate productive stock of capital (KP_t) is by means of a Törnqvist index as given by (2.9):

$$\ln(KP_t) - \ln(KP_{t-1}) = \sum_j 0.5[v_{j,t} + v_{j,t-1}][\ln(KP_{j,t}) - \ln(KP_{j,t-1})];\ v_{j,t} = \frac{CS_{j,t}}{CS_t} \tag{2.9}$$

Wealth Capital Stock and Depreciation

The Wealth Capital Stock of asset *j* at current prices is its market value in a given year *t*, expressed at that year's prices. The market value is the present discounted value of the future income that is expected to be earned by the asset during its service life.

Wealth (Net) Capital Stock of asset *j* at constant prices equals the market value, but expressed at base year prices (1995 in the Spanish estimates). Thus, Wealth Capital Stock is the market value of the Productive Capital Stock.

In order to estimate Wealth Capital Stock, an age-price function is needed. This function is closely related to the age-efficiency function, the relationship between the two being given by:

$$Z_{j,\tau} = \sum_{\tau=0}^{T} \frac{h_{j,\tau}}{(1+r)^{\tau+1}} \tag{2.10}$$

where r is, as before, the real interest rate, which has been fixed at 4%. Z can be normalised, taking as the unit value that corresponding to its first year in service:

$$z_{j,\tau} = \frac{Z_{j,\tau}}{Z_{j,0}} \tag{2.11}$$

Therefore, $z_{j,\tau}$ is the normalised age-price function of a τ-year old asset j in relation to its first year in service. The Wealth Capital Stock of asset j at constant prices ($KW_{j,t}$) can then be obtained by:

$$KW_{j,t} = \sum_{\tau=0}^{T} IR_{j,t-\tau} \bullet F_{j,\tau} \bullet z_{j,\tau} \tag{2.12}$$

The corresponding expression at current prices $KW_{j,t}^{C}$ will be given by (2.13):

$$KW_{j,t}^{C} = KW_{j,t} \bullet p_{j,t} \tag{2.13}$$

Finally, bearing in mind that the depreciation of asset j at time t ($D_{j,t}$) can be written as:

$$D_{j,t} = IR_{j,t} - \left(KW_{j,t} - KW_{j,t-1}\right) \tag{2.14}$$

the depreciation rate of asset j ($d_{j,t}$) will be given by (2.15):

$$d_{j,t} = \frac{D_{j,t}}{KW_{j,t}} \tag{2.15}$$

The depreciation rate thus calculated is the one entering the user's cost expression given by (2.6).

Once Wealth Capital Stock series for all assets have been calculated, at constant or current prices as in (2.12) or (2.13), the corresponding aggregated stocks are obtained by adding up the value of each individual asset.

The calculation of wealth stock depends on the normalised age-price function, $z_{j,\tau}$, which in turn depends on the age-efficiency function, $h_{j,\tau}$, and the assumed real interest rate, r. In order to test the sensitivity of wealth stock estimates to different assumptions about r, Table 2.4 computes the percentage difference between the levels of this variable generated by the assumed 4% interest rate and three alternative rates: 3%, 5% and 8.5%. We continue to take the Spanish software data as a reference (Winfrey S-3, hyperbolic $\beta = 0.5$, three years of average service life, $r = 4\%$).

As can be seen from Table 2.4, the selection of a given interest rate does not have practical consequences, because percentage differences of estimated levels are only slightly higher than 1% when $r = 8.5\%$ instead of the selected 4%. In terms of growth rates the differences are also minor. Once again, the highest is when $r = 8.5\%$.

TABLE 2.4: Wealth capital stock in software
Differences from the assumed 4% interest rate

a) Levels (percentage)

	1964	1975	1984	1993	2002
r = 3%	–0.24	–0.24	–0.23	–0.27	–0.26
r = 5%	0.24	0.24	0.22	0.26	0.26
r = 8.5%	1.04	1.04	0.98	1.15	1.13

b) Average annual rates of growth (percentage points differences)

	1965–74	1975–81	1982–88	1989–95	1996–2002	1965–2002
r = 3%	0.001	–0.001	0.001	–0.004	–0.001	–0.000
r = 5%	–0.001	0.001	–0.001	0.004	0.001	0.000
r = 8.5%	–0.006	0.004	–0.005	0.017	0.005	0.002

To summarise, the main assumptions made in the estimation of the Spanish capital stock series are the following: (i) The retirement function is assumed to be Winfrey S-3, as in previous Spanish capital stock estimates; (ii) the age-efficiency function adopted is the hyperbolic function, with β values of 0.75 for dwellings and other constructions, and 0.5 for equipment; and (iii) the internal rate of return is exogenous, assuming a 4% real interest rate.

Before going to the data, it is interesting to compare the results obtained under the above assumptions (referred to for convenience as *the OECD assumptions*) with the ones that would have been obtained if Jorgenson's methodology (1995) had been applied instead. In this case, no retirement functions are considered, whereas a geometric age-efficiency function is assumed. The values for the geometric rate of depreciation can be taken from Fraumeni (1997), where the estimated values for the double declining balance rate, R, and the average service lives (T) of different assets can be found. The depreciation rate would then be given by R/T.

Considering that software receives a special treatment in BEA estimates, the values for R and T cannot be taken directly from Fraumeni (1997), and we will make a comparison with "Office machinery and computer equipment." For this asset, BEA assumes that $T = 7$ and $R = 2.1832$. We have recalculated productive capital stock for this asset by making use of the Spanish GFCF and Deflators data, but considering Jorgenson's methodology. The resulting average annual growth rates have been compared with the rates obtained following the OECD methodology as given by equation (2.3). The results of the comparisons are given in Table 2.5.

TABLE 2.5: Jorgenson vs. OECD Methodology. Productive capital stock of "Office machinery and computer equipment"
Average annual growth rates
(percentage)

	1964–74	1974–84	1984–94	1994–2002	1964–2002
OECD assumptions*	17.11	15.84	16.30	19.86	17.14
Jorgenson assumptions**	17.53	16.08	14.73	21.20	17.18

* Winfrey S-3; seven years of service life; hyperbolic (beta = 0.5) age-efficiency function.
** No retirement function, seven years service life, geometric depreciation function, Declining Rate (R) = 2.1832.

The conclusion that can be drawn from Table 2.5 is that for the whole period that has been considered, 1964–2002, the differences in annual growth rates are so slight that it may be safely concluded that the choice of methodology does not have practical consequences. For shorter periods of time the differences can be as high as 2 percentage points.

2.3. The data

In order to implement the methodology summarised in section 2.2, two pieces of related information are required: (i) GFCF; and (ii) Deflators—with both thereof dis-aggregated by asset types. Table 2.6 presents the classification of assets finally adopted for the BBVA Foundation-Ivie estimates, as well as the average service lives for each asset considered in the Spanish capital stock estimates. The most problematical task was to dis-aggregate "Software" from "Other products," and "Communication" from "Other machinery and equipment." The methodology used is briefly outlined below, but the details can be found in Mas, Pérez and Uriel (2005).

GFCF in "Software" was estimated by a two-step procedure. The first step was to estimate the data for 1995 and 1998. The GFCF series for the rest of the period was obtained from these benchmark years. The primary source for information on Software GFCF for 1995 was the INE (Instituto Nacional de Estadística) *Encuesta de Servicios Informáticos* (Information Technologies Services Survey), whose population sample is intended to cover all firms whose core business falls within division 72 of CNAE93 *Actividades Informáticas* (Information Technologies Activities). In order to test the

TABLE 2.6: GFCF's proposed classification by types of assets and average service lives

Asset	Average service life
1. Dwellings	60
2. Other constructions	
2.1. Road infrastructure	50
2.2. Water infrastructure	40
2.3. Railway infrastructure	40
2.4. Airport infrastructure	40
2.5. Port infrastructure	50
2.6. Urban infrastructure	40
2.7. Other construction n.e.c.	50
3. Transport equipment	
3.1. Motor vehicles	8
3.2. Other transport material	20
4. Machinery, equipment and other products	
4.1. Agricultural, livestock and fish products	14
4.2. Machinery and metal products	
4.2.1. Metal products	16
4.2.2. Machinery and mechanical equipment	16
4.2.3. Office machinery and computer equipment	7
4.2.4. Other machinery and equipment	
4.2.4.1. Communications	15
4.2.4.2. Other machinery and equipment n.e.c.	12
4.3. Other products	
4.3.1. Software	3
4.3.2. Other products n.e.c.	7

representativity of the sample, two additional sources were used: the 1995 Input-Output Table and the LFS (Labor Force Survey). For 1998, the Input-Output Framework was used as well as the *Encuesta Anual de Servicios 1998* (1998 Annual Services Survey), which contains data on IT (Information Technology) firms.

Once the 1995 and 1998 data for Software GFCF had been obtained, the estimation of the series for 1981–2002 relied on the previous estimation of the "Supply destined for domestic end user demand," and import/export information. For the first, the information comes from SEDISI (Asociación Española de Empresas de Tecnologías de la Información) and Computerworld publications. For imports and exports the source is, once again, the INE Input-Output Tables for the years in which they are available. For the remaining years, the annual rate of change provided by SEDISI has been applied. Once the series are obtained, the growth rates are applied to the definitive data of the Input-Output Framework (which includes the net product taxes).

Following the OECD (2001c) practice, Table 2.7 presents the communication items considered in this study according to the ISIC (International Standard Industrial Classification):

TABLE 2.7: **Communication assets**

3130	Insulated wire and cable
3210	Electronic valves and tubes and other components
3220	Television and radio transmitters and apparatus for line telephony and line telegraphy
3230	Television and radio receivers, sound or video recording or reproducing apparatus and associated goods
3312	Instruments and appliances for measuring, checking, testing, navigating and other purposes, except industrial process equipment
3313	Industrial process control equipment

An estimate of the GFCF in these ISIC items is required in order to estimate communications capital stock. However, national accounts do not offer such information. INE includes "Communications" GFCF in the item "Other machinery and equipment" which, in addition to "Communications," is broken down into "Machinery and electrical materials (except cables)," "Medical and surgical, optical and watch-making machinery" and "Furniture and other manufactured products not considered elsewhere (n.e.c.)." Hence, it has been necessary to separate "Communications" GFCF from "Other machinery and equipment."

This was achieved in two steps. Firstly, GFCF for "Other machinery and equipment" and its components for benchmark period 1995–98 were calculated in the same way as for software. The starting point was to estimate each of the components of "Other machinery and equipment" obtained from the Input-Output tables (INE) and using the *Encuesta Industrial de Empresas* (Industrial Enterprises Survey) (INE) to obtain a breakdown of sectors 31 and 33. Additionally, it was necessary to estimate intermediate consumption, imports, exports and household consumption. Different statistical sources were used, such as *Encuesta Industrial* (Industrial Survey) (INE), *Estadística Industrial de España* (Spain's Industrial Statistics) (INE), Comex database (Eurostat [Statistical Office of European Communities]) and CNEe-86 (Contabilidad Nacional de España enlazada 1986). The second step was to obtain the evolution of the variables estimated in the first step to calculate GFCF for the period 1970–2002.

Deflators

Since the INE does not provide information on deflators for two of the three ICT (Information and Communication Technologies) components, and for software only for the period 1995–2002, we have followed the harmonized procedure described in Schreyer and Dupont (2006) when INE data was not available.

2.4. Results

This section presents some results related to the four variables involved in the estimation: GFCF, Deflators, Capital Stocks and Capital Services.

Tables 2.8 and 2.9 provide the information related to GFCF. Table 2.8 gives average annual GFCF growth rates at constant prices. The deflators used (base year 1995) appear in Table 2.9. GFCF grew in Spain 4.5% per year, on average over the whole period 1964–2002. The highest growth rates corresponded to "Office machinery and computer equipment" (17.2%) and "Software" (14%). In the last part of the period, 1995–2002, the growth rate of these two items was 22% and 9.8% respectively, the highest, together with "Communications" (10.9%), "Railway infrastructure" (17.3%) and "Airport infrastructure" (10%).

Table 2.10 provides the composition of wealth stock by asset types for five selected years. The following comments are relevant. In the first place, dwellings represent the highest share of total wealth stock, 47.4% in 2002, although they show a marked cyclical profile. The second highest share corresponds to "Other constructions," 40.9% in 2002. In this case, the Spanish estimates make it possible to distinguish between infrastructure items and the rest. As can be observed, the rest of "Other construction n.e.c." components has steadily risen during the period, while only the "Road infrastructure" component has shown a similar increasing share. For the other three infrastructure components, the shares have been almost stable during the period. Of the total, infrastructure represented 10.9% of total wealth capital stock in 2002.

TABLE 2.8: GFCF (constant prices)
Average annual growth rates
(percentage)

	1964–80	1980–90	1990–95	1995–2002	1964–2002
1. Dwellings	**2.3**	**1.8**	**–0.7**	**5.9**	**2.5**
2. Other constructions	**5.8**	**6.8**	**0.8**	**4.7**	**5.2**
2.1. Road infrastructure	4.0	14.0	–0.7	–0.4	5.4
2.2. Water infrastructure	–0.1	6.6	1.4	–3.7	1.3
2.3. Railway infrastructure	2.3	9.1	–7.1	17.3	5.7
2.4. Airport infrastructure	10.1	11.1	–7.1	10.0	6.7
2.5. Port infrastructure	1.3	8.7	–0.9	3.1	3.5
2.6. Urban infrastructure	5.3	17.0	–1.8	5.7	7.5
2.7. Other construction n.e.c.	7.1	5.1	1.6	5.1	5.5
3. Transport equipment	**5.6**	**4.8**	**0.1**	**4.0**	**4.8**
3.1. Motor vehicles	4.0	4.2	4.8	3.7	4.7
3.2. Other transport material	9.9	6.1	–12.4	4.9	5.1
4. Machinery, equipment and other products	**5.7**	**7.4**	**–0.8**	**8.0**	**5.9**
4.1. Agricultural, livestock and fish products	23.0	–7.0	7.9	2.0	9.3
4.2. Machinery and metal products	5.3	7.1	–1.8	7.9	5.3
4.2.1. Metal products	11.4	3.1	0.1	5.8	6.8
4.2.2. Machinery and mechanical equipment	3.3	4.8	–6.7	6.2	3.0
4.2.3. Office machinery and computer equipment	15.6	20.4	9.4	22.0	17.2
4.2.4. Other machinery and equipment	4.6	7.3	–1.5	5.9	4.9
4.2.4.1. Communications	4.6	10.7	–3.3	10.9	6.4
4.2.4.2. Other machinery and equipment n.e.c.	4.6	5.3	–0.3	2.5	4.2
4.3. Other products	8.9	11.8	5.2	8.3	8.5
4.3.1. Software	14.8	19.4	6.3	9.8	14.0
4.3.2. Other products n.e.c.	6.3	1.0	0.6	–1.0	2.9
Total GFCF	**4.6**	**5.4**	**–0.1**	**5.8**	**4.5**

Secondly, the share of “Machinery, equipment and other products” in total wealth capital stock has experienced a continuous fall, from 18% in 1964 to 9.2% in 2002. Of the three ICT components, and as a result of their price evolution, “Software” increased its weight while “Office machinery and computer equipment” and “Communications” showed the most stable profiles.

For productivity analysis the relevant concept is not the wealth stock but the Volume Index of Capital Services. Graph 2.1 depicts the evolution of both variables, computed as Törnqvist indices, during the period 1965–2002. As can be seen, the average growth rate of the wealth stock has been on average higher than the productive stock. As expected, the difference between the evolution of the two concepts is more marked for ICT capital (not shown).

TABLE 2.9: GFCF deflators
(1995 = 100)

	1964	1980	1990	1995	2002
1. Dwellings	**3.80**	**34.07**	**80.35**	**100.00**	**144.63**
2. Other constructions	**5.32**	**34.84**	**80.66**	**100.00**	**129.02**
2.1. Road infrastructure	5.23	34.32	80.47	100.00	127.50
2.2. Water infrastructure	5.23	34.32	80.47	100.00	127.50
2.3. Railway infrastructure	5.23	34.32	80.47	100.00	127.50
2.4. Airport infrastructure	5.23	34.32	80.47	100.00	127.50
2.5. Port infrastructure	5.23	34.32	80.47	100.00	127.50
2.6. Urban infrastructure	5.23	34.32	80.47	100.00	127.50
2.7. Other construction n.e.c.	5.37	34.96	80.75	100.00	129.59
3. Transport equipment	**11.57**	**38.82**	**88.60**	**100.00**	**115.21**
3.1. Motor vehicles	11.57	38.82	88.60	100.00	115.21
3.2. Other transport material	11.57	38.82	88.60	100.00	115.21
4. Machinery, equipment and other products	**10.89**	**44.76**	**88.85**	**100.00**	**88.10**
4.1. Agricultural, livestock and fish products	13.29	53.02	83.62	100.00	103.67
4.2. Machinery and metal products	10.78	43.90	87.88	100.00	82.99
4.2.1. Metal products	10.24	40.82	81.40	100.00	114.55
4.2.2. Machinery and mechanical equipment	10.24	40.82	81.40	100.00	114.55
4.2.3. Office machinery and computer equipment	207.32	181.17	142.68	100.00	29.45
4.2.4. Other machinery and equipment	10.06	42.21	85.94	100.00	100.44
4.2.4.1. Communications	9.63	45.57	92.39	100.00	87.39
4.2.4.2. Other machinery and equipment n.e.c.	10.24	40.82	81.40	100.00	114.55
4.3. Other products	13.67	55.31	97.66	100.00	121.92
4.3.1. Software	26.02	69.38	99.57	100.00	121.69
4.3.2. Other products n.e.c.	12.03	47.99	91.51	100.00	124.02
Total GFCF	**6.16**	**37.21**	**83.43**	**100.00**	**118.80**

TABLE 2.10: Percentage share of each asset on total wealth (net) capital stock

	1964	1980	1990	1995	2002
1. Dwellings	**47.4**	**52.2**	**49.3**	**46.8**	**47.4**
2. Other constructions	**29.8**	**31.2**	**35.8**	**39.7**	**40.9**
2.1. Road infrastructure	3.1	3.7	4.4	5.3	5.2
2.2. Water infrastructure	2.4	2.5	2.5	2.6	2.2
2.3. Railway infrastructure	2.3	1.5	1.5	1.5	1.6
2.4. Airport infrastructure	0.3	0.3	0.3	0.3	0.4
2.5. Port infrastructure	0.8	0.5	0.5	0.6	0.5
2.6. Urban infrastructure	0.4	0.4	0.7	0.9	1.1
2.7. Other construction n.e.c.	20.5	22.2	26.0	28.6	30.0
3. Transport equipment	**4.8**	**3.1**	**3.0**	**2.8**	**2.5**
3.1. Motor vehicles	3.3	1.8	1.6	1.5	1.5
3.2. Other transport material	1.5	1.3	1.5	1.3	1.0
4. Machinery, equipment and other products	**18.0**	**13.5**	**11.8**	**10.8**	**9.2**
4.1. Agricultural, livestock and fish products	0.4	0.2	0.2	0.1	0.1
4.2. Machinery and metal products	17.0	12.9	11.1	10.1	8.5
4.2.1. Metal products	0.8	1.6	1.2	1.1	1.1
4.2.2. Machinery and mechanical equipment	8.1	6.6	4.8	4.2	3.5
4.2.3. Office machinery and computer equipment	0.6	0.4	0.7	0.6	0.4
4.2.4. Other machinery and equipment	7.5	4.3	4.4	4.3	3.6
4.2.4.1. Communications	1.3	1.6	2.0	1.8	1.6
4.2.4.2. Other machinery and equipment n.e.c.	6.1	2.6	2.3	2.5	1.9
4.3. Other products	0.7	0.4	0.6	0.5	0.6
4.3.1. Software	0.1	0.1	0.3	0.3	0.5
4.3.2. Other products n.e.c.	0.6	0.3	0.2	0.2	0.1
Total Wealth (Net) Capital Stock	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

GRAPH 2.1: Annual rate of growth of real wealth (net) stock and volume index of capital services (excluding dwellings)
(1965 = 100)

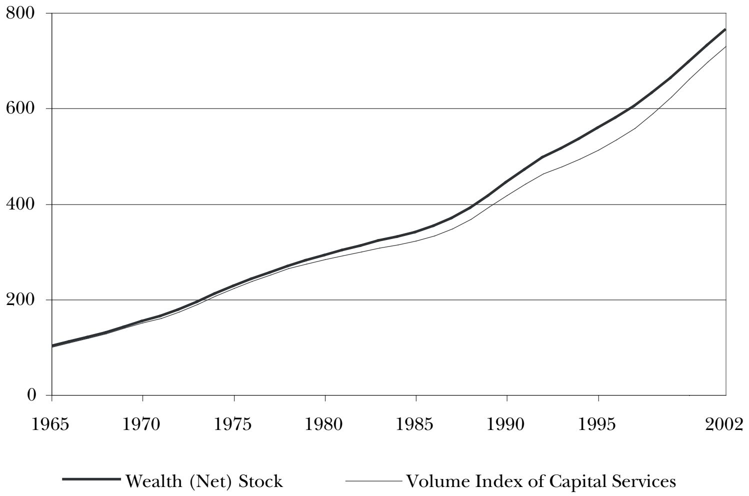


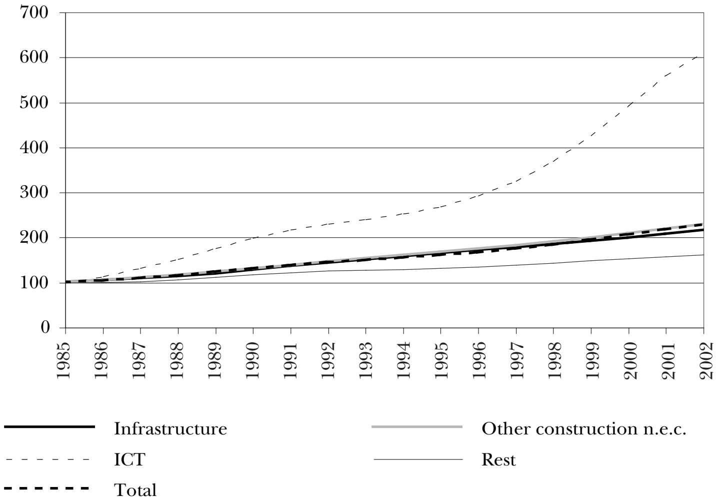
Table 2.11 gives the average annual growth rates of the volume index of capital services for the whole 1965–2002 period, for four selected sub-periods, seventeen individual types of assets as well as the three aggregations (dwellings have not been considered as part of the productive capital). The average annual growth rate for the period 1965–2002 was 5.7%. However, differences between assets can be very substantial, the highest growth rates being those presented by "Office machinery and computer equipment" (17.2% per year on average during 1965–2002) and "Software" (14.2%). "Communications" showed also one of the highest growth rates, with 7.6%. Therefore, ICT components are the ones that have experienced the fastest growth rates during the entire 1965–2002 period.

This result is illustrated by Graph 2.2 where it can be seen that while ICT capital services multiplied by a factor of six since 1985, the other forms of capital only doubled during the years 1985–2002. The reason for the fast growth of the ICT aggregate rests on all three components, but especially on "Office machinery and computer equipment." This type of capital multiplied by a factor of 17.5 while software multiplied by a factor of five in the seventeen year period (see Graph 2.3).

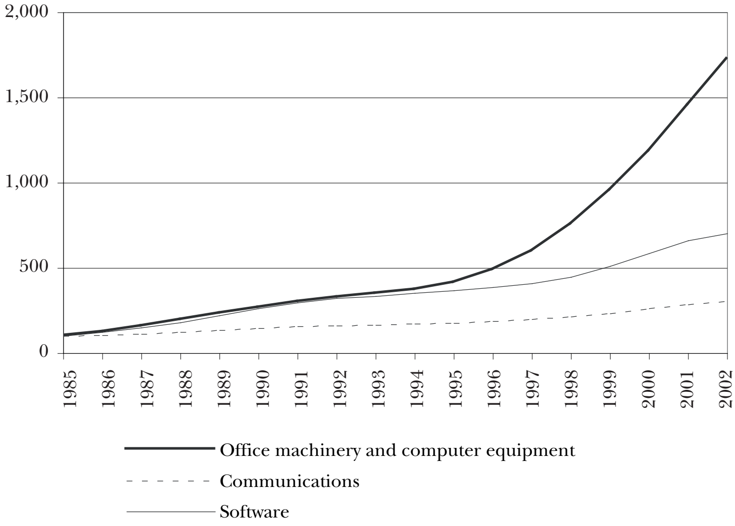
TABLE 2.11: Average annual rate of change of the volume index of capital services
(percentage)

	1965–80	1980–90	1990–95	1995–2002	1965–2002
2. Other constructions	**6.1**	**4.5**	**5.1**	**4.3**	**5.3**
2.1. Road infrastructure	7.6	4.8	6.8	4.1	6.0
2.2. Water infrastructure	6.3	3.4	3.6	2.2	4.4
2.3. Railway infrastructure	3.5	2.6	3.3	4.7	3.4
2.4. Airport infrastructure	4.3	3.3	3.1	4.4	5.1
2.5. Port infrastructure	3.6	3.1	4.0	3.0	3.5
2.6. Urban infrastructure	6.0	9.0	8.4	6.5	7.3
2.7. Other construction n.e.c.	6.3	4.7	5.1	4.5	5.5
3. Transport equipment	**7.1**	**2.0**	**3.4**	**4.5**	**5.3**
3.1. Motor vehicles	6.6	1.1	3.7	5.7	5.2
3.2. Other transport material	9.3	4.9	2.7	1.4	5.7
4. Machinery, equipment and other products	**7.7**	**4.7**	**3.3**	**6.1**	**6.1**
4.1. Agricultural, livestock and fish products	4.2	6.8	–4.0	3.0	3.6
4.2. Machinery and metal products	7.8	4.1	3.1	5.9	5.8
4.2.1. Metal products	14.1	2.1	2.2	4.2	7.5
4.2.2. Machinery and mechanical equipment	8.3	1.3	0.6	2.7	4.4
4.2.3. Office machinery and computer equipment	15.9	20.2	8.8	21.0	17.2
4.2.4. Other machinery and equipment	5.3	4.2	4.0	4.6	4.6
4.2.4.1. Communications	9.5	6.2	3.7	7.7	7.6
4.2.4.2. Other machinery and equipment n.e.c.	4.2	2.9	4.2	2.1	3.9
4.3. Other products	7.5	10.9	5.5	7.4	7.7
4.3.1. Software	14.8	19.2	6.6	9.8	14.2
4.3.2. Other products n.e.c.	5.0	1.6	2.7	–2.7	2.3
Volume Index of Capital Services	**7.3**	**4.1**	**4.0**	**5.2**	**5.7**

GRAPH 2.2: Volume index of capital services. Spain
(1985 = 100)



GRAPH 2.3: Volume index of capital services. Spain. ICT components
(1985 = 100)



The ICT volume index of capital services has shown a very marked cyclical profile, the strongest of all the asset types. In Graph 2.4 it can be seen that it grew at a rate as high as 15% per year in the second half of the eighties, mainly due to the initial low levels of this type of capital. During the first half of the nineties—when the Spanish economy went through a deep but short recession—ICT accumulation slowed down to more modest growth rates of around 5%. The second half of the nineties once again saw a strong recovery of ICT capital, which halted in the first years of this century.

Table 2.12 sets out the share of the value of capital services by asset types in total non-residential capital services. The most striking fact is the fall experienced in 2002 by "Other constructions," both in the aggregate as well as by its components. This fall is matched by the rise in the shares of "Transport equipment" and "Machinery equipment and other products."

GRAPH 2.4: Volume index of capital services. Spain
Annual rate of change
(percentage)

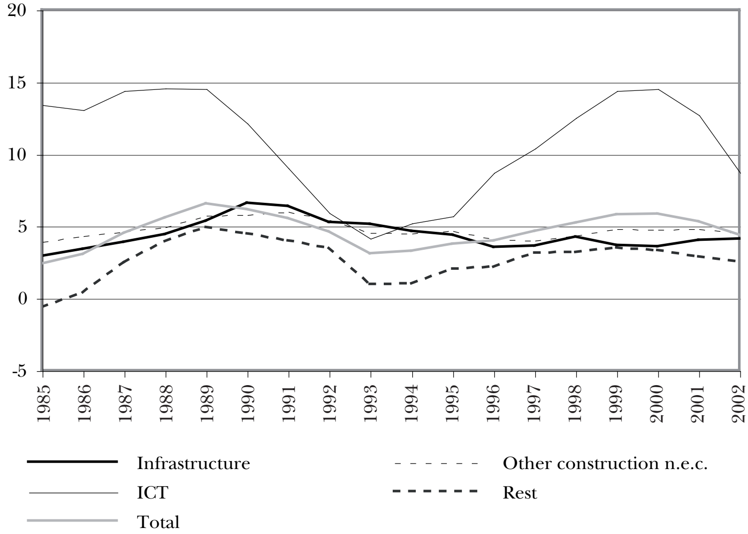


TABLE 2.12: Percentage share of the value of capital services for each asset on total value of capital services

	1965	1980	1990	1995	2002
2. Other constructions	**30.1**	**17.2**	**34.9**	**44.3**	**35.0**
2.1. Road infrastructure	3.4	1.9	3.9	5.4	4.4
2.2. Water infrastructure	2.4	1.6	3.0	3.5	2.9
2.3. Railway infrastructure	3.1	1.2	1.8	2.1	1.8
2.4. Airport infrastructure	0.4	0.2	0.3	0.4	0.4
2.5. Port infrastructure	0.8	0.3	0.6	0.7	0.5
2.6. Urban infrastructure	0.5	0.3	0.7	1.0	1.0
2.7. Other construction n.e.c.	19.6	11.7	24.6	31.3	24.0
3. Transport equipment	**17.6**	**14.3**	**13.5**	**12.9**	**14.7**
3.1. Motor vehicles	13.6	11.8	9.1	8.8	10.9
3.2. Other transport material	4.0	2.5	4.4	4.1	3.7
4. Machinery, equipment and other products	**52.3**	**68.5**	**51.5**	**42.8**	**50.3**
4.1. Agricultural, livestock and fish products	2.0	0.7	0.8	0.5	0.5
4.2. Machinery and metal products	46.7	64.0	45.9	37.5	42.0
4.2.1. Metal products	1.9	6.5	4.8	3.4	4.1
4.2.2. Machinery and mechanical equipment	18.6	31.0	18.9	12.9	14.6
4.2.3. Office machinery and computer equipment	2.9	4.4	4.9	5.2	4.5
4.2.4. Other machinery and equipment	23.3	22.1	17.3	16.0	18.8
4.2.4.1. Communications	2.5	7.9	6.9	7.3	8.3
4.2.4.2. Other machinery and equipment n.e.c.	20.8	14.3	10.3	8.8	10.5
4.3. Other products	3.6	3.8	4.9	4.9	7.8
4.3.1. Software	0.5	1.4	3.4	3.6	6.7
4.3.2. Other products n.e.c.	3.1	2.4	1.5	1.2	1.1
Total value capital services	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

In the case of "Transport equipment," its increase is motivated by the "Motor vehicles" component, while for "Machinery, equipment and other products" all its components except "Agriculture, livestock and fish products," and "Office machinery and computer equipment" experienced a rise in the latter part of the period, between 1995 and 2002.

2.5. Conclusions

This paper presents the methodology used in the new estimates of Spanish capital stock endowments, as well as some preliminary results for the period 1964–2002. The methodology applied closely follows that of the OECD, as given in its two Manuals (OECD 2001a, 2001b).

The key feature of the new estimates is the distinction between (net) wealth and productive capital stocks. An estimation of capital stock requires a decomposition of GFCF data to be previously available, as well as price deflators by types of assets. Such information with the necessary degree of dis-aggregation, especially concerning ICT assets, was not available for the Spanish economy. Therefore, a major statistical effort has been made in this direction, as summarised in section 2.3.

As mentioned in section 2.2, at least two well-established methodologies could be followed in the estimation of capital stocks and capital services: the one selected by the two OECD manuals and, as an alternative Jorgenson's procedure. The main feature of the OECD's methodology is the consideration of a retirement function, together with a hyperbolic age-efficiency profile in order to obtain the productive capital stocks. For wealth (net) capital stock estimates an age-price profile is applied, derived from the age-efficiency profile. For its part, Jorgenson's methodology does not explicitly consider a retirement function, and applies a geometric age-efficiency pattern.

The selection of a particular methodology is not the only problem. A further decision must be taken concerning specific topics, such as the average service life of each individual asset, as well as the specific functional forms for the retirement and age-efficiency functions. In order to highlight the consequences of making a given assumption, a sensitivity analysis was carried out, and the different results were compared with the baseline assumption on which our estimates are founded. The general conclusion was that all the assumptions have practical consequences for the estimated values of levels and growth rates, the specification of the average service lives of the assets being the most crucial.

A comparison between the OECD and Jorgenson's methodologies was also made, taking "Office machinery and computer equipment" as a reference. The main conclusion is that the average annual growth rates of productive capital obtained by both methodologies are very similar for long periods of time, but differences can be detected for shorter time spans. Therefore, the selection of either of the two methodologies available appears to have slight practical consequences in the long run.

The results presented refer to a period when important changes in GFCF composition by asset types took place. The data highlights the upsurge of the new ICT in the capital accumulation process. Two illustrations of this upsurge are that while ICT productive capital increased by a factor of six between 1985 and 2002, the other forms of capital only doubled in the same period. As a consequence, the share of ICT value of capital services in total also increased, from 15.2% in 1990 to 19.5% in 2002. Another important change was the reduced share of "Other construction n.e.c.," with a drop of over nine percentage points in its share in the total value of capital services in the same years. This drop was due to a fall in the "Other construction n.e.c." component, since infrastructure retained its share in the aggregate.

These transformations in the asset composition of capital stock, and the services that it provides, reflect an on-going modernisation of the structure of the Spanish economy. The database that has been put forward in this paper will allow an analysis of capital accumulation in Spanish economic growth to be reviewed, as well as an evaluation of the role played by ICT in the Spanish productivity performance (Mas and Quesada 2005).

References

DIEWERT, Erwin W. "Aggregation Problems in the Measurement of Capital." In Dan Usher, ed. *The Measurement of Capital.* Chicago and London: The University of Chicago Press, 1980, 433–538.

—. "Index Numbers." In John Eatwell, Murray Milgate and Peter Newman, eds. *The New Palgrave: A Dictionary of Economics.* London: Macmillan, 1987, 767–80.

EUROSTAT. *Intra- and extra-EU trade COMEX.* Luxembourg: Eurostat, 2000.

FRAUMENI, Barbara. "The Measurement of Depreciation in the US National Income and Products Accounts." *Survey of Current Business* 77 (July 1997): 7–23.

HULTEN, Charles R., and Frank C. WYKOFF. "Economic Depreciation and the Taxation of Structures in United States Manufacturing Industries: An Empirical Analysis." In Dan Usher, ed. *The Measurement of Capital.* Chicago and London: The University of Chicago Press, 1980, 83–120.

INE. *Contabilidad Nacional de España (CNE).* Madrid: Instituto Nacional de Estadística, several years.

—. *Encuesta de Servicios Informáticos 1995.* Madrid: Instituto Nacional de Estadística, several years.

—. *Encuesta Industrial.* Madrid: Instituto Nacional de Estadística, several years.

—. *Encuesta Industrial de Empresas.* Madrid: Instituto Nacional de Estadística, several years.

—. *Encuesta de Población Activa.* Madrid: Instituto Nacional de Estadística, several years.

—. *Tablas Input-Output.* Madrid: Instituto Nacional de Estadística, several years.

JORGENSON, Dale W. "Capital Theory and Investment Behavior." *American Economic Review* 53 (1963): 247–59.

—. *Productivity.* Vols. 1 and 2. Cambridge, MA: MIT Press, 1995.

MAS IVARS, Matilde, Francisco PÉREZ GARCÍA, and Ezequiel URIEL JIMÉNEZ. "Estimation of the Stock of Capital in Spain." *The Review of Income and Wealth* 46, no. 1 (March 2000): 103–16.

—, dirs. *El Stock de Capital en España y su Distribución Territorial (1964–2000).* 4th ed. Bilbao: BBVA Foundation-Ivie, 2002. Also available in CD-ROM.

—. *El stock y los servicios de capital en España (1964–2002). Nueva Metodología.* Bilbao: BBVA Foundation-Ivie, 2005.

MAS IVARS, Matilde, and Javier QUESADA IBAÑEZ. *Las Nuevas Tecnologías y el Crecimiento Económico en España.* Bilbao: BBVA Foundation-Ivie, 2005.

OECD. *Methods Used by OECD Countries to Measure Stocks of Fixed Capital.* Paris: Organisation for Economic Co-operation and Development, 1993.

—. *Measuring Capital, OECD Manual.* Paris: Organisation for Economic Co-operation and Development, 2001a.

—. *Measuring Productivity, OECD Manual.* Paris: Organisation for Economic Co-operation and Development, 2001b.

—. *Measuring the ICT Sector.* Paris: Organisation for Economic Co-operation and Development, 2001c.

SCHREYER, Paul. *The Contribution of Information and Communication Technology to Output Growth: a Study of the G7 Countries.* OECD Science, Technology and Industry Working Paper no. 2000/2. Paris: OECD Directorate for Science, Technology and Industry, 2000.

SCHREYER, Paul, and Julien DUPONT. "OECD Capital Services Estimates: Methodology and a First Set of Results." Chapter 1, this volume.

SEDISI. *Las Tecnologías de la Información en España.* Madrid: Asociación Española de Empresas de Tecnologías de la Información y Ministerio de Ciencia y Tecnología, several years.

UNIVERSIDAD COMERCIAL DE DEUSTO. *Riqueza Nacional de España*. Bilbao: Universidad Comercial de Deusto, 1968.

WARD, Michael. *The Measurement of Capital. The Methodology of Capital Stock Estimates in OECD Countries*. Paris: Organisation for Economic Co-operation and Development, 1976.

WYKOFF, Frank C. "Economic Depreciation and Business-Leased Automobiles." In Dale W. Jorgenson and Ralph Landau, eds. *Technology and Capital Formation*. Cambridge, MA: MIT Press, 1989.

3. From James Watt to Wired Networks: Technology and Productivity in the Long Run[1]

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In some respects, the impact of ICT (Information and Communication Technologies) on productivity growth matches historical experience. The initial impact tends to be positive but limited to a few sectors, while aggregate effects become visible only with a substantial delay. However, there are some important differences that distinguish ICT from earlier technological episodes. First, the diffusion of ICT has been faster in comparison to earlier technologies such as steam and electricity. Second, relative price declines of ICT goods have been extremely rapid, inducing high investment growth in cutting-edge technologies. Third, the contribution of ICT to productivity growth seems to be larger than that of previous technologies. Finally, ICT investment is heavily concentrated in service industries, whereas steam and electricity were more confined to the mining, manufacturing and transport sectors. This may have implications for the (measured) productivity impact of ICT.

[1] The views expressed in this paper are those of the author and do not necessarily reflect those of the European Commission or its staff. I thank participants at the Ivie (Valencian Institute of Economic Research) Workshop on ICT and Productivity Growth and Ben Gales for helpful comments. Of course, I alone remain responsible for any errors.

3.1. Introduction

The extensive empirical work done in recent years on the link between ICT and productivity growth has produced many interesting results, even though there is still a lot of work ahead. The other contributions to this volume encompass a broad overview of the results of this work obtained so far. What did we learn so far and what puzzles remain? A brief summary may read as follows. ICT does matter for productivity growth, not only in the U.S. but also elsewhere (compare Vijselaar and Albers 2002). However, estimates of the ICT contribution to output and productivity growth and their correct interpretation pose many problems and there is no consensus as yet on how to read the evidence. Growth accounts and sectoral data give some indications of the main features of productivity growth on both sides of the Atlantic and of the impact of ICT. ICT capital accumulation accounts for an appreciable part of overall productivity growth (somewhat more in the U.S. than in the euro area), but it appears that the increase of its contribution over the last cycle has been relatively modest. Furthermore, while in recent discussions the role of ICT has been hotly debated, most of the actual productivity divergence between the euro area and the U.S. is in fact accounted for by other factors, notably trends in *other* capital formation and TFP (Total Factor Productivity), according to the latest estimates at our disposal.

A closer look at sectoral developments reveals that substantial increases in the growth of ALP (Average Labor Productivity) over the last decade has been limited to a relatively small number of buoyant industries only, notably ICT producing manufacturing, telecommunications, retail trade and parts of the financial services sector. This seems to be a pattern remarkably similar on both sides of the Atlantic. That said, it appears that ICT did play an important role in some of the most dynamic sectors identified. Nevertheless, the data give no clear evidence of an ICT driven substantial upsurge in overall productivity that would qualify as a radical break with past experience. This is certainly not the case for the euro area, whereas for the U.S. the evidence is more mixed (a pick-up in ALP growth is visible from the mid-1990s onwards but the strength and sustainability of this remains an issue). Arguably some of the most marked developments of the second half of the 1990s, notably in the U.S., should be attributed partly to cyclical and one-off effects. All in all, the data give little support for the claims of the more radical *new economy* enthusiasts. It does still leave us, however, with a variant of the well-worn Solow paradox: if new technologies are important determinants of economic performance (and to that view I largely subscribe), why has their measured impact on overall productivity been so limited so far and why does it take so long for the effects to become visible in the macro-economic aggregates?

In the remainder of this contribution I offer a perspective from a long-term point of view. These reflections do not so much intend to resolve the paradox, but may help to put developments into a more proper perspective. I would say that what follows is not at all original but rather follows already familiar lines (see the seminal contribution by David 1990). Let us first take a step back and ask what can be expected of the productivity effects of a new technology in the light of historical experience. This is a bit of a speculative approach because of the limitations of any historical comparison, but it may nevertheless be illuminating.

3.2. The impact of technology on productivity: some lessons from earlier experience

To begin with, one has to bear in mind that technological development and productivity growth should not be equated, for example by supposing that technological impact can be fully judged by productivity growth.[2] With this caveat in mind, a broad and inevitably incomplete assessment from the experience of several so-called GPTs (General Purpose Technologies), notably steam power and textile machinery, electricity, the internal

[2] This is one of the limitations of the growth accounting techniques used, which can account for the proximate sources of growth which is not necessarily the same as explaining in a causal sense. To be sure, we believe in the usefulness of growth accounting but one has to realise the limitations as well.

combustion engine and lastly ICT, yields the following stylised facts.[3] Early phases of the creation of new technologies tend to be located in a few so-called *leading* sectors and are likely to encounter high development costs without commensurate economic benefits (Von Tunzelmann 2000).[4] In other words, initially the productivity gains of a new technology tend to be concentrated in a few cutting-edge sectors only, with a limited effect on overall output and productivity growth in other sectors. Outside these leading sectors, the economy will not benefit very much until the technology gradually spreads across sectors. In the early phases of diffusion, adoption and adaptation, the necessity for structural changes in the economy and the associated adjustment and learning costs are likely to outweigh the immediate economic benefits and may even lead to a retardation of productivity growth. Thus, the fact that the new technologies are associated with high adaptation costs and that their positive contribution to productivity is delayed through diffusion, learning and adoption lags may explain why typically no sudden break with past productivity growth can be discerned as far as the whole economy is concerned.

Furthermore, one should try to separate long-term and short-term effects of innovation and structural change. To the extent that productivity effects finally do feed through with long and intractable lags, there tends to be an overshooting of expectations of what technology will bring us in terms of faster economic growth and profitability, and in terms of consumption and economic activity (excess demand). This triggers speculation and bubbles on financial markets with an impact on the real economy as capital

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[3] This section cannot do full justice to the rich related literature (see Crafts 2002; Bresnahan and Trajtenberg 1995). I consider the question to what extent ICT measures up to any great inventions of the past not very relevant for its own sake. Arguably, electric light may have changed the lives of ordinary people in a more far-reaching way than the Internet (see Gordon 2001) but for productivity analysis or a broad analysis of the impact of technology on economic performance this is not necessarily the key point.

[4] This is indeed the perspective taken in many historical studies. While the nature of the British Industrial Revolution continues to be debated among economic historians, the dominant view now is that aggregate TFP growth was moderate and concentrated in relatively few sectors, and increased only very slowly during the early stages of industrial development (Harley and Crafts 2000).

floods to the firms producing and using the new technology.[5] This has happened many times in the past and the railway booms and automobile rages of past centuries are not fundamentally different from the recent ICT bubble in that respect. A bubble typically starts with justifiable optimism about the arrival of a *new era* that will boost productivity and bring down inflation. High credit growth and higher asset prices and the associated amplification mechanisms contribute to the upswing and the general mood of optimism as the bubble is inflated beyond what can be justified by economic fundamentals. Thus, rational (or justified) optimism progressively turns into its opposite: irrational exuberance (Shiller 2000). Then the bubble finally bursts. There have been many such cycles since the dawn of industrialisation. In analyzing the productivity effect of new technologies one should allow for the importance of cyclical effects, financial bubbles and hence the sustainability of any short-term *trends* discerned, and try to discern the underlying trends.

As stated, the impact of new technologies and innovation of the economy has never been straightforward and linear. The consolidation, adaptation and restructuring phase is essential to reap the economic benefits of innovation. These benefits are not apparent at the outset but rather need to be developed by a prolonged restructuring of production processes (a classical example is the stepwise change of factory layout following the switch from steam to electric power). In the initial stages of adaptation the investment effort required typically leads to a duplication of capital. Heavy investment in new technologies is added to the existing capital stock, rather than substituted for it. The major capital-saving contribution to productivity will only come at a later stage, after restructuring of the production process. In this respect the experience of steam, electricity and ICT is similar, to the extent that in all three cases more is involved than

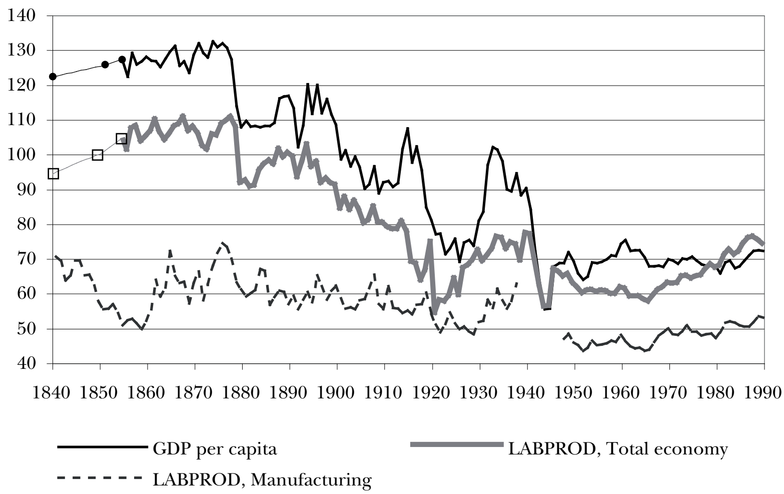
[5] Judging from previous experience, the expectation of higher-than-average returns to investment in these cutting-edge sectors has invariably been proven wrong. As investors rush in to invest in the new sectors this erodes supra-normal returns that may have been earned initially. Brookes and Wahhaj (2000) argue that in the longer run the only unambiguous beneficiaries would be the consumers who are able to enjoy lower prices of goods of services and newer products.

the straightforward substitution of a new form of productive input for an earlier alternative. At first, the new technology is added to existing capacity rather than substituting it, which for some time may even lead to a fall in capital and TFP. For instance, the first personal computers were under-utilised as they were added to existing mainframe capacity rather than substituted for it, in a way that is reminiscent of the early use of steam alongside wind and water power and of electric motors alongside steam. The capital-saving impact of redesigning production processes will become dominant only later in the transition process.

In other words, innovation involves rounds of consecutive restructuring of production and sales processes in upstream and downstream industries that again have an effect on supply and demand and on productivity. In this context, amongst other factors McKinsey Global Institute (2001) cites the emergence of the Internet and the accelerating processing requirements of upgraded Windows operating systems as triggering factors for a demand boom that helped increase productivity growth in the computer manufacturing sector. However, none of the benefits is guaranteed: the use and diffusion of technological opportunities is facilitated by ample learning capabilities and by flexible and innovative product, labor and capital markets. These conditioning factors can even be seen as prerequisites for a successful adoption of new technologies. In fact, the availability of technology *blueprints* is a necessary but by no means a sufficient condition for successful use, among other things because the translation from a technical invention to a form that is successful in a consumer market (Bijker 1995). Conversely, one does not need to invent in order to successfully implement new technologies, as the economic history of some successful *follower* nations shows.

The ascendancy of the U.S. to world productivity leadership at the end of the 19th century, surpassing the UK, the first industrial nation, is a case in point (Graph 3.1). It cannot be explained solely in terms of technological leadership. In fact, the key technologies underlying the American drive to economic leadership from the latter part of the nineteenth century onwards (like electricity and the internal combustion engine) originated in Europe, while in manufacturing U.S. productivity leadership had existed for at least most of the nineteenth century. Also, it is important to note that the United States overtook Britain gradually (without sudden discontinuities) in comparative productivity levels for the whole economy due to trends in services rather than in manufacturing, as is clear from the graph. Broadberry and Ghosal (2002) have argued that although innovations in communication and information processing—the predecessors of present-day ICT—played a key role in this respect, the pattern of diffusion was essentially determined not by technological factors in a narrow sense but by the structure of demand and the organisation of work. Thus, not *hard-core* technology alone but rather a host of other factors, including the capital saving effect of electrification, standardisation and economies of scale, relative factor abundance, industry structure, organisational innovation and institutional factors seem to have played a key role (Van Ark, Albers, and Rensman 1997).

GRAPH 3.1: **Relative productivity United Kingdom–United States 1840–1990**
GDP (Gross Domestic Product) per capita and GDP per person employed. Total economy and manufacturing
(U.S. = 100)



Source: Van Ark, Albers and Rensman (1997).

A proposed partial answer to the productivity paradox is that it is not a true paradox at all when placed in historical context (by now, this should be a well-known proposition). Technological breakthroughs and their economic impact tend to be widely separated. Indeed, too close a focus on a single factor (a new technology) risks leading to an initial overestimation of what the likely impact will be. As this belief has proven unfounded, it tends to lead to a misapprehension of the real gains innovation has brought. Because the long-term positive impact is spread over time and often difficult to discern, the lasting gains of innovation are often not widely acknowledged.

Tables 3.1 and 3.2 are summary historical growth accounts for the United Kingdom and the United States covering the pre-ICT era. The data could be expanded to cover other countries but these tables should suffice to make the basic point. Aggregate productivity growth rates (whether labor productivity or TFP), while still very low in the early stages of industrialisation and while they did increase later this was more of a gradual process. Sudden jumps or discontinuities have been the exception and not the norm and as a rule cannot be easily attributed to technological factors.[6] In other words, at first sight the long-term record does not support the expectation that overall productivity growth should necessarily accelerate markedly in response to the introduction of new technologies.

TABLE 3.1: Growth accounts for Great Britain 1760–1913

	1760–80	1780–1831	1831–73	1873–99	1899–1913
GDP growth (percentage per year)	0.6	1.7	2.4	2.1	1.4
Percentage point contribution from:					
Capital	0.25	0.60	0.90	0.80	0.80
Labor	0.35	0.80	0.75	0.55	0.55
TFP	0.00	0.30	0.75	0.75	0.05

Source: Crafts (2003).

[6] Admittedly, there may be some exceptions to this rule. The best example of a sharp acceleration in productivity growth occurred around World War I. This can arguably be linked to the introduction of electricity, but only in interaction with important structural and organisational changes. Moreover, this jump was located in the manufacturing sector (Albers and De Jong 1995; David and Wright 1999).

TABLE 3.2: **Growth accounts for the United States 1800–1989**

	1800–55	1855–90	1890–1927	1929–66	1966–89
Labor productivity growth (percentage)	0.39	1.06	2.00	2.52	1.23
Percentage point contributions from:					
Capital deepening[1]	0.19	0.69	0.51	0.67	0.88
Labor quality	-	-	0.15	0.40	0.31
TFP	0.20	0.37	1.34	1.45	0.04

[1] Including correction for capital quality.
Note: Figures may not add up due to rounding.
Source: David and Wright (1999).

Of course, the results of growth accounts should be interpreted with some caution. As a caveat, one should bear in mind that the results of traditional growth accounts might be biased for a number of reasons. Possible measurement errors, for instance as regards prices and quality-adjustment, remain an important issue. While I think it unlikely that they can explain all or indeed most of the perceived productivity gaps or puzzles (as some observers would have it) they remain important to analyze, if only to show what they *cannot* explain (Vijselaar and Albers 2002). Furthermore, non-neutrality of technical change may also bias the results of growth accounts.

A final issue worth mentioning in this section concerns the term of trade. This may also be relevant from a policy perspective and again economic history offers us some interesting observations. The rapid development of ICT industries and strong productivity growth in those industries may prompt countries to follow suit and try and set up their own ICT producers. Not only would economies of scale militate against such a strategy but it also does not take into account the effects of the sharp relative price declines for high-tech goods and services on the terms of trade. A heavy focus on ICT production typically leads to deterioration in the terms of trade for countries that are heavy ICT producers. That should of course not deter anyone enjoying a comparative advantage in the production of certain new technologies to proceed along those lines. By implication, ICT importers can benefit from positive terms of trade effects from the exports of more traditional goods and services for which they enjoy a comparative advantage. Thus, to some extent importing may be a wiser strategy than to try and set up an own ICT industry.

Again, this should come as no surprise judging from historical experience. Agricultural nations and regions benefited from positive terms-of-trade effects during the early stages of the first Industrial Revolution, as they benefited from relative price declines of manufactured products. Of course, this is not to argue that it would be detrimental rather than useful to produce new technologies. In my view the opposite is true: technical progress is the single most important ultimate source of growth and welfare doubtless improves through higher (productivity) growth. In the longer run innovation and structural change is needed to catch up and to exploit the comparative advantages of a specific country or region. The point is that as a few lead countries and/or sectors reap most of the initial benefits of new technologies (as well as suffer possible setbacks), for followers it does not necessarily pay to try to follow exactly the same pattern of specialisation. Adapting new technologies to local circumstances and comparative advantage may pay off better in the long run, while in the short run terms-of-trade effects may attenuate some of the relative income losses that follower countries or regions suffer.

3.3. Historical comparisons: pitfalls and limitations

There seems to be a growing awareness that it is worthwhile to take a longer-term view in order to put recent developments in productivity and the possible relation to technologies in a proper perspective. As a result comparing electrification and the introduction of ICT has become quite popular in recent literature (Coyle 2002, is just one example). Caution is in order when drawing historical parallels. However illuminating the similarities that were primarily stressed in the previous section, inevitably the comparison between ICT and previous technological periods goes astray in a number of important aspects as well. History repeats itself, but differently.

For instance, one of the striking differences between present-day advanced economies and the countries that first experienced modern economic growth is that the pace of economic change and indeed the average rate of economic growth is now much higher than two hundred or even a hundred years ago. This is probably due to a complex set of factors, including faster technology diffusion, deeper levels of inter-sectoral and international integration (to some extent precisely because of the efficiency of communication technologies themselves), complex social interactions, and developments in macro-economic policy. As an example, take the integration of capital markets. Integration is much deeper at present than shortly before World War I, even though there are some similarities, for instance as regards the relative size of cross-border capital flows (Bordo, Eichengreen, and Kim 1998). The list of differences between ICT and electricity (or steam) is possibly even longer. Electrification initially mainly affected sectors and small-size firms previously untouched by mechanisation and boosted industrial development in regions that before had suffered from limited transport facilities and a lack of fossil fuels. Subsequently, electrification generated direct efficiency gains and economies of scale from the integration and extension of centralised power transmission over expanded territories. For each phase the pattern of diffusion and the linkages to upstream and downstream industries would have been quite different, but it is beyond the scope of this contribution to examine this more thoroughly. Also, ICT has arguably been more revolutionary to the extent that it did not pass through a similarly prolonged phase of supplanting earlier production processes.

The remainder of this section briefly presents some (of course patchy) empirical evidence that may help highlight key differences between ICT on the one hand, and steam and electricity on the other. For this I draw on some research on the UK and the U.S. and on some examples from Dutch economic history, the latter largely based on own research. These data of course only can give a summary impression but again do help to illustrate some basic points.

An important difference between ICT and earlier GPTs concerns the speed of diffusion. Table 3.3 shows the evolution of power sources in industry in the Netherlands from the early nineteenth to the mid-twentieth century. The table shows that the diffusion of steam power was quite slow, like in Britain, which of course adopted steam power on a large scale much earlier. Whereas it took some 50 odd years for steam to account for half of industrial primary power,

TABLE 3.3: Power sources in industry in the Netherlands 1810–1960[1]
(percentage of total, corrected for primary power in electric utilities)

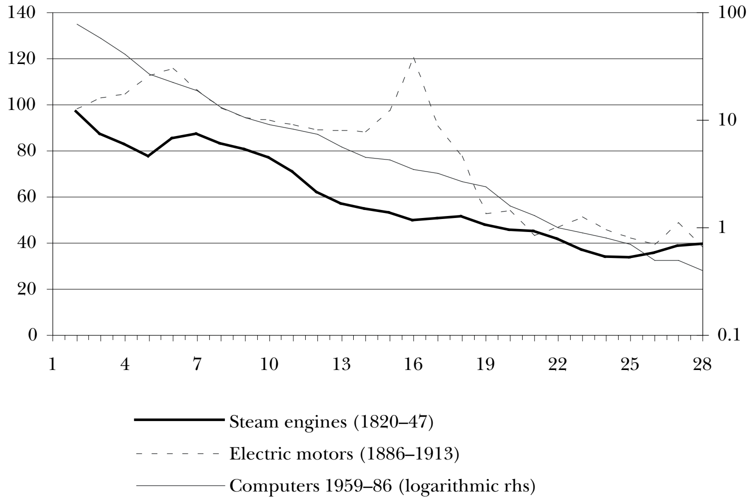
	Steam	Electricity	Gas and petrol	Water and wind
1810	0.2	—	—	99.8
1830	3.5	—	—	96.5
1850	29.9	—	—	70.1
1860	52.1	—	—	47.9
1870	70.9	—	—	29.1
1880	79.9	—	0.1	20.1
1890	88.4	0.7	0.4	10.4
1900	85.3	3.4	6.0	5.3
1908	61.0	27.5	8.7	2.7
1913	40.4	52.3	5.7	1.6
1921	na	59	na	na
1950	na	78	na	na
1960	na	84	na	na

[1] Figures may not add up due to rounding.
Source: Albers (2002) for 1810–1913, De Jong (1999) subsequently.

the diffusion of electric motors seems to have gone quicker. Even so, the lag between the original inventions of the late 1860s to the final spurt in application around World War I was quite long. While it is not easy to produce comparable diffusion statistics, it is clear that the diffusion of modern ICT proceeded at a much more rapid pace (see, for instance, the indicators in OECD 2002).

A second element to stress is that the size of relative price changes and associated substitution effects is much larger for ICT. As regards price trends, Graph 3.2 gives a comparison of investment prices (all with hedonic quality adjustment) for three technologies: steam engines, electric motors and computers for the first quarter century or so after their introduction. Quality-adjusted price estimates for steam engines and electric motors are from historical research on the Netherlands (Albers 2002), while data for prices for computers and peripherals are from the U.S. NIPA (National Income and Product Accounts). The graph clearly shows that relative price declines have been incomparably faster for computers than for the steam engines or electrical equipment of earlier episodes, which entails that the accompanying substitution effects have also been much stronger. One additional piece of evidence may be worth mentioning in this respect: ICT investment as a share of total non-residential investment was around 23% in the Netherlands in 2001 (still lower than in some other countries, notably the U.S.). However, a rough estimate suggests

GRAPH 3.2: Investment prices for three technologies after their introduction
Quality-adjusted price indices
(year 1 = 100)



Source: Albers (2002) for prices of steam engines and electric motors (Netherlands); Bureau of Economic Analysis for computer prices (U.S.).

that the share of electric motors in non-residential gross fixed capital formation in 1913 was only around 1%, evidently much smaller.[7] The price data also suggest that TFP growth in ICT production has been much faster than in the production of electrical or steam equipment, which is the next issue to be considered.

Tables 3.4 and 3.5, taken from the work of Crafts, give some estimates of the contribution of steam and electricity to labor productivity in the UK and the U.S. respectively.[8] As far as steam is concerned, the British estimates show only a mild and slow acceleration in the contribution of steam to labor productivity and of TFP, consistent with the relatively slow diffusion of steam. The measured pick-up in productivity (mainly concentrated in

[7] Of course, this figure is likely to be biased upwards for ICT to some extent as the figures include peripheral equipment while the estimates for investment in electric motors is much more narrowly defined and refers to power machinery only. Furthermore the relative share in total capital services also depends on other factors such as asset lives and rates of depreciation.

[8] In principle, such estimates could be produced for the Netherlands as well but these would require some restrictive assumptions I am a bit hesitant to make.

TABLE 3.4: Contributions to British labor productivity growth from steam 1760–1910 (percentage point per year)

	1760–1800	1800–30	1830–50	1850–70	1870–1910
Stationary steam engines					
Capital deepening	0.004	0.02	0.02	0.06	0.09
TFP	0.005	0.00	0.02	0.06	0.05
Total stationary (a)	0.009	0.02	0.04	0.12	0.14
Railways					
Capital deepening	—	—	0.14	0.12	0.01
TFP	—	—	0.02	0.14	0.06
Total railways (b)	0.009	0.02	0.16	0.26	0.07
Total steam technology TFP (a + b)	**0.02**	**0.04**	**0.20**	**0.38**	**0.21**

Source: Crafts (2003).

TABLE 3.5: Contribution of electricity to U.S. labor productivity 1899–1929

	1899–1929	1919–29
Labor productivity growth (percentage)[1]	2.50	2.19
Percentage point contributions from:		
Electric utilities capital deepening (a)	0.15	0.12
Electrical machinery capital deepening (b)	0.21	0.48
Electric utilities TFP (c)	0.04	0.01
Electrical machinery TFP (d)	0.01	0.02
Estimated TFP spillover (e)	0.15	0.45
Total contribution of electricity (a + b + c + d + e)	0.56	1.08
Total TFP contribution of electricity (c + d + e)	0.19	0.48
Total electricity contribution, excl. TFP spillover (a + b + c + d – e)	**0.41**	**0.63**

[1] GDP per hour worked.
Note: Figures may not add up due to rounding.
Source: Crafts (2002), Van Ark, Albers and Rensman (1997), own calculations.

the manufacturing sector) seems to have been more marked in the era of electrification starting around the World War I. This verdict seems to depend, however, also on the assumptions used to estimate TFP spillovers. The data on the productivity impact of steam and electricity confirm the point made already in section 3.2 on aggregate productivity over the very long run. The impact of new technologies on aggregate economic performance tends to be quite small in the initial stages of diffusion, reflecting the small share of cutting-edge sectors in overall activity. The full impact on output and productivity only feeds through with very long lags. Now to what extent is ICT different—if at all?

Consider Table 3.6 on the productivity impact of ICT.[9] The available data clearly show that the contribution of TFP growth in the ICT sector to the aggregate has been larger than in the case of electricity, and at a shorter time distance from the initial technological breakthrough. More sceptical observers may argue that the measured productivity impact of ICT performance has not been really outstanding in view of the much faster rate of diffusion and the dramatic changes in relative prices (keeping in mind also the impact of cyclical factors). In other words, so far we have not seen a sudden and radical break in the growth rates of productivity of an order of magnitude fundamentally different from past experience. The numbers available undermine the claims of the most enthusiastic *new era* pundits and suggest that ICT is not fundamentally different from earlier general-purpose technologies. In the words of Crafts (2002, 2003), the contribution of ICT is relatively large by comparison to earlier epochs, but the true paradox may be why economists expected it to be sooner from ICT. On the other hand, while I largely subscribe to the verdict of Crafts, it is also partly a matter of whether one wishes to stress the similarities or the differences. Arguably, in spite of many similarities the sheer speed of diffusion, the substantial relative price effects, and the size of the apparent impact on overall productivity do make ICT stand out in comparison to earlier experience. After all, even on conservative estimates the direct productivity impact of ICT clearly exceeds the acceleration in the era of electrification around World War I, which in itself was a quite remarkable episode.

Finally, it is worth mentioning an element which does seem to distinguish ICT from steam or electricity. The use of ICT is more concentrated in service sectors, whereas the application of earlier GPTs tended to be more narrowly confined to industry and transport. Tables 3.7 and 3.8 show some interesting comparisons with respect to the pattern of diffusion across sectors, based on data for the Netherlands on the distribution across industries of

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[9] The table reproduces estimates by Oliner and Sichel for the United States. One could also use similar estimates by others also for countries or regions as given elsewhere in this volume but what matters is the order of magnitude and in this respect some striking differences with steam or electricity stand out.

TABLE 3.6: Contribution of ICT to labor productivity growth, U.S. 1974–2001

	1974–90	1991–95	1996–2001
Growth of labor productivity non-farm business sector (percentage)	**1.36**	**1.54**	**2.43**
Percentage point contributions from:			
ICT capital deepening (a)	0.41	0.46	1.02
Other capital deepening	0.37	0.58	0.99
Labor quality	0.22	0.45	0.25
ICT TFP growth (b)	0.27	0.41	0.77
TFP growth other sectors	0.11	0.17	0.23
Total ICT contribution non-farm business (a + b)	**0.68**	**0.87**	**1.79**
Total ICT contribution whole economy[1]	**0.50**	**0.64**	**0.98**

[1] Estimate using the ratio of average labor productivity in the whole economy and in the non-farm business sectors.

Note: Figures may not add up due to rounding.
Source: Oliner and Sichel (2002), BEA (Bureau of Economic Analysis).

power capacity (for the older technologies) and on capital stock (in the case of ICT). The tables show that ICT is very heavily used in knowledge intensive service industries. By contrast, steam and electric power (and the internal combustion engine) were much more narrowly confined to the mining, manufacturing and transport sectors. This may have implications for the productivity impact of the technologies concerned, although these are not straightforward to ascertain a priori. Some may argue that this suggests a role for possible mis-measurement of productivity growth in certain services sectors, which tend to be highly ICT intensive. It is beyond the scope of this paper to discuss such issues in any detail. However, as already mentioned earlier I do not think measurement problems can be the full explanation for the puzzles we are facing.

3.4. Conclusions

After all the words of caution are there any lessons we can still draw? First, there is no compelling reason to be disappointed that the ICT *revolution* has not led to a clear surge in overall productivity

TABLE 3.7: Share in total power capacity by industry. The Netherlands 1904[1]
(percentage)

Industry branch	ISIC[2] code	Electricity	Steam	Gas and petrol	Wind and water	Total
Agriculture, hunting, forestry and fishing	01–05	0.0	6.5	0.8	34.9	6.4
Mining and quarrying	10–14	5.8	1.9	0.0	1.5	2.0
Food products, beverages and tobacco	15–16	15.7	22.5	30.9	51.7	23.5
Textiles, textile products, leather and footwear	17–19	5.6	15.3	3.5	2.0	13.5
Wood and products of wood and cork	20	2.1	3.8	6.8	4.5	3.9
Pulp, paper, paper products, printing and publishing	21–22	9.5	4.3	6.8	0.4	4.7
Chemical and fuel products	23–24	1.8	3.4	2.8	2.3	3.2
Rubber and plastics products	25	0.0	0.1	0.0	0.0	0.0
Non-metallic mineral products	26	1.2	4.0	2.9	0.5	3.6
Metals and fabricated metal products, exc. mach. and equip.	27–28	4.2	1.9	5.1	0.3	2.2
Machinery and equipment	29–33	6.2	2.3	4.8	0.1	2.7
Transport equipment	34–35	15.1	2.2	1.6	0.3	3.0
Manufacturing n.e.c.; recycling	36–37	0.1	0.8	0.3	0.0	0.7
Electricity, gas and water supply	40–41	7.6	7.3	13.1	0.2	7.6
Construction	45	0.6	7.0	3.8	0.8	6.2
Transport and communications, storage	60–63	5.1	10.2	8.2	0.0	9.4
Other commercial and public services	50–55, 64–99	19.3	6.7	8.5	0.5	7.5
Total		**6.6**	**83.0**	**7.7**	**2.7**	**100.0**
of which: MANUFACTURING		*4.1*	*50.2*	*5.0*	*1.7*	*60.9*

[1] Excluding rail and tramway locomotives, merchant and naval vessels, agricultural locomobiles, and engines used in public administration and defense.
[2] International Standard Industrial Classification.
Note: Figures may not add up due to rounding.
Source: Albers (2002), Ongevallenstatistiek (1904), own calculations.

TABLE 3.8: Share of IT (Information Technology) gross capital stock by industry. The Netherlands 2000[1]
(percentage)

Industry class	ISIC code	Share
Agriculture, hunting, forestry and fishing	01–05	0.8
Mining and quarrying	10–14	0.8
Food products, beverages and tobacco	15–16	2.0
Textiles, textile products, leather and footwear	17–19	0.3
Wood and products of wood and cork	20	part of manuf. n.e.c.
Pulp, paper, paper products, printing and publishing	21–22	2.3
Chemical and fuel products	23–24	1.7
Rubber and plastics products	25	0.4
Non-metallic mineral products	26	part of manuf. n.e.c.
Metals and fabricated metal products, exc. mach and equip.	27–28	2.2
Machinery and equipment	29–33	5.4
Transport equipment	34–35	0.8
Manufacturing n.e.c.; recycling	20, 26, 36–37	1.0
Electricity, gas and water supply	40–41	1.5
Construction	45	2.3
Wholesale and retail trade, restaurants and hotels	50–55	10.9
Post and telecommunications	64	4.5
Transport and storage	60–63	3.5
Financial intermediation	65–67	21.7
Computer and related activities	72	4.2
Other commercial services	70–71, 73–74	13.2
Public administration, defense and education	75, 80	14.7
Health and other public and community services	85, 90–93, 95, 99	5.9
Total		**100.0**
of which: MANUFACTURING		*16.0*

[1] IT comprises computers and software; figures may not add up due to rounding.

Source: Statistics Netherlands, own calculations based on asset lives of 8 years for computers and 4 years for software.

growth throughout a wide range of advanced economies. Economic history suggests that it would be naïve to expect otherwise. Then again, the economic impact of ICT appears to be quite substantial in comparison to earlier general purpose technologies such as steam and electricity, in terms of speed of diffusion, developments in relative prices, contribution to aggregate growth and sectoral composition. There still seems to be scope for improvement. However, one should not infer mechanically that a productivity boom is bound to follow that would not only mirror the experience of the 1920s in the wake of electrification but even exceed it. Prospects depend critically not only on technological possibilities but also on the complex interrelationship between private investment and expenditure decisions, managerial and organisational innovations, and public policy. This observation in itself should be enough to show that any historical comparison is hazardous and that it is surely wrong to narrow down the analysis of long-term growth to technological determinism (compare David and Wright 1999).

At any rate, action from firms, consumers and policy makers is needed to exploit the full potential of new technologies. This never happens at an even pace. As regards ICT, from a European perspective it may be tempting to look at the United States and see in that country the mirror image of our own future. But to realise the full potential of new technologies, we need to shape our own future and create an economic structure that is fertile ground for innovation. Europeans cannot afford to sit back and wait until a global wave of technical progress lifts us up and bring prosperity without effort. In that sense, the computer era cannot be expected to be any different from previous experience.

References

Albers, Ronald M. *Machinery Investment and Economic Growth: the Dynamics of Dutch Development 1800–1913.* Amsterdam: Aksant, 2002.

Albers, Ronald M., and Herman J. de Jong. "Produktiviteitsontwikkelingen in de Nederlandse industrie: een repliek." In *NEHA-Jaarboek 1995.* Amsterdam: Nederlandsch Economisch-Historisch Archief, 1995, 297–304.

Bijker, Wiebe E. *Of Bicycles, Bakelites and Bulbs. Toward a Theory of Sociotechnical Change.* Cambridge, MA: MIT Press, 1995.

Bordo, Michael D., Barry Eichengreen, and Jongwoo Kim. *Was There Really an Earlier Period of International Financial Integration Comparable to Today?* NBER Working Paper no. 6738. Cambridge, MA: National Bureau of Economic Research, 1998.

Bresnahan, Timothy F., and Manuel Trajtenberg. "General Purpose Technologies: Engines of Growth?" *Journal of Econometrics* 65, no. 1 (1995): 83–108.

Broadberry, Stephen, and Sayantan Ghosal. "From the Counting House to the Modern Office: Explaining Anglo-American Productivity Differences in Services, 1870–1990." *The Journal of Economic History* 62 (2002): 967–98.

Brookes, Martin, and Zaki Wahhaj. "Is the Internet Better than Electricity?" *World Economics Journal* 2, no. 2 (2001): 53–72.

Coyle, Diane. "Policy Implications and their Statistical Needs." Keynote presentation to the IAOS Conference on Official Statistics and the New Economy, London, 2002.

Crafts, Nicholas. "The Solow Productivity Paradox in Historical Perspective." CEPR Discussion Paper no. 3142, 2002.

—. *Steam as a General Purpose Technology: A Growth Accounting Perspective.* LSE Working Paper no. 75/03, 2003. (Later published in *The Economic Journal* 114, no. 495 [2004]: 338–51.)

David, Paul A. "The dynamo and the computer: an historical perspective on the modern productivity paradox." *American Economic Review* 80 (1990): 355–61.

David, Paul A., and Gavin Wright. *Early Twentieth Century Growth Dynamics: An Inquiry into the Economic History of "Our Ignorance."* SIEPR Discussion Paper no. 98–3. Stanford: Stanford Institute for Economic Policy Research, 1999.

De Jong, Herman J. *De Nederlandse industrie 1913–1965: Een vergelijkende analyse op basis van de productiestatistieken.* Amsterdam: Nederlandsch Economisch-Historisch Archief (NEHA), 1999.

Harley, C. Knick, and Nicholas Crafts. "Simulating the Two Views of the British Industrial Revolution." *The Journal of Economic History* 60, no. 3 (2000): 819–41.

McKinsey Global Institute. *US Productivity Growth 1995–2000: Understanding the Contribution of Information Technology relative to other Factors.* Washington, DC: Mckinsey Global Institute, 2001.

OECD. *Measuring the Information Economy.* Paris: Organisation for Economic Co-operation and Development, 2002.

Oliner, Stephen D., and Daniel E. Sichel. "Information Technology and Productivity: Where Are We Now and Where Are We Going?" *Economic Review* 87, no. 3, Third Quarter, Federal Reserve Bank of Atlanta (2002): 15–44. Also available online at http://www.frbatlanta.org/filelegacydocs/oliner_sichel_q302.pdf.

Shiller, Robert J. *Irrational Exuberance.* Princeton and Chichester: Princeton University Press, 2000.

Van Ark, Bart, Ronald M. Albers, and Marieke Rensman. "Capital Intensity and Productivity Performance in the UK and the USA, 1840–1990: Revisiting the Empirical Evidence on 150 Years of Technological Leadership." Mimeo, University of Groningen, Groningen, 1997.

Vijselaar, Focco W., and Ronald M. Albers. *New Technologies and Productivity Growth in the Euro Area.* ECB Working Paper no. 122. Frankfurt: European Central Bank, 2002. Also available online at http://www.ecb.int/pub/pdf/scpwps/ecbwp122.pdf.

Von Tunzelmann, Nick. "Technology Generation, Technology Use and Economic Growth." *European Review of Economic History* 4 (2000): 121–46.

4. The Impacts of ICT on Productivity Growth: Perspectives from the Aggregate, Industry and Firm Level[1]

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Organisation for Economic Co-operation and Development

THIS paper examines the contribution of ICT (Information and Communication Technologies) to productivity at the macroeconomic, industry and firm level. It also examines the diffusion of ICT across OECD (Organisation for Economic Co-operation and Development) countries, as an important determinant of economic impacts. The paper shows that ICT investment is having far-reaching impacts on the success of individual firms in many OECD countries, in particular where combined with investment in skills, organisational change, innovation and new company creation. These impacts can be observed in firm level studies for many OECD countries, but have only translated into stronger economic performance at the economy-wide or industry level in a few OECD countries.

4.1. Introduction

ICT has turned into a key technology over the past decade. The rapid diffusion of the Internet, of mobile telephony and of broadband networks all demonstrate how pervasive this technology has become. But how precisely does ICT affect economic growth and the efficiency of firms?

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[1] This paper reflects the views of the author and not necessarily those of the organization or its member countries.

In most analyses of economic growth, three effects of ICT are distinguished. First, as a capital good, investment in ICT contributes to overall capital deepening and therefore helps raise labor productivity. Second, rapid technological progress in the production of ICT goods and services may contribute to growth in the efficiency of using capital and labor, or MFP (Multifactor Productivity), in the ICT producing sector. And third, greater use of ICT may help firms increase their overall efficiency, and thus raise multi-factor productivity, or the overall efficiency of capital and labor. Moreover, greater use of ICT may contribute to network effects, such as lower transaction costs and more rapid innovation, which will improve the overall efficiency of the economy, i.e. MFP.

This paper will examine the evidence for these three effects in sections 4.3, 4.4 and 4.5, on the basis of empirical analysis at the aggregate, industry and firm level. The next section first briefly examines the extent of diffusion of ICT, as an important determinant of the economic impacts of ICT. The final section concludes and examines why empirical findings at the aggregate and industry level may differ from those at the firm level.

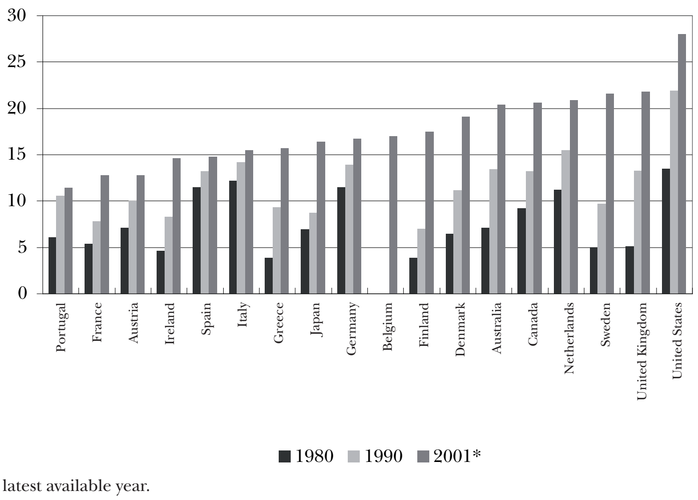
4.2. The diffusion of ICT in OECD countries

The economic impact of ICT is closely linked to the extent to which different ICT technologies have spread across OECD economies. This is partly because ICT is a network technology; the more people and firms that use the network, the more benefits it generates. The diffusion of ICT currently differs considerably between OECD countries, however, since some countries have invested more or have started earlier to invest in ICT than other countries. Investment in ICT establishes the infrastructure for the use of ICT (the ICT networks) and provides productive equipment and software to businesses. While ICT investment has accelerated in most OECD countries over the past decade, the pace of that investment differs widely. The data show that ICT investment rose from less than 15% of total non-residential investment in the early 1980s, to between 15% and 30% in 2001.

In 2001, the share of ICT investment was particularly high in the United States, the United Kingdom, Sweden, the Netherlands, Canada and Australia (Graph 4.1). ICT investment in many European countries and in Japan was substantially lower than in the United States over the past decade.

The high growth of ICT investment has been fuelled by a rapid decline in the relative prices of computer equipment and the growing scope for the application of ICT. Due to rapid technological progress in the production of key ICT technologies, such as semi-conductors, and strong competitive pressure in their production,[2] the prices of key technologies have fallen by between 15% and 30% annually, making investment in ICT attractive to firms. The lower costs of ICT are only part of the picture. ICT is also a technology that may offer large potential benefits to firm, e.g. in enhancing information flows and productivity.

GRAPH 4.1: ICT investment in selected OECD countries
Total economy
(percentage of non-residential gross fixed capital formation)



* Or latest available year.
Note: Estimates of ICT investment are not yet fully standardised across countries, mainly due to differences in the capitalisation of software in different countries. See Ahmad (2003).
Source: OECD, Database on capital services.

[2] Aizcorbe (2002) shows that part of the decline in the prices of Intel chips can be attributed to a decline in Intel's mark-ups over the 1990s, which points to stronger competition.

A second important aspect of the diffusion of ICT is the size of the ICT sector, i.e. the sector that produces ICT goods and services. Having an ICT producing sector can be important for ICT diffusion. For example, it may help firms that wish to use ICT, since the close proximity of producing firms might have advantages when developing ICT applications for specific purposes. In addition, having a strong ICT sector should also help generate the skills and competencies needed to benefit from ICT use. And it could also lead to spin-offs, as in the case of Silicon Valley or in other high technology clusters. Having an ICT sector can thus support ICT diffusion, although previous OECD work has shown that it is not a prerequisite to benefiting from the technology (OECD 2001).

In most OECD countries, the ICT sector is relatively small, although it has grown rapidly over the 1990s.[3] Its share in business employment ranges from between 3.7% in Portugal, to 11.3% in Finland (OECD 2003a). Its share in value added is slightly larger, indicating that it has an above-average level of labor productivity, and ranges from around 6% in the Slovak Republic, Greece and Mexico, to 16.5% in Ireland and Finland of business sector value added (Graph 4.2). ICT manufacturing is typically only a small part of this total and ranges between 1.3% and 14% of manufacturing employment, and between 1.6% and 23% of manufacturing value added. Finland and Ireland have the largest ICT manufacturing sectors, followed by Korea. Australia, Greece, Italy, New Zealand, Portugal and Spain, in contrast, have only a small sector producing manufactured ICT goods (OECD 2003a). The relative size of the service part of the ICT sector also varies considerably across countries, with Germany, Japan, Korea and Mexico having a relatively small ICT service sector. Some of this variation is linked to the telecommunications sector, which is very large in the Czech Republic, Hungary and Portugal and quite small in Mexico, Korea and Italy. Another part is linked to computer and related services, the sector that accounts for much of the production of software. This sector is particularly large in Ireland, Sweden and Belgium (OECD 2003a).

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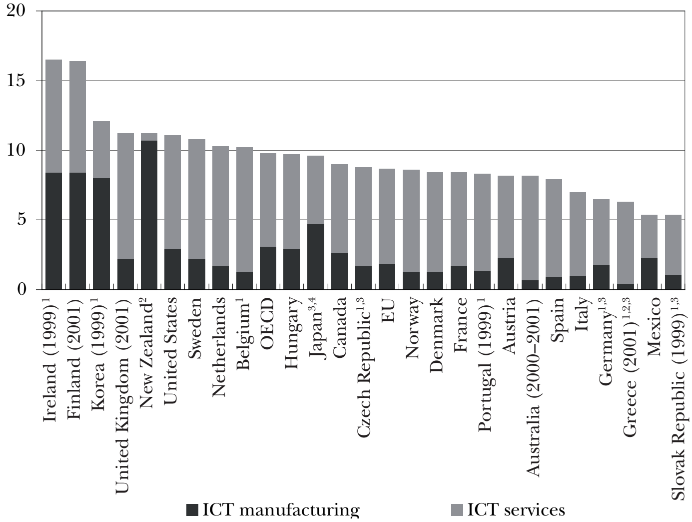
[3] These estimates are based on the OECD definition of the ICT sector (OECD 2002).

GRAPH 4.2: Share of the ICT sector in value added, non-agricultural business sector, 2000
(percentage)



[1] Excludes rental of ICT (ISIC [International Standard Industrial Classification] 7123).
[2] Includes postal services.
[3] Excludes ICT wholesale (ISIC 5150).
[4] Includes only part of computer-related activities.
Source: OECD (2003a), http://www.oecd.org/sti/scoreboard.

A third key aspect of ICT diffusion and the resulting impacts of ICT in different OECD countries is the distribution of ICT across the economy. In contrast to Solow's famous remark, "you see computers everywhere but in the productivity statistics" (Solow 1987), computers are, in fact, heavily concentrated in the service sector. Evidence for the United States shows that more than 30% of the total stock of equipment and software in legal services, business services and wholesale trade consists of IT (Information Technology) and software (OECD 2003a). Education, financial services, health, retail trade and a number of manufacturing industries (instruments, printing and publishing) also have a relatively large share of IT capital in their total stock of equipment and software. The average for all private industries is just over 11%. The goods-producing sectors (agriculture, mining, manufacturing and construction) are much less IT-intensive; in several of these industries less than 5% of total equipment and software consists of IT.

The relative distribution of ICT investment across sectors for other OECD countries is not very different for other OECD countries (Van Ark, Inklaar, and McGuckin 2002; Pilat, Lee, and Van Ark 2002); services sectors such as wholesale trade, financial and business services are typically the most intensive users of ICT.[4] Indicators of the uptake of the Internet by economic activity also suggest a high uptake in certain service sectors, notably financial and business services, as well as real estate (Graph 4.3). These results suggest that any impacts on economic performance might be more visible in the services sectors than in other parts of the economy. Nevertheless, ICT is commonly considered to be a general-purpose technology, as all sectors of the economy use information in their production process (though not necessarily to the same extent), which implies that all sectors might be able to benefit from the use of ICT.

The distribution of ICT also differs according to the size of firms. Smaller firms are typically less ICT intensive than large firms. This is illustrated in Graph 4.4 which shows the uptake of the Internet by size of firm. There are several reasons why large firms tend to be more ICT intensive. First, they typically have greater scope to improve communication flows within the firm, e.g. by establishing intra-firm networks, or by outsourcing different tasks, e.g. through the creation of extranets. But large firms also invest more in ICT than small firms since ICT investment—and the changes that it may entail—is risky and uncertain, which may be more difficult to bear for small firms. This may obviously imply that the impacts of ICT use could be greater in large firms than in small firms.

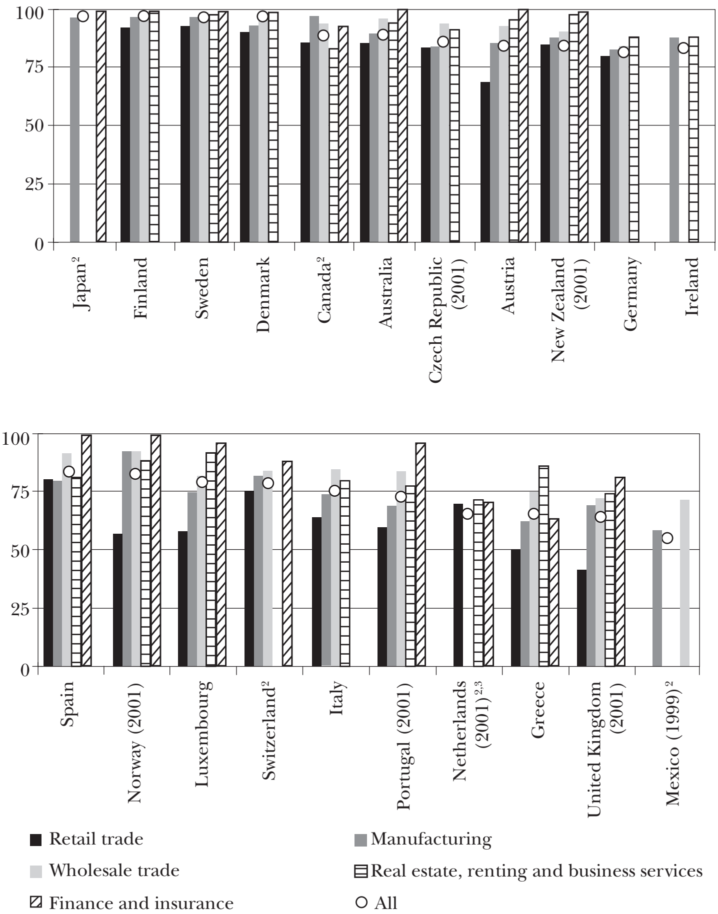
The indicators shown in Graphs 4.3 and 4.4 are also available for the economy as a whole. Graph 4.5 shows that in many countries almost all enterprises with ten or more employees are connected to the Internet. Many of these also have their own website; in Finland, Denmark, Canada, Sweden and Ireland, two-thirds or more of all enterprises with ten or more employees have websites.

One further indicator that points to the uptake of ICT is the proportion of businesses that use the Internet to make purchases and sales (Graph 4.6). This is not available for all OECD countries, but suggests that a large number of firms use the Internet for sales

[4] Health and education are also intensive ICT users but are ignored here as their output is difficult to measure.

GRAPH 4.3: Internet penetration by activity, 2002 or latest available year

(percentage of businesses with ten or more employees using the Internet)[1]



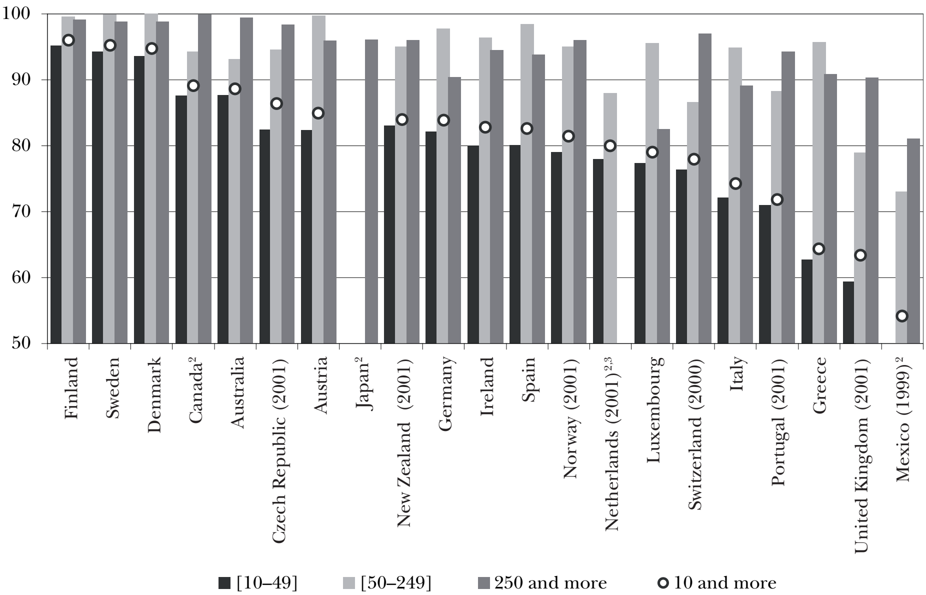
[1] In European countries, only enterprises in the business sector, but excluding NACE (Nomenclature Générale des Activités Ëconomiques dans les Communautés Européennes) activity E (electricity, gas and water supply), NACE activity F (construction) and NACE activity J (financial intermediation), are included. The source for these data is the Eurostat (Statistical Office of European Communities) Community Survey on enterprise use of ICT. In Australia, all employing businesses are included, with the exception of businesses in general government, agriculture, forestry and fishing, government administration and defence, education, private households employing staff and religious organisations. Canada includes the industrial sector. Japan excludes agriculture, forestry, fisheries and mining. New Zealand excludes electricity, gas and water supply, and only includes enterprises with NZD 30,000 or more in turnover. Switzerland includes the industry, construction and service sectors.

[2] For Canada, 50–299 employees instead of 50–249 and 300 or more instead of 250 or more. For Japan, businesses with 100 or more employees. For the Netherlands, 50–199 employees instead of 50–249. For Switzerland, 5–49 employees instead of 10–49 and 5 or more employees instead of 10 or more. For Mexico, businesses with 21 or more employees, 21–100 employees instead of 10–49, 101–250 instead of 50–249, 151–1000 instead of 250 or more.

[3] Internet and other computer-mediated networks.

Source: OECD, ICT database and Eurostat, Community Survey on ICT usage in enterprises 2002, May 2003.

GRAPH 4.4: Internet penetration by size of firm, 2002 or latest available year
(percentage of businesses with ten or more employees using the Internet)[1]



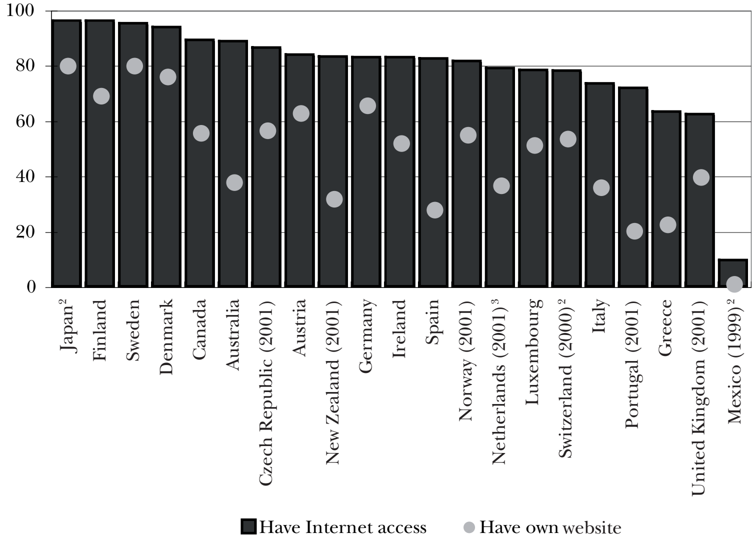
[1] See Graph 4.3 for notes 1, 2 and 3.
Source: OECD, ICT database and Eurostat, Community Survey on ICT usage in enterprises 2002, May 2003.

or purchases in the Nordic countries (Denmark, Finland, Norway and Sweden) as well as in Australia, the Netherlands and New Zealand. In contrast, only few firms in Greece, Italy, Portugal and Spain use the Internet for sales or purchases, even if many are connected to the Internet.

There are many other indicators that point to the role of ICT in different OECD economies, most of which are available in separate OECD studies (OECD 2002, 2003a). In practice, the different indicators are closely correlated and tend to point to the same countries as having the highest rate of diffusion of ICT. These typically are the United States, Canada, New Zealand, Australia, the Nordic countries and the Netherlands. From this perspective, it is likely that the largest economic impacts of ICT should also be found in these countries.

GRAPH 4.5: Business use of the Internet and websites, 2002 or latest available year

(percentage of businesses with ten or more employees)[1]



[1] See note 1 of Graph 4.3 for details.

[2] For Japan, businesses with 100 or more employees. For Switzerland, five or more employees. For Mexico, businesses with 21 or more employees.

[3] Internet and other computer-mediated networks.

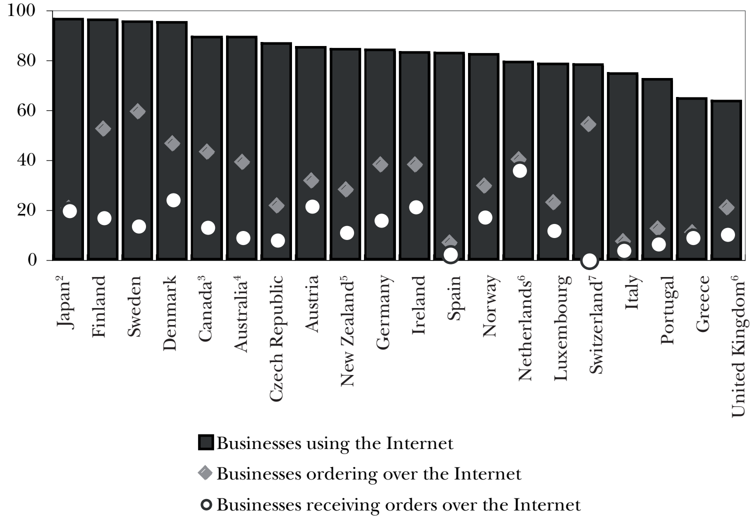
Source: OECD, ICT database and Eurostat, Community Survey on ICT usage in enterprises 2002, May 2003.

The diffusion of ICT in OECD countries has been relatively rapid compared to some other technologies, although technological diffusion typically takes considerable time.[5] For example, over 90% of firms with more than ten employees in Denmark, Japan, Finland and Sweden had Internet access in 2001, only six years after the introduction of the World Wide Web in 1995 (OECD 2002). Certain recent ICT technologies (such as the Internet) have thus already reached a large proportion of potential users only a few years after their introduction. Other ICT technologies (such as broadband) are in an earlier stage of the diffusion process, however.

The diffusion of ICT continues across OECD economies, despite the current economic slowdown. The share of ICT investment in total capital formation grew rapidly until 2000,

[5] Technological diffusion often follows an S-shaped curve, with slow diffusion when a technology is new and expensive, rapid diffusion once the technology is well established and prices fall, and slow diffusion once the market is saturated.

GRAPH 4.6: Proportion of businesses using the Internet for purchases and sales, 2001 or latest available year[1]
(percentages of businesses with ten or more employees)



[1] In European countries, except the Netherlands, Portugal and the United Kingdom, the figures refer to orders received and placed over the Internet in 2001, while the use of the Internet refers to the beginning of 2002. Only enterprises with ten or more employees in the business sector, excluding NACE activity E (electricity, gas and water supply), NACE activity F (construction) and NACE activity J (financial intermediation), are included. The source for these data is the Eurostat Community Survey on enterprise use of ICT. All other countries, unless otherwise noted, refer to enterprises at the beginning of 2001 for Internet use and to 2000 for purchases and sales.
[2] Data refer to 2002 and to enterprises with 100 or more employees. Agriculture, forestry, fisheries and mining are excluded.
[3] Data refer to 2002 and include the industrial sector.
[4] Data for Internet use refer to 2002 while data for sales and purchases refer to 2001–02. All employing businesses are included, except businesses in: general government, agriculture, forestry and fishing, government administration and defence, education, private households employing staff and religious organisations.
[5] Data refer to 2001 and include enterprises with more than ten employees in all industries except electricity, gas and water; government administration and defence; and personal and other services.
[6] Use, orders received and placed refer to Internet and other computer-mediated networks.
[7] Data refer to 2000 and include industry, construction and services.
Source: OECD 2003a.

and remained at a high share of investment even in 2001 and 2002, suggesting that ICT investment has not been affected disproportionally by the slowdown compared with other types of investment. Evidence for the United States shows that ICT was among the first areas of investment to recover in 2002. The continued diffusion of ICT can also be observed in other areas. For example, the number of broadband subscribers in the OECD area rose from 33 million by the end of 2001, to more than 55 million by the end of 2002 and to over 70 million in June 2003. Large ICT networks are now in place throughout the business sector. These will have to be maintained and updated, and will increasingly be made to work and generate economic returns.

This section has shown that ICT has diffused rapidly across OECD countries, and is continuing to spread despite the recent slowdown. However, large cross-country differences persist, also across firms and activities within countries. The United States, Canada, New Zealand, Australia, the Nordic countries and the Netherlands typically have the highest rate of diffusion of ICT. From this perspective, it is likely that the largest economic impacts of ICT should also be found in these countries. However, many studies have shown that having the equipment or networks is not enough to derive economic impacts. Other factors play a role and countries with equal rates of diffusion of ICT will not necessarily have similar impacts of ICT on economic performance. The next sections therefore turn to empirical evidence on the impacts of ICT on productivity.

4.3. The impact of ICT investment

The introduction alluded to three possible impacts of ICT on productivity, namely from ICT investment, from ICT production, and from ICT use. Evidence on the first effect, i.e. the role of ICT investment, is primarily available at the macroeconomic level. The available studies all show that ICT has been a very dynamic area of investment, due to the steep decline in ICT prices which has encouraged investment in ICT, at times shifting investment away from other assets. The capital deepening which results from investment in ICT is an important driver of economic growth. It establishes the infrastructure for the use of ICT (the ICT networks) and provides productive equipment and software to businesses. ICT investment in OECD countries rose from less than 15% of total non-residential investment in the early 1980s, to between 15% and 30% in 2001, though with considerable differences between countries (OECD 2003b).

OECD estimates show that ICT investment typically accounted for between 0.3 and 0.8 percentage points of growth in GDP (Gross Domestic Product) over the 1995–2001 period (Graph 4.7). The United States, Australia, the Netherlands and Canada received the largest boost; Japan and United Kingdom a more modest one, and Germany, France and Italy a much smaller one.[6] Investment in software accounted for up to a third of the overall contribution of ICT investment. Since investment mechanically adds to the capital available to workers it also contributes to labor productivity growth.

The results of Graph 4.7 have been confirmed by many studies for individual countries. National studies may differ from the results shown in Graph 4.7, however, due to differences in measurement. France and the United States, for instance, use specially designed *hedonic* deflators for computer equipment: these deflators adjust prices for key quality changes induced by technological progress, like higher processing speed and greater disk capacity. They tend to show faster declines in computer prices than conventional price indices, and that means more rapid growth. As a result, countries that use hedonic indices are likely to record faster real growth in investment and production of ICT than countries that do not use them. This faster real growth will translate into a larger contribution of ICT capital to growth performance.[7] The method used in Graph 4.7 adjusts for these differences. The results are therefore more comparable than those of individual national studies. Nevertheless, the national studies typically show the same countries as experiencing a large impact of ICT investment on growth, e.g. Australia, Canada and the United States.

The impact of ICT investment on economic growth have not disappeared with the economic slowdown. Technological progress in the production of computers, e.g. the release of increasingly powerful computer chips, is projected to continue for the foreseeable future. The same is true for communications

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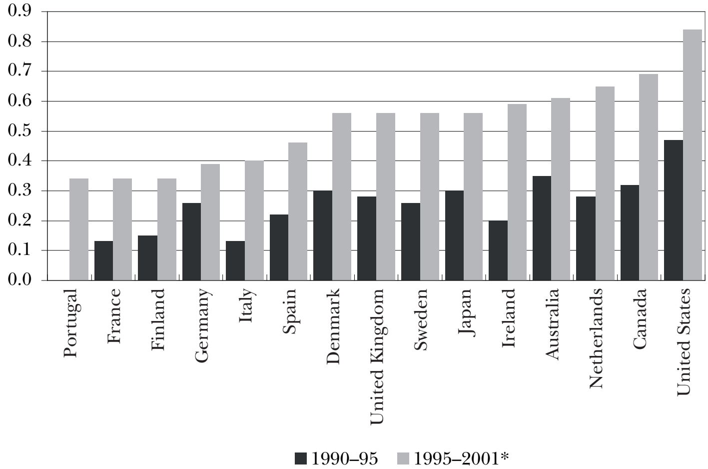
[6] The differences in ICT investment across OECD countries are discussed in OECD (2003b, 2004).

[7] Although not necessarily to more rapid growth for the economy as a whole (Schreyer 2001).

GRAPH 4.7: The contribution of investment in ICT capital to GDP growth
(percentage points contribution to annual average GDP growth, total economy)



*Or latest available year, i.e. 1995–2000 for Denmark, Finland, Ireland, Japan, Netherlands, Portugal and Sweden.
Source: OECD 2003b.

technologies. As long as firms producing these technologies are confronted with sufficient competitive pressure, the (quality-adjusted) prices of these technologies will continue to decline, encouraging ICT investment and stimulating further productivity growth. The level of ICT investment may well be lower than before 2000, however, as the 1995–2000 period was characterised by some one-off investment peaks, e.g. related to explain Y2K (Year 2000 Effect) and the spread of the Internet. On the other hand, some countries may still have scope for catch-up; by 2000, Japan and the European Union area had a share of total investment in ICT similar to that of the United States in 1980 (OECD 2003b).

4.4. The impact of the ICT producing sector

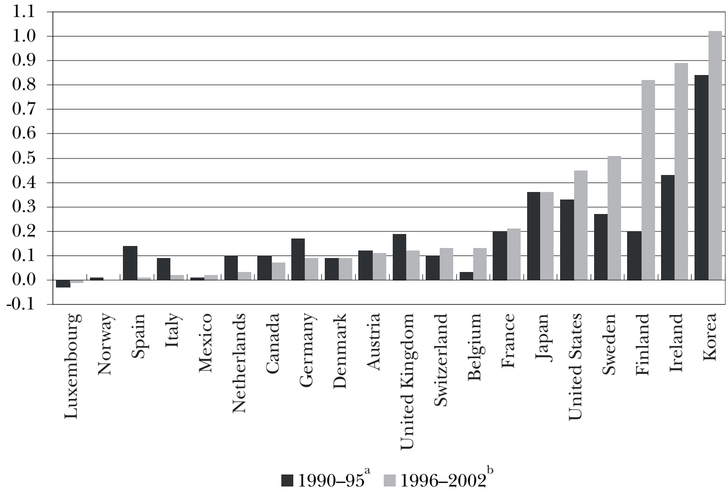
The second important economic impact of ICT is linked to having a sector producing ICT goods and services. Having such a sector can be important for growth, since ICT production has been characterised by rapid technological progress and very strong demand. The sector has therefore grown very fast, making a large contribution to economic growth, employment and exports. Moreover, having a strong ICT sector may help firms that wish to use the technology, since the close proximity of firm producers might have advantages when developing ICT applications for specific purposes. Having an ICT producing sector can thus support growth, although previous OECD work has shown that it is not a prerequisite to benefit from the technology (OECD 2001).

Empirical studies show that in Finland, Ireland and Korea, close to 1 percentage point of aggregate labor productivity growth over the 1995–2001 period was due to the strong productivity performance of the ICT manufacturing sector (Graph 4.8). In the United States, Japan and Sweden, the ICT producing sector also contributed significantly to productivity growth. This can partly be attributed to rapid technological progress in the production of certain ICT goods, such as semi-conductors, which has contributed to more rapid price declines and thus to higher growth in real volumes. However, there is a large variation in the types of ICT goods that are being produced in different OECD countries. Some countries only produce peripheral equipment, which is characterised by much slower technological progress and consequently by much less change in prices, and consequently in productivity growth.[8]

The ICT producing services sector (telecommunications and computer services) plays a smaller role in aggregate productivity growth (Graph 4.9), but has also been characterised by rapid progress. Partly, this is due to the liberalisation of telecommunications markets and the high speed of technological change in this market. The contribution of this sector to overall productivity growth increased in several countries over the 1990s,

[8] The large product variety also affects productivity comparisons. Some countries, such as the United States, use hedonic price indices to capture rapid quality changes in the ICT producing sector. This typically raises productivity growth for these sectors compared to countries that do not use these methods. However, the U.S. hedonic price index can not simply be used (or adapted) for other countries, as the quality changes that are implicit in the U.S. price index for ICT manufacturing may not be appropriate for a country producing only peripheral equipment (see Pilat, Lee, and Van Ark 2002, for details).

GRAPH 4.8: **The contribution of ICT manufacturing to aggregate labor productivity growth**
Contribution to annual average labor productivity growth
(percentage points)

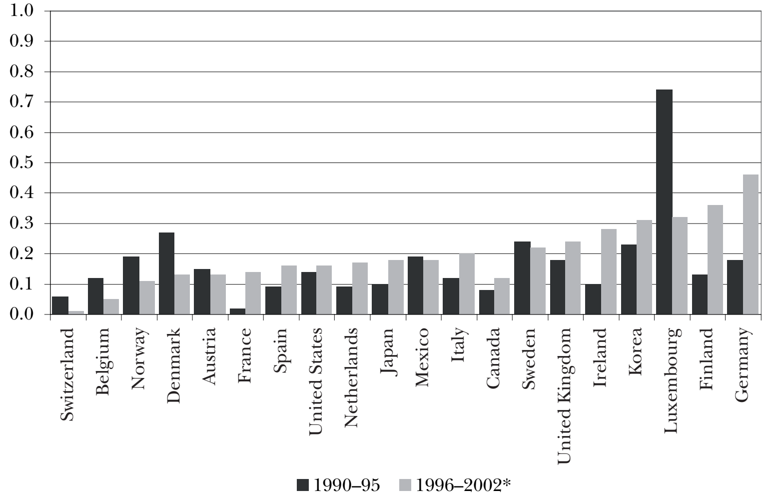


[a] 1991–95 for Germany; 1992–95 for France and Italy and 1993–95 for Korea.
[b] 1996–98 for Sweden, 1996–99 for Korea and Spain, 1996–2000 for Ireland, Norway and Switzerland, 1996–2001 for France, Germany, Japan, Mexico, the Netherlands, the United Kingdom and the United States.
Source: Pilat and Wölfl (2004), estimates on the basis of the OECD STAN (Structural Analysis) database, February 2004.

notably in Canada, Finland, France, Germany, Ireland and the Netherlands. Some of the growth in ICT producing services is due to the emergence of the computer services industry, which has accompanied the spread of ICT. The development of these services has been important in implementing ICT, as the firms in these sectors offer key advisory and training services and also help develop appropriate software to be used in combination with the ICT hardware.

The ICT manufacturing sector is thus only an important driver of the acceleration in productivity growth in a limited number of OECD countries, notably Finland, Ireland, Japan, Korea, Sweden and the United States. This is because only few OECD countries are specialised in those parts of ICT sector that are characterised by very rapid technological progress, e.g. the production of semi-conductors and electronic computers. Indeed, much of the production of ICT hardware is highly concentrated, because of its

GRAPH 4.9: The contribution of ICT producing services to aggregate productivity growth
Contribution to annual average labor productivity growth
(percentage points)



* Or latest available year. See Graph 4.8 for period coverage.
Source: Pilat and Wölfl (2004), estimates on the basis of the OECD STAN database, February 2004.

large economies of scale and high entry costs. In other words, a hardware sector cannot simply be set up, and only a few countries will have the necessary comparative advantages to succeed in it (OECD 2001). In addition, a large part of the benefits of ICT production typically accrue to importing countries and other users, due to terms-of-trade effects and an increased consumer surplus. The ICT producing services sector may offer scope for further productivity growth in a broader range of OECD countries.

4.5. The impact of ICT use

4.5.1. Impact at the industry level

A much larger part of the economy uses ICT in the production process. Several studies have examined the performance of those sectors of the economy that are intensive users of ICT. Most of these are located in the services sector, e.g. industries such as finance, business services and distribution.[9] Graph 4.10 shows the contribution of the key ICT using services (wholesale and retail trade, finance, insurance and business services) to aggregate productivity growth over the 1990s. The graph suggests small improvements in the contribution of ICT using services in Finland, the Netherlands, Norway and Sweden, and substantial increases in Australia, Canada, Ireland, Mexico, the United Kingdom and United States. The strong increase in the United States is due to more rapid productivity growth in wholesale and retail trade, and in financial services (securities), and is confirmed by several other studies (e.g. McKinsey 2001; Bosworth and Triplett 2003). The strong increase in productivity growth in Australia has also been confirmed by other studies (e.g. Gretton, Gali, and Parham 2004). In some other countries, ICT using services made a negative contribution to aggregate productivity growth. This is particularly the case in Switzerland in the first half of the 1990s, resulting from poor productivity growth in the banking sector.[10]

Stronger growth in labor productivity in ICT using industries could simply be due to greater use of capital. Estimates of MFP growth adjust for growth in capital stock and can help show whether ICT using sectors have indeed improved their overall efficiency in the use of capital and labor. Breaking aggregate MFP growth down in its sectoral contributions can also help show whether changes in MFP growth should be attributed to ICT manufacturing, to ICT using sectors, or to other sectors.

The available OECD estimates of MFP growth at the sectoral level point to growing contributions of ICT using services to aggregate productivity in Denmark and Finland. In several other countries, however, MFP growth in the ICT using services was negative over the 1990s. In some countries for which no OECD MFP estimates at the sectoral level are available, notably the

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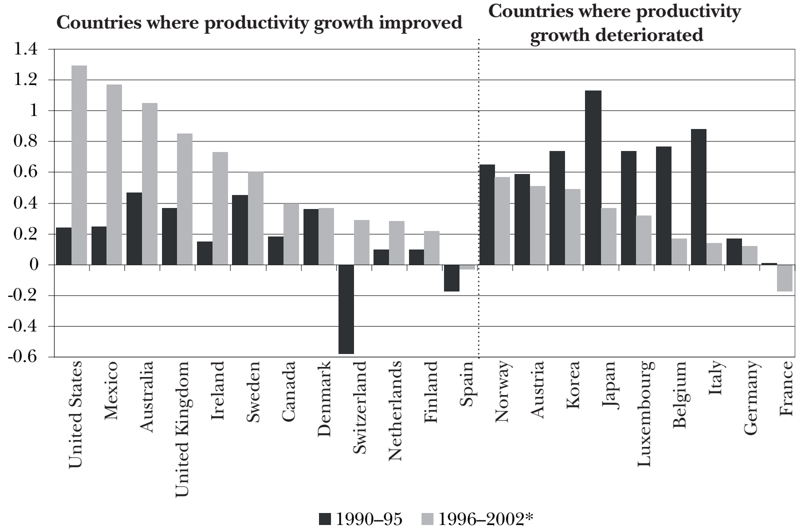
[9] Certain manufacturing sectors, e.g. printing and publishing, are also intensive users of ICT. These are not considered here, as the impact of ICT use on productivity growth in these sectors is difficult to separate from other factors. Van Ark, Inklaar and McGuckin (2002) provides some evidence on these industries.

[10] Poor measurement of productivity in financial services may be partly to blame. The OECD is currently working with member countries to improve methods to capture productivity growth in this sector.

GRAPH 4.10: The contribution of ICT using services to aggregate productivity growth

Contribution to annual average labor productivity growth
(percentage points)



* See Graph 4.8 for period coverage. Data for Australia are for 1996–2001.
Source: Pilat and Wölfl (2004), estimates on the basis of the OECD STAN database, February 2004.

United States and Australia, there is also evidence that sectors that have invested most in ICT, such as wholesale and retail trade, have experienced an increase in MFP growth (McKinsey 2001; Bosworth and Triplett 2003; Gretton, Gali, and Parham 2004).

The evidence for strong MFP growth in the United States in ICT using services seems due to a few factors. First, a considerable part of the pick-up in productivity growth can be attributed to retail trade, where firms such as Wal-Mart used innovative practices, such as the use of ICT to reduce inventories, increase asset utilisation and improve planning and management, to gain market share from its competitors (McKinsey 2001). The larger market share for Wal-Mart and other productive firms raised average productivity and also forced Wal-Mart's competitors to improve their own performance. Among the other ICT using services, securities accounts also for a large part of the pick-up in productivity growth in the 1990s. Its strong performance has been attributed to a combination of buoyant financial markets (i.e. large trading volumes), effective use of ICT (mainly in automating trading processes) and stronger competition (McKinsey 2001). These impacts of ICT on MFP are therefore primarily due to efficient use of labor and capital linked to the use of ICT in the production process. They are not necessarily due to network effects, where one firms' use of ICT has positive spill-overs on the economy as a whole. Spill-over effects may also play a role; however, as ICT investment started earlier, and was stronger in the United States than in most OECD countries.

The United States is not the only country where ICT use may already have had impacts on MFP growth. Studies for Australia (e.g. Gretton, Gali, and Parham 2004) suggest that a range of structural reforms have been important in driving the strong uptake of ICT by firms and have enabled these investments to be used in ways that generate productivity gains. This is particularly evident in wholesale and retail trade and in financial intermediation, where most of the Australian productivity gains in the second half of the 1990s have occurred.

4.5.2. Impact at the firm level

The discussion thus far has shown that ICT investment contributed to growth in most OECD countries in the 1990s, and that ICT production contributed to growth in some OECD countries. It has also shown that ICT using industries in the United States and Australia experienced a strong increase in productivity growth in the second half of the 1990s, partly due to their use of ICT.[11] Few other countries have thus far experienced similar productivity gains in ICT using services, although some aggregate evidence suggests that the growth in MFP may be linked to the productivity-enhancing benefits from the use of ICT (OECD 2003b). Nevertheless, much of the current interest in ICT is linked to the potential economic benefits arising from its use in the production process.

[11] Mexico also experienced a strong pick-up in productivity growth in ICT using services over the 1990s. However, this is primarily linked to its recovery from a major economic crisis in 1995, not necessarily to more effective use of ICT.

The strongest evidence for the economic impact of ICT use emerges from firm level studies.[12] Firm level data point to factors influencing the impacts of ICT that cannot be observed at the aggregate level. For example, the role of ICT in helping firms gain market share can only be examined with firm level data, as can the role of organisational change. Over the past years, much progress has been made in developing statistics on the use of various ICT technologies in the economy. In addition, many countries have developed databases that provide detailed and comprehensive data on the performance of individual firms. Combining these two sources of information can help establish a link between firm performance and their use of ICT. Moreover, providing that these databases cover a large proportion of the economy, they can also link the performance of individual firms to that of the economy as a whole.

4.5.2.1. ICT can strengthen firm performance

There is evidence from many firm level studies, and for many OECD countries, that ICT use has a positive impact on firm performance. These impacts can vary. For example, a study for Canada (Baldwin and Sabourin 2002) found that Canadian firms that used either one or more ICT technologies had a higher level of productivity than firms that did not use these technologies. Moreover, the gap between technology-using firms and other firms increased between 1988 and 1997, as technology-using firms increased relative productivity compared to non-users. The study also found that some ICT technologies were more important in enhancing productivity than other technologies; communication network technologies being particularly important. A study with Australian firm level data (Gretton, Gali, and Parham 2004) found that the use of computers has a positive effect on MFP growth in the mid-1990s, i.e. before the peak in ICT investment, with considerable variation across industries.

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[12] This section provides references to some of the available firm level studies. The OECD work has benefited from close co-operation with researchers in 13 countries that were involved in work with firm level data. More detail on their work and other firm level studies is available in OECD (2003b, 2004).

These studies are confirmed by many others. For example, firms using ICT typically pay higher wages. In addition, the studies show that the use of ICT does not guarantee success; many of the firms that improved performance thanks to their use of ICT were already experiencing better performance than the average firm. Moreover, the benefits of ICT appear to depend on sector-specific effects and are not found in equal measure in all sectors.

There is also evidence from many firm level studies that ICT can help in the competitive process. Firm level studies have found that the use of advanced technology is positively correlated with plant expansion and negatively with plant exit. For example, in a recent study for Canada, Baldwin and Sabourin (2002) found that a considerable amount of market share was transferred from declining firms to growing firms over a decade. At the same time, the growers increased their productivity relative to the declining firms. Those technology users that were using communications technologies or that combined technologies from several different technology classes increased their relative productivity the most. In turn, gains in relative productivity were accompanied by gains in market share.

4.5.2.2. The role of computer networks

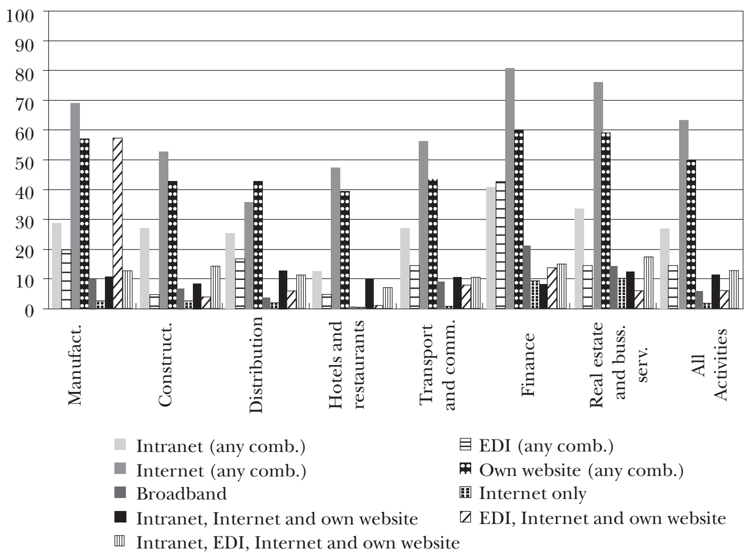
Some ICT technologies may be more important to strengthen firm performance than others. Computer networks may be particularly important, as they allow a firm to outsource certain activities, to work more closely with customers and suppliers, and to better integrate activities throughout the value chain. These technologies are often considered to be associated with network or spill-over effects. In recent years, more data have become available on this technology. For the United States, Atrostic and Nguyen (2002) found that average labor productivity was higher in plants with networks and that the impact of networks was positive and significant after controlling for several production factors and plant characteristics. Networks were estimated to increase labor productivity by roughly 5%. Atrostic et al. (2004) also provided evidence for Japan and found that both interfirm and intrafirm networks were correlated with higher MFP levels in firms. Open networks, such as the Internet, as well as EDI (Electronic Data

Interchange) networks, were particularly important. For the United Kingdom, Criscuolo and Waldron (2003) found that the use of networks had an important impact on productivity growth, but primarily through electronic purchasing, not through selling. This result confirms that networks can help firms improve the management of their supply chain.

4.5.2.3. Impact on services

ICT use is more widespread in the services sector than in manufacturing. Moreover, not all sectors use the same technologies. Evidence for the United Kingdom suggests that financial intermediation is the sector most likely to use network technologies, including broadband technology, and also the sector to use combinations of network technologies. The combination of several network technologies shows that these sectors are intensive users of information and thus have the greatest scope to benefit from ICT (Graph 4.11).

GRAPH 4.11: Use of ICT network technologies by activity, United Kingdom, 2000[1]
(percentage of all firms, business weighted)



[1] Broadband includes xDSL and all other broadband connections.
Source: Clayton and Waldron (2003).

Firm level evidence demonstrates that ICT can affect the performance of the services sector. For example, Doms, Jarmin and Klimek(2002) showed that growth in the U.S. retail sector involved the displacement of traditional retailers by sophisticated retailers introducing new technologies and processes, thus confirming the sectoral evidence on the U.S. distribution sector discussed above. There is also growing evidence for other OECD countries that ICT can be beneficial to services sector performance. For Germany, Hempell (2002) showed significant productivity effects of ICT in firms in the German services sector. Experience gained from past process innovations helped firms to make ICT investments more productive. ICT investment may thus have increased the productivity differences between firms, and potentially also between countries. A comparative study for Germany and the Netherlands (Hempell et al. 2004) confirmed the link between ICT and innovation in the German services sector, and also found such a link for the services sector of the Netherlands. Moreover, the study found that ICT capital had a significant impact on productivity in the Netherlands' services sector. For Australia, Gretton, Gali, and Parham (2004) found positive impacts of ICT use on labor and MFP growth in several services sectors, in both sectoral and firm level analysis.

The firm level evidence thus suggests that ICT use is beneficial —though under certain conditions—to firm performance in all countries for which micro-level studies have been conducted. However, the sectoral evidence is less conclusive as there is little evidence that ICT using industries have experienced more rapid productivity growth in OECD countries, the United States and Australia being the major exceptions. There are several reasons why this may be the case and why aggregate evidence may differ from firm-specific evidence. First, aggregation across firms and industries, as well as the effects of other economic changes, may disguise some of the impacts of ICT in sectoral analysis that are more evident from firm level analysis. Second, the firm level benefits of ICT may be larger in the United States than in other OECD countries, and thus show up more clearly in aggregate and sectoral evidence. This may be because the conditions under which ICT is beneficial to firm performance, such as sufficient scope for organisational change, might be more firmly established in the United States than in other countries. Third, measurement may play a role as the impacts of ICT may be insufficiently picked up in data outside the United States, due to differences in the measurement of output. For example, the United States is currently one of the few countries that have changed the measurement of banking output to reflect the convenience of automated teller machines.

4.5.3. Factors that affect the impact of ICT at the firm level

The evidence summarised above suggests that the use of ICT does have impacts on firm performance, but primarily, or only, when accompanied by other changes and investments. Some early studies on the rates of return to ICT investment suggested that the returns to ICT were relatively high compared to other investments in fixed assets. This is now commonly attributed to the fact that ICT investment is accompanied by other expenditures, which are not necessarily counted as investment (Brynjolfsson and Hitt 2003). This includes expenditure on skills and organisational change. This is also confirmed by many empirical studies suggesting that ICT primarily affects firms where skills have been improved and organisational changes have been introduced. Another important factor is innovation, since users often help make investment in technologies, such as ICT, more valuable through their own experimentation and invention. Without this process of *co-invention*, which often has a slower pace than technological invention, the economic impact of ICT may be limited. The firm level evidence also suggests that the uptake and impact of ICT differs across firms, varying according to size of firm, age of the firm, activity, etc. This section looks at some of this evidence and discusses the main complementary factors for ICT.

4.5.3.1. ICT use is complementary to skills

A substantial number of longitudinal studies address the interaction between technology and human capital, and their joint impact on productivity performance. Many firm level studies confirm the complementarity between technology and skills in improving productivity performance. Studies for Canada, for example, have found that use of advanced technology is associated with a higher level of skill requirements (Baldwin, Gray, and Johnson 1995). In Canadian plants using advanced technologies, this often led to a higher incidence of training. The study also found that firms adopting advanced technologies increased their expenditure on education and training. For Australia, Gretton, Gali and Parham (2004) found that the positive benefits of ICT use on MFP growth were typically linked to the level of human capital and the skill base within firms, as well as firms' experience in innovation, their application of advanced business practices and the intensity of organisational change within firms. Many researchers also found that computers are a skill-biased technology, i.e. increasing the demand for skilled workers and reducing the demand for unskilled workers.

A few reports have also looked at other worker-related impacts. For example, Luque and Miranda (2000) found that the skill-biased technological change associated with the uptake of advanced technologies also affects worker mobility. The larger the number of advanced technologies adopted by a plant, the higher is the probability that a worker will leave. Their interpretation is that workers at technologically advanced plants have greater (often unobserved) abilities, and therefore can claim a higher wage when they leave. The other mechanism at work is that less skilled workers tend to be pushed to plants that are less technologically advanced.

4.5.3.2. Organizational change is key to making ICT work

Closely linked to human capital is the role of organizational change. Research work typically find that the greatest benefits from ICT are realised when ICT investment is combined with other organisational changes, such as new strategies, new business processes and practices, and new organisational structures. The common element among these practices is that they entail a greater degree of responsibility of individual workers regarding the content of their work and, to some extent, a greater proximity between management and labor. Because such organisational change tends to be firm-specific, empirical studies show on average a positive return to ICT investment, but with a huge variation across organizations.

A number of papers have addressed ICT's link to human capital, organisational change and productivity growth. Black and Lynch (2001), for example, found that the implementation of human resource practices is important for productivity, e.g. giving employees greater voice in decision-making, profit-sharing mechanisms and new industrial relations practices. They also found that productivity was higher in firms with a large proportion of non-managerial employees that use computers, suggesting that computer use and the implementation of human resource practices go hand-in-hand.

Several studies on organisational change are also available for European countries. For Germany, Falk (2001) found that the introduction of ICT and the share of training expenditures were important drivers of organisational changes, such as the introduction of total quality management, lean administration, flatter hierarchies and delegation of authority. The prospects for such organisational changes may be affected by policy barriers, however. In a 2000 survey of German firms, more than 23% of firms outside the ICT sector cited legal restrictions as a barrier to the adoption of ICT and 19% of non-ICT firms mentioned internal resistance within the firm as a barrier to uptake (Hempell, Van Leeuwen, and Van Der Wiel 2004). For France, Greenan and Guellec (1998) found that the use of advanced technologies and the skills of the workforce were both positively linked to organisational variables. Organisations that enabled communication within the firm and that innovated at the organisational level seemed more successful in the uptake of advanced technologies. Moreover, such organisational changes also increased the ability of firms to adjust to changing market conditions, e.g. through technological innovation and the reduction of inventories. Research does not always find clear results regarding the importance of organisational factors, however. For example, for Switzerland, Arvanitis (2004) found that ICT and human capital are positively correlated with productivity; and that the effect of organisation is positive but not statistically significant. Moreover, new organisational practices did not seem to contribute to a higher productivity of either ICT or human capital.

4.5.3.3. Firm size and age affect the impact of ICT

Much work has been done on the relationship between ICT and firm size, notably with regard to differences in the uptake of ICT by size of firm.[13] This question has been addressed in a large number of studies, most of which find that the adoption of advanced technologies, such as ICT, increases with the size of firms and plants.

Evidence for the United Kingdom, with 2000 data for a variety of network technologies used in different combinations, shows that large firms of over 250 employees are more likely to use network technologies such as Intranet, Internet or EDI than small firms; they are also more likely to have their own website. However, small firms of between 10 and 49 employees are more likely to use Internet as their only ICT network technology. Large firms are also more likely to use a combination of network technologies. For example, over 38% of all large UK firms use intranet, EDI and Internet, and also have their own website, as opposed to less than 5% of small firms. Moreover, almost 45% of all large firms already used broadband technologies in 2000, as opposed to less than 7% of small firms.

These differences are partly due to the different uses of the network technologies by large and small firms. Large firms may use the technologies to redesign information and communication flows within the firm, and to integrate these flows throughout the production process. Some small firms only use the Internet for marketing purposes. Moreover, skilled managers and employees often help in making the technology work in large firms (Gretton, Gali, and Parham 2004).

4.5.3.4. ICT use is closely linked to innovation

There are indications of an important link between the use of ICT and the ability of a company to adjust to changing demand and to innovate. For example, work for Germany based on innovation surveys found that firms that had introduced process innovations in the past were particularly successful in using ICT (Hempell 2002).

[13] There is also a question whether ICT has an effect on the size of firms or changes the boundaries of firms over time (see OECD 2003b, for some discussion of this issue).

The output elasticity of ICT capital for these firms was estimated to be about 12%, about four times that of other firms. This shows that the productive use of ICT is closely linked to innovation in general, and notably to process innovation. Work carried out in other countries also confirm this link. For example, Greenan and Guellec (1998) found that organisational change and the uptake of advanced technologies increased the ability of firms to adjust to changing market conditions through technological innovation. For the Netherlands, Hempell, Van Leeuwen and Van Der Wiel (2004) found that services firms that engaged in permanent non-technological innovation benefited more from ICT than those that did not. The links between ICT and innovation go both ways. On the one hand, firms that have innovated in the past are more likely to have the abilities required to implement ICT and make the changes that are needed to benefit from ICT. On the other hand, ICT can help firms to strengthen innovation, as it helps to foster networking and informal learning between firms, which is often the key to innovation in services.

4.5.3.5. The impact of ICT use often only emerge over time

Given the time it takes to adapt to ICT, it should not be surprising that the benefits of ICT may only emerge over time. This can be seen in the relationship between the use of ICT and the year in which firms first adopted ICT. Evidence for the United Kingdom shows that among the firms that had already adopted ICT in or before 1995, close to 50% bought using electronic commerce in 2000 (Clayton and Waldron 2003). For firms that only adopted ICT in 2000, less than 20% bought using e-commerce. The evidence presented by Clayton and Waldron also suggests that firms move towards more complex forms of electronic activity over time; out of all firms starting to use ICT prior to 1995, only 3% had not yet moved beyond the straightforward use of ICT in 2000. Most had established an Internet site, or bought or sold through e-commerce. Of the firms adopting ICT in 2000, over 20% had not yet gone beyond the simple use of ICT.

The role of time also emerges from analysis for Australia. Gretton, Gali and Parham (2004) used firm level information on productivity growth and the duration of computer use to examine the dynamics of the impact of the introduction of computers. They found that computers had a positive effect on MFP growth that varied between industries and that the positive effect was largest in the earlier years of uptake but appeared to taper off as firms returned to *normal* growth after the productivity boost of the new technology. This indicates that the ultimate productivity effect from adoption of ICT is a step up in levels, rather than a permanent increase in the rate of growth. However, further technical developments can set further productivity-enhancing processes in motion.

4.5.4. Does the impact of ICT at the firm level differ across countries?

Cross-country studies on the impact of ICT at the firm level are still relatively scarce, primarily since many of the original data sources were of an ad hoc nature and not comparable across countries. In recent years, the growing similarity of official statistics is enabling more comparative work, which has been further encouraged in the recent OECD work with statistical offices. An example of such a study is a recent comparison between the United States and Germany (Haltiwanger, Jarmin, and Schank 2003), that examined the relationship between labor productivity and measures of the choice of technology. The study distinguished between different categories of firms according to their total level of investment and their level of investment in ICT. It found that firms in all categories of investment had much stronger productivity growth in the United States than in Germany. Moreover, firms with high ICT investment had stronger productivity growth than firms with low or zero ICT investment. The study also found that firms in the United States have much greater variation in their productivity performance than firms in Germany. This may be because U.S. firms engage in much more experimentation than their German counterparts; they take greater risks and opt for potentially higher outcomes.

Hempell, Van Leeuwen and Van Der Wiel (2004) provide an international comparison of ICT impacts on the services sector in Germany and the Netherlands. They found that ICT capital deepening raises labor productivity in both countries and that investment in ICT capital appears to be complementary to innovation in both countries. They also found some differences, e.g. innovation had a more direct impact on productivity in Germany than in the Netherlands. Another international comparison of the impact of computer networks on firm productivity was recently carried out for Denmark, Japan and the United States (Atrostic et al. 2004). It demonstrated a sizeable impact of these networks on productivity, in particular for the United States. Such international comparisons should contribute to further insights and can help in explaining cross-country differences in the benefits that are being drawn from ICT.

4.6. Concluding remarks

Examining the role of ICT at the aggregate, sectoral and firm level raises some difficult questions (see Gretton, Gali, and Parham 2004; OECD 2004). The firm level evidence suggests that ICT use is beneficial under certain conditions to firm performance in all countries for which micro-level studies have been conducted. However, the aggregate and sectoral evidence is less conclusive about the benefits of ICT use. It shows that investment in ICT capital has contributed to growth in most OECD countries, and that the ICT producing sector has contributed to productivity growth in some OECD countries. There is, however, little evidence that ICT using industries have experienced more rapid productivity growth, the United States and Australia being the major exceptions. There are several reasons why this may be the case and why aggregate evidence may differ from firm-specific evidence.

First, aggregation across firms and industries, as well as the effects of other economic changes, may disguise some of the impact of ICT in sectoral and aggregate analysis that are more evident from firm level analysis. This may also be because the impact of ICT depends on other factors and policy changes, which may differ across industries. The size of the aggregate effects over time depends on the rate of development of ICT, their diffusion, lags, complementary changes, adjustment costs and the productivity-enhancing potential of ICT in different industries (Gretton, Gali, and Parham 2004).

Second, the firm level benefits of ICT may be larger in the United States (and possibly also in Australia) than in other OECD countries, and thus show up more clearly in aggregate and sectoral evidence. There is some evidence from cross-country comparisons of the productivity impact of ICT that the firm level impacts of ICT may be smaller in European countries such as Germany, than in the United States (Haltiwanger, Jarmin, and Schank 2003). Given the more extensive diffusion of ICT in the United States, and its early start, this interpretation should not be surprising. This is particularly the case if it takes time before the benefits from ICT become apparent, e.g. because of the high costs of adjustment to the new technology. Moreover, the conditions under which ICT is beneficial to firm performance, such as sufficient scope for organisational change, might be more firmly established in the United States than in some other OECD countries.

Measurement may play a role as well. The impacts of ICT may be insufficiently picked up in macroeconomic and sectoral data outside the United States, due to differences in the measurement of output. For example, the United States is one of the few countries that has changed the measurement of banking output to reflect the convenience of automated teller machines. Since services sectors are the main users of ICT, inadequate measurement of service output might be a considerable problem. Improvements in measurement may make some of the benefits of ICT more clearly visible.

Fourth, countries outside the United States may not yet have benefited from spill-over effects that could create a wedge between the impact observed for individual firms and at the macroeconomic level. The discussion above has already suggested that the impact of ICT may be larger than the direct returns flowing to firms using ICT. For example, ICT may lower transaction costs, which can improve the functioning of markets (by improving the matching process), and make new markets possible. Another effect that can create a gap between firm level returns and aggregate returns is ICT's impact on knowledge creation and innovation. ICT enables more data and information to be processed at a higher speed and can thus increase the productivity of the process of knowledge creation. A greater use of ICT may thus gradually improve the functioning of the economy. Such spill-over effects may already have shown up in the aggregate statistics in the United States, but not yet in other countries.

Finally, the state of competition may also play a role in the size of spill-over effects. In a large and highly competitive market, such as the United States, firms using ICT may not be the largest beneficiaries of investment in ICT. Consumers may extract a large part of the benefits, in the form of lower prices, better quality, improved convenience, and so on. In other cases, firms that are upstream or downstream in the value chain from the firms using ICT might benefit from greater efficiency in other parts of the value chain. In countries with a low level of competition, firms might be able to extract a greater part of the returns, and spill-over effects might thus be more limited. Further cross-country research may help to address these questions, and provide new insights in the extent of ICT-related spill-overs.

The empirical evidence presented above also points to a number of general conclusions. First, while ICT investment has dropped off during the recent slowdown, it is likely to increase once the recovery gets underway. Technological progress in ICT goods and services is continuing at a rapid pace, driving prices down and contributing to a wide range of new services and applications. The level of ICT investment is likely to be lower than that observed prior to the slowdown, however, as the 1995–2000 period was characterised by some one-off investment peaks, e.g. investments related to Y2K and the diffusion of the Internet. Second, further technological progress in ICT production should imply a continued positive contribution of the ICT sector to MFP growth, notably in those countries with large ICT-producing sectors. Third, productivity growth in the United States, Canada and Australia, examples of ICT-led growth, has continued to be strong during the recent slowdown, suggesting that part of the acceleration in productivity growth over the second half of the 1990s was indeed structural.

Finally, the largest economic benefits of ICT are typically observed in countries with high levels of ICT diffusion. OECD data show that the United States, Canada, New Zealand, Australia, the Nordic countries and the Netherlands typically have the highest rates of diffusion of ICT. ICT networks in these countries have now spread throughout the business sector and will increasingly be made to work to enhance productivity and business performance. Many other OECD countries lag in the diffusion of ICT and have scope for greater uptake. But having the equipment or networks is not enough to derive economic benefits. Other factors, such as the regulatory environment, the availability of appropriate skills, the ability to change organisational set-ups, as well as the strength of accompanying innovations in ICT applications, affect the ability of firms to make ICT effective in the workplace and seize the benefits of ICT.

References

AHMAD, Nadim. *Measuring Investment in Software*. STI Working Paper no. 2003/6. Paris: Directorate for Science, Technology and Industry, OECD, 2003. Also available online at http://www.olis.oecd.org/olis/2003doc.nsf/linkto/dsti-doc(2003)6.

AIZCORBE, Ana. *Why are Semiconductor Prices Falling So Fast? Industry Estimates and Implications for Productivity Measurement*. Finance and Economics Discussion Series no. 2002-20. Washington, DC: Board of Governors of the Federal Reserve System, 2002. Available online at http://www.federalreserve.gov/pubs/feds/2002/200220/200220pap.pdf.

ARVANITIS, Spyros. "Information Technology, Workplace Organisation, Human Capital and Firm Productivity: Evidence for the Swiss Economy." In OECD, ed. *The Economic Impact of ICT – Measurement, Evidence and Implications*. Paris: Organisation for Economic Co-operation and Development, 2004, 551–602.

ATROSTIC, Barbara K., Peter BOEGH-NIELSEN, Kazuyuki MOTOHASHI, and Sang V. NGUYEN. "IT, Productivity and Growth in Enterprises: Evidence from New International Micro Data." In OECD, ed. *The Economic Impact of ICT – Measurement, Evidence and Implications*. Paris: Organisation for Economic Co-operation and Development, 2004, 736–80.

ATROSTIC, Barbara K., and Sang V. NGUYEN. *Computer Networks and US Manufacturing Plant Productivity: New Evidence from the CNUS Data*. Economic Studies no. 02-01. Washington, DC: Bureau of the Census, Department of Commerce, Government of the United States, 2002.

BALDWIN, John R., Tara GRAY, and Joanne JOHNSON. *Technology Use, Training and Plant-Specific Knowledge in Manufacturing Establishments*. Research Paper no. 86. Ottawa: Statistics Canada, Analytical Studies Branch, 1995. Also available online at http://www.statcan.ca/english/research/11F0019MIE/11F0019MIE1995086.pdf.

BALDWIN, John R., and David SABOURIN. *Impact of the Adoption of Advanced Information and Communication Technologies on Firm Performance in the Canadian Manufacturing Sector*. STI Working Paper no. 2002/1. Paris: Directorate for Science, Technology and Industry, OECD, 2002. Also available online at http://www.olis.oecd.org/olis/2002doc.nsf/LinkTo/dsti-doc(2002)1.

BLACK, Sandra E., and Lisa M. LYNCH. *What's Driving the New Economy: The Benefits of Workplace Innovation.* NBER Working Paper no. 7479. Cambridge, MA: National Bureau of Economic Research, 2000.

—. "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity." *The Review of Economics and Statistics* 83, no. 3 (August 2001): 434–45.

BOSWORTH, Barry P., and Jack E. TRIPLETT. "Services Productivity in the United States: Griliches' Services Volume Revisited." Paper prepared for CRIW Conference in Memory of Zvi Griliches, Brookings Institution, Washington, DC, September 2003. Also available online at http://www.nber.org/books/CRIW03-BH/bosworth-triplett3-24-05.pdf.

BRYNJOLFSSON, Erik, and Lorin HITT. "Computing Productivity: Firm-level Evidence." *Review of Economic Statistics* 85, no. 4 (2003): 793–808.

CLAYTON, Tony, and Kathryn WALDRON. "E-Commerce Adoption and Business Impact, A Progress Report." *Economic Trends* 591, National Statistics (UK) (February 2003). Also available online at http://www.statistics.gov.uk/articles/economic_trends/ETFeb03Clayton.pdf.

CRISCUOLO, Chiara, and Kathryn WALDRON. "Computer Network Use and Productivity in the United Kingdom." Mimeo, Centre for Research into Business Activity, Office of National Statistics, London, 2003.

DOMS, Mark E., Ron S. JARMIN, and Shawn D. KLIMEK. *IT Investment and Firm Performance in US Retail Trade.* Economic Studies no. 02–14. Washington D.C.: Bureau of the Census, Department of Commerce, Government of the United States, 2002.

FALK, Martin. *Organizational Change, New Information and Communication Technologies and the Demand for Labor in Services.* ZEW Discussion Paper no. 01–25. Mannheim: Centre for European Economic Research (ZEW), 2001. Also available online at ftp://ftp.zew.de/pub/zew-docs/dp/dp0125.pdf.

GREENAN, Nathalie, and Dominique GUELLEC. "Firm Organization, Technology and Performance: An Empirical Study." *Economics of Innovation and New Technology* 6, no. 4 (1998): 313–47.

GRETTON, Paul, Jyothi GALI, and Dean PARHAM. "The Effects of ICTs and Complementary Innovations on Australian Productivity Growth." In OECD ed. *The Economic Impact of ICT – Measurement, Evidence and Implications.* Paris: Organisation for Economic Co-operation and Development, 2004, 405–53.

HALTIWANGER, John, Ron JARMIN, and Thorsten SCHANK. *Productivity, Investment in ICT and Market Experimentation: Micro Evidence from Germany and the United States.* Economic Studies no. 03–06. Washington D.C.: Bureau of the Census, Department of Commerce, Government of the United States, 2003.

HEMPELL, Thomas. *Does Experience Matter? Productivity Effects of ICT in the German Service Sector.* Discussion Paper no. 02–43, Mannheim: Centre for European Economic Research (ZEW), 2002. Also available online at ftp://ftp.zew.de/pub/zew-docs/dp/dp0243.pdf.

Hempell, Thomas, George Van Leeuwen, and Henry Van Der Wiel. "ICT, Innovation and Business Performance in Services: Evidence for Germany and the Netherlands." In OECD ed. *The Economic Impact of ICT – Measurement, Evidence and Implications.* Paris: Organisation for Economic Co-operation and Development, 2004, 454–98.

Luque, Adela, and Javier Miranda. *Technology Use and Worker Outcomes: Direct Evidence from Linked Employee-Employer Data.* Economic Studies no. 00-13. Washington, DC: Bureau of the Census, Department of Commerce, Government of the United States, 2000.

McKinsey Global Institute. *US Productivity Growth 1995–2000: Understanding the Contribution of Information Technology Relative to Other Factors.* Washington, DC: McKinsey Global Institute, 2001.

OECD. "The New Economy: Beyond the Hype." Final report of the OECD Growth Project, Organisation for Economic Co-operation and Development, Paris, 2001.

—. *Measuring the Information Economy 2002.* Paris: Organisation for Economic Co-operation and Development, 2002. Also available online at http://www.oecd.org/sti/measuring-infoeconomy.

—. *OECD Science, Technology and Industry Scoreboard 2003.* Paris: Organisation for Economic Co-operation and Development, 2003a.

—. *ICT and Economic Growth – Evidence from OECD Countries, Industries and Firms.* Paris: Organisation for Economic Co-operation and Development, 2003b.

—. *The Economic Impact of ICT – Measurement, Evidence and Implications.* Paris: Organisation for Economic Co-operation and Development, 2004.

Pilat, Dirk, Frank Lee, and Bart Van Ark. *Production and use of ICT: A sectoral perspective on productivity growth in the OECD area.* OECD Economic Studies 35. Paris: Organisation for Economic Co-operation and Development, 2002, 47–78.

Pilat, Dirk, and Anita Wölfl. "ICT production and ICT use – what role in aggregate productivity growth?" In OECD, ed. *The Economic Impact of ICT – Measurement, Evidence and Implications.* Paris: Organisation for Economic Co-operation and Development, 2004, 405–53.

Schreyer, Paul. *Computer Price Indices and International Growth and Productivity Comparisons.* OECD Statistics Directorate Working Paper. Paris: Organisation for Economic Co-operation and Development, 2001. (Later published in *Review of Income and Wealth* 48, no. 1 [March 2002]: 15–31.)

Schreyer, Paul, and Dirk Pilat. *Measuring Productivity.* OECD Economic Studies 33. Paris: Organisation for Economic Co-operation and Development, 2001, 127–70.

Schreyer, Paul, Pierre-Emmanuel Bignon, and Julien Dupont. *OECD Capital Services Estimates: Methodology and a First Set of Results.* OECD Statistics Working Papers 2003/6. Paris: Organisation for Economic Co-operation and Development, 2003.

Solow, Robert M. "We'd Better Watch Out." *New York Times* 12, Book Review, no. 36 (July 1987).

Van Ark, Bart, Robert Inklaar, and Robert H. McGuckin. *Changing Gear – Productivity, ICT and Services: Europe and the United States.* Research Memorandum GD-60. Groningen: Groningen Growth and Development Center, University of Groningen, 2002. Also available online at http://www.ggdc.net/pub/online/gd60(online).pdf.

5. Computers and the Big Divide: Productivity Growth in the European Union and the United States[1]

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THIS paper compares the investment intensity in IT (Information Technology) between the European Union and the United States from 1990 to 2000, and looks at its impact on their differential growth performance. Following Jorgenson's study for the U.S. (Jorgenson 2001), it is shown that faster GDP (Gross Domestic Product) and labor productivity growth in the United States vis-à-vis the European Union in the latter half of the 1990s is linked to more investment in IT. A higher share of IT goods production in GDP provides an additional boost to productivity growth in the U.S. However, it is argued that the different impact of IT production and investment does not account for most of the forging ahead of the U.S. relative to Europe since the mid-1990s. This is mainly due to the deceleration of TFP (Total Factor Productivity) growth outside the IT goods production industries in Europe.

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[1] The authors are grateful to representatives from many statistical offices across the European Union for their help on identifying the appropriate sources, and for providing guidance in interpreting the series. We thank Alessandra Colecchia and Paul Schreyer for their advice on the earlier OECD (Organisation for Economic Co-operation and Development) work. Gerard Ypma has provided excellent statistical assistance. We are grateful to Ronald Albers, Michel Fouquin, Barbara Fraumeni, Robert Inklaar, Dale Jorgenson, Robert H. McGuckin, Johanna Melka, Nanno Mulder, Laurence Nayman, Mary O'Mahony, Werner Roeger, Kevin Stiroh, Focco Vijselaar as well as participants at various workshops at which the report was presented for comments. The authors are solely responsible for the results presented in this paper. Updates of the results in this paper are avaliable in Timmer and Van Ark (2005).

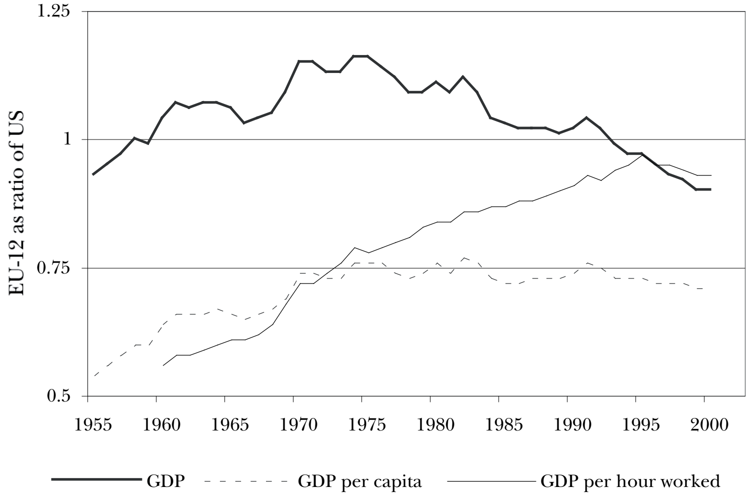
5.1. Introduction

During the second half of the 1990s the comparative growth performance of OECD economies has undergone a marked change. For the first time since World War II labor productivity growth in the EU fell behind the U.S. for a considerable length of time, and the gap in relative per capita income widened. Until the beginning of the 1970s rapid productivity growth in the EU was coupled with a similar catching-up in GDP per capita levels. A first break of this pattern occurred in the mid 1970s. While catching-up in terms of labor productivity continued, relative GDP per capita levels in the EU stagnated (see Graph 5.1). This was a reflection of slower growth in labor input in Europe, related to increased unemployment, a decline in the labor force participation rates and a fall in average working hours. The total GDP level of all countries that make up today's European Union dropped below that of the U.S. by the early 1990s. The second break, which is the focus of this paper, falls in the mid-1990s when the catching up of labor productivity also came to a halt. Compared with the first half of the 1990s, productivity growth in the EU slowed down by as much as 1 percentage point, whereas it accelerated at the same rate in the United States.[2]

The acceleration of productivity growth in the U.S. since the mid-1990s has been related to the explosive growth of investment in ICT (Information and Communication Technologies) and a rise in TFP growth, mainly in IT production (Jorgenson and Stiroh 2000; Jorgenson 2001). Others have also indicated a role for the impact of IT use on TFP growth in the non-IT production sector of the U.S. economy (Oliner and Sichel 2002; Baily and Lawrence 2001). Evidence for a limited number of OECD countries suggests that IT investment has less impact on growth outside the U.S. (Colecchia and Schreyer 2002; Daveri 2002; Vijselaar and Albers 2002). On the basis of these observations one might conclude that a slower reaction of the EU to the opportunities provided by the IT revolution may explain the EU-U.S. productivity growth differential

[2] Despite the slowdown during the period from 2000 to 2002, the underlying trend in faster productivity growth in the U.S. over Europe has held up.

GRAPH 5.1: **GDP, GDP per capita and GDP per hour, 1955–2000**



Note: EU refers to EU-12, U.S. = 1.
Source: GGDC total economy database Web site http://www.eco.rug.nl/ggdc/dseries/totecon.shtml.

since 1995. But in order to test this hypothesis, a comprehensive estimate of the effects of the IT revolution on economic growth in the European Union is needed. So far this has been missing, mainly because of the lack of internationally comparable investment series for IT hardware and software.

This paper fills the gap by providing for the first time internationally harmonized growth accounting estimates for the European Union, based on series of investment in IT and non-IT assets in individual member states, specifically developed for the purpose of this study. Here we concentrate our discussion on the development of European Union averages relative to the U.S. using a growth accounting framework (see Van Ark et al. 2002, for a detailed discussion of results for individual countries). We show that lower IT investment and a smaller share of the IT goods production sector in total output are two major reasons for slower GDP and productivity growth in Europe vis-à-vis the U.S. since 1995. But when placing the experience of the period from 1995 to 2000 in a longer time perspective, it is seen that the different contributions of IT cannot explain the sudden widening of the labor productivity gap between the EU and the United States since the mid-1990s.[3] The slowdown in the EU is primarily accounted for by a decline in the non-IT capital intensity ratio and especially a strong decline in TFP growth in industries outside the IT goods production industries. This conclusion suggests a role for explanatory factors other than differences in IT investment and production per se.

Sections 5.2 to 5.4 elaborate upon the data and methods used to derive the growth accounting results. Section 5.2 discusses the data sources and estimation of IT investment series in constant prices. Section 5.3 outlines the estimate of IT and non-IT capital services. In section 5.4 their contribution to GDP growth in the European Union and the United States is discussed using a growth accounting framework. This section also provides an indication of the different contribution of IT goods production to TFP growth. Section 5.5 gives a conclusion.

Although this study largely follows the methodology used in Jorgenson (2001), our comparative estimates for the U.S. are not fully consistent with his estimates. For comparisons with the EU, due to data availability, we use a broader concept of IT assets which, alongside IT hardware, includes all other office and accounting machinery. We also exclude service flows from land, inventories and residential structures, and we cannot make imputations of service flows from durable consumer goods. On the whole, the numerical differences between our results for the U.S. and those of Jorgenson are small, and do not lead to different conclusions on the role of IT in the acceleration of U.S. growth in the 1990s.

5.2. IT investment series for the European Union

IT growth accounting studies for European countries are sparse and earlier studies have relied heavily on private data sources that measure total expenditures on IT (including household expenditures) that are used as a proxy to investment.[4] Although the situation

[3] Updates of the results are available in Timmer and Van Ark (2005); see also http://www.ggdc.net/dseries/growth-accounting.html.

[4] Daveri (2002) makes use of IT expenditure data from the International Data Corporation data sources. Colecchia and Schreyer (2002) and Vijselaar and Albers (2002) make use of genuine IT investment series, but for a limited number of countries only.

is rapidly improving, official long term series on IT investment and capital stocks are not yet available on a comprehensive and sufficiently long term basis for many EU countries. Van Ark et al. (2002) complemented the existing official series with their own estimates of IT investment based on a *commodity flow* method. The main characteristics of this database are discussed here. For a full treatment the reader is referred to Van Ark et al. (2002).[5]

In contrast to many other studies, the definition of IT investment in Van Ark et al. (2002) is relatively broad. Three IT asset types are distinguished: "Computers," which comprises the whole category of office, accounting and computer equipment,[6] "Communications equipment" which includes radio, television and communications equipment[7] and "Software," including pre-packaged, own account and customized software. This is in line with Triplett and Bosworth (2002), who argue in favor of a broad IT concept, as the electronic-driven technological change that is most characteristic of computer and communications equipment is also evident, for example, in photocopiers and related equipment.

Despite the fact that for many of the smaller EU countries there were no or only short investment series on IT, official series for a substantial length of time are available for the largest countries in the EU, including France, Germany, Italy, Spain and the United Kingdom. For the early period in these countries and for countries where no official series existed, the *commodity flow* method was used. This method traces commodities from their domestic production or importation to their final purchase, i.e. consumption or investment.[8]

[5] The estimates include Austria, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Portugal, Spain, Sweden and the United Kingdom. Data for Belgium, Luxembourg and Greece are missing. Hence 95% of EU GDP in 2000 is covered. EU totals are based on summation of country figures using the official national currency/euro exchange rates as of 1 January 1999. With this method price differences in output and capital inputs across EU countries are neglected. This omission is mainly due to lack of appropriate Purchasing Power Parities for IT assets.

[6] It includes computers, peripheral equipment such as printers, etc., but also photocopiers and related equipment. This is equal to all products included in ISIC (International Standard Industrial Classification) rev. 3 industry 30 that is almost similar to U.S. SIC87 industry 357.

[7] This is equal to products included in ISIC rev. 3 industry 32 (U.S. SIC87 industry 366).

[8] This supply side method resembles what many statistical offices in Europe in fact use to develop their investment numbers. An alternative estimation method that is used by some countries is a *demand-side* approach, which collects capital expenditure data directly from purchasers.

First, production and trade statistics, final domestic purchases from the office and computer equipment, and communications equipment industries are derived using national accounts. These are equal to domestic production plus imports, less exports. Second, investment shares in final domestic purchases are derived from benchmark input-output (I/O) tables. Finally, to obtain IT investment series these shares are applied to the annual figures on the production, exports and imports for separate industries as follows:

$$I_{i,t} = (Q_{i,t} + M_{i,t} - E_{i,t}) \left(\frac{I_i^{IO}}{(Q_i^{IO} + M_i^{IO} - E_i^{IO})} \right) \tag{5.1}$$

where I_i is investment in asset i, Q_i is domestic production, E_i is exports and M_i is imports. Subscript t indicates time and the superscript *IO* indicates that the data is derived from benchmark I/O-tables.[9]

Investment series for software create the greatest problems in terms of international comparability (Lequiller et al. 2003). For some countries software investment series are separately distinguished in the national accounts. For other countries, only data on total intangible investment was available. Software investment was then obtained by applying an estimated share of software in total intangible investment. In case no data on intangible investment was available, an estimated ratio of software to office and computer equipment investment was applied to the country-specific investments in office and computer equipment.

Graph 5.2 provides a comparison of the share of IT investment in total investment in machinery and equipment in the EU and the U.S. in current prices. In both regions there is a clear upward trend in the share of IT investment in the beginning of the 1980s and again in the latter half of the 1990s. However, the level of IT investment is much higher in the U.S. than in the EU and, importantly, the gap has not narrowed much. In contrast to what has been suggested by

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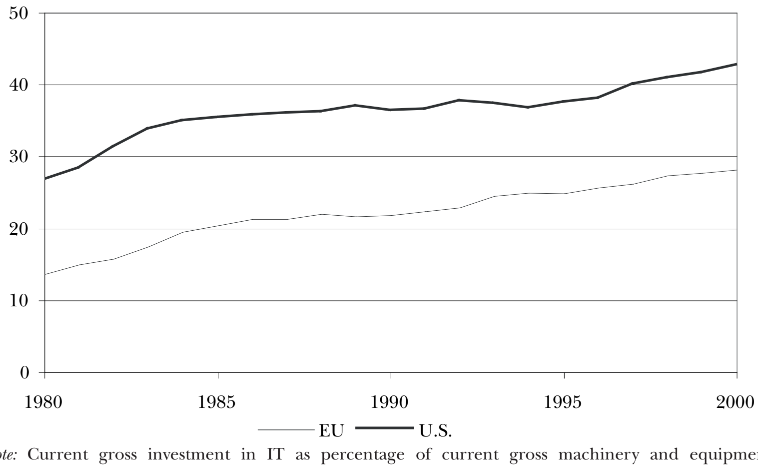
[9] As supply and use tables with sufficient industry detail are mostly not available on an annual basis, the shares of investment in production and imports were interpolated for intermediate years, and kept constant for years before (or after) the first (or the latest) year for which an I/O table was available.

some scholars (e.g., Daveri 2002), we find no significant catching-up of the share of IT in total investment in Europe relative to the U.S. In fact, in 2000 the IT investment rate in the European Union was comparable to the rate in the U.S. in the beginning of the 1980s.

For deflating current investment series to constant price series, account must be taken of differences in the measurement of constant quality indices for IT goods between the U.S. and most EU countries. The major source of difference in price indices for IT goods, which decline much more rapidly in the U.S. than in Europe, is of a methodological nature. For the U.S., IT deflators explicitly take account of quality changes by applying a hedonic price index for computers and peripheral equipment, pre-packaged software, telephone switching equipment and LAN (Local Area Network) equipment. In most EU countries, however, price indices for these goods are based on a matched model method, and the incidence of quality adjustments then differs highly between countries depending on the frequency of resampling and the actual quality adjustment method (Wyckoff 1995; Schreyer 2002). But whatever adjustments are made to match model indices, in general the hedonic approach shows much stronger price declines.

GRAPH 5.2: Investment shares of IT, 1980–2000
(percentage)



Note: Current gross investment in IT as percentage of current gross machinery and equipment investment.

Source: Author's calculations.

To put IT price deflators on a consistent basis across countries, we adopted the *price index harmonization* method that was proposed by Schreyer (2002), and applied it to develop country-specific deflators for IT assets. The harmonization method starts from the assumption that the U.S. hedonic price index for IT assets most adequately reflects *constant quality* price changes. Following Schreyer (2002), before applying the U.S. price index to other countries, we made an adjustment for differences in general inflation levels. When a separate domestic price index for non-IT capital goods is available, we applied the ratio of the U.S. price index for IT relative to non-IT capital goods to the price index for non-IT capital goods for each specific country. Otherwise, the U.S. ratio of the IT price index to the overall GDP deflator was applied to the GDP deflator for each specific country.[10]

5.3. IT capital services

Capital stocks are constructed for six asset types: office and computing equipment, communications equipment, software, non-IT machinery, transport equipment and non-residential buildings. The sources for IT investment series have been described above. The other investment series are taken from the OECD *National Accounts*, complemented by national statistical sources on investment. Residential capital is excluded from the analysis in this study.[11] By including dwellings, much of the findings on the differential impact of IT on growth remain hidden. The housing

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[10] It should be noted that the harmonized deflation procedure applied here is not the perfect method to deflate IT investment in EU countries. First, it implicitly assumes that there is a global (U.S.) hedonic model on the basis of which the *predicted* price of a model can be estimated across the OECD. Second, as the U.S. price index for the group office and computer equipment is constructed from three detailed asset type indices by using U.S. weights, it does not allow for international differences in composition of investment within that asset group, and much the same can be said of the communication and software price indices. Third, a substantial part of IT investment goods in Europe is imported rather than domestically produced, and it is unknown whether the price indices of domestically produced investment goods and imported items develop in the same way. Schreyer (2002) provides a sensitivity analysis of various alternative procedures.

[11] GDP is adjusted accordingly by excluding actual and imputed rents paid. See below.

markets perform differently across the European Union and also relative to the U.S., and national accounts vary in the way services of owner-occupied dwellings are imputed. Capital stocks are constructed for each asset type using the perpetual inventory method with a geometric depreciation rate:

$$K_{i,T} = \sum_{\tau=0}^{\infty} (1-\partial_i)^t I_{i,T-t} = K_{i,T-1}(1-\partial_i) + I_{i,T} \tag{5.2}$$

with $K_{i,T}$ the capital stock for a particular asset type i at time T, ∂_i the constant rate of depreciation, and $I_{i,T-t}$ the investment in year $T-t$. Although international differences in the depreciation rates may exist, there is little evidence that this is the case. Hence we use depreciation rates that are common for all countries.[12]

Growth in capital input is best measured by capital service flows. Following Jorgenson and Griliches (1967), growth in aggregate capital service flows can be derived by:

$$\Delta \ln K = \ln K_T - \ln K_{T-1} = \sum_i \bar{v}_i \, [\ln K_{i,T} - \ln K_{i,T-1}] \tag{5.3}$$

where weights are given by the average shares of each asset type in the value of property compensation: $\bar{v}_i = \frac{1}{2}[v_{i,T} + v_{i,T-1}]$ and $v_{i,T} = \frac{p_{i,T}K_{i,T}}{\sum_i p_{i,T}K_{i,T}}$ with p_i the rental price of capital services from asset type i, and Δ refers to first differences. The rental price is defined as:

$$p_{i,T} = p^I_{i,T}\left(r_T + \partial_i - \pi_{i,T}\right) \tag{5.4}$$

with r_T representing the nominal rate of return, ∂_i the depreciation rate, $p^I_{i,T}$ the investment price and $\pi_{i,T}$ the rate of inflation in

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[12] These rates are comparable to those used by Jorgenson and Stiroh (2000, Table B1) for the U.S.: 0.115 for communications equipment, 0.315 for software, 0.132 for non-IT machinery, 0.191 for transport equipment and 0.028 for non-residential buildings and other structures. Due to its broad definition, the rate for office and computing equipment varies over time. It is a weighted average for the BEA (Bureau of Economic Analysis) rates of computers, office and accounting equipment and photocopying equipment, and it increases over time from 0.222 in 1980 to 0.295 in 2000. The increase is due to the rising share of computers, which have a higher depreciation rate than the other asset types in this group.

the investment price of asset type *i*.[13] The rates of inflation and depreciation rates of each asset type can be easily obtained from the capital stock estimates above. The estimate of the internal rate of return is based on the ex-post approach and was obtained by estimating the capital revenue on the basis of the gross operating surplus as reported in the national accounts, from which an imputed income for self-employed persons was deducted.

Graph 5.3 shows the contribution of various asset types to growth in total capital service input in the European Union and the United States for the periods 1990–95 and 1995–2000. Table 5.1 provides a more detailed breakdown of these contributions. Whereas in the early 1990s, the total capital service growth was about the same between the EU and the U.S., a big gap opened up in the latter half of the 1990s. Capital service input growth in the U.S. accelerated from an annual average of 3.2% to 5.2% whereas growth almost stagnated in the EU, increasing from 3.2% to 3.5%. Similar to what was found by Jorgenson (2001), the U.S. acceleration was mainly due to increased service flows from IT capital.[14] Growth rates of all IT assets are high and of similar magnitude between the two regions. But due to its much lower share in capital compensation, the contribution of IT capital to total capital service growth in the EU is much lower than in the U.S. This is the result of lagging levels of IT investment in the EU as witnessed in Graph 5.2. In addition, U.S. capital growth was driven by an acceleration in non-IT equipment services. In contrast, service growth rates from non-IT in the EU declined.

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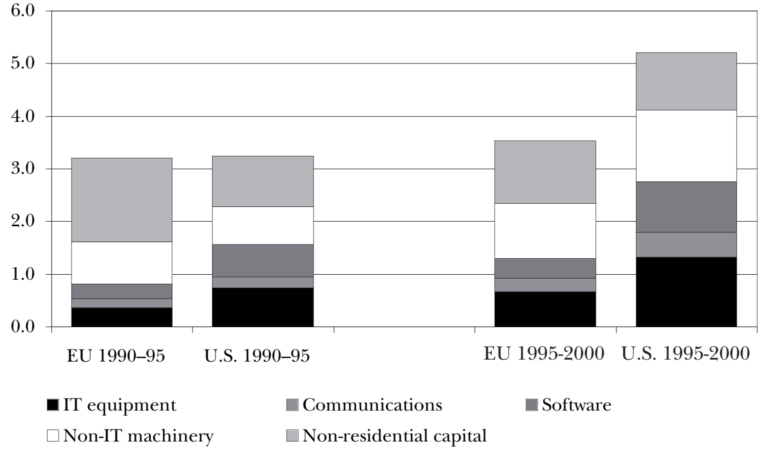
[13] In contrast to Jorgenson and Stiroh (2000), differences in tax treatment between asset types have not been considered due to a lack of data on these for most European countries.

[14] The estimated contribution of IT capital to total capital service input in the U.S. during the 1990s is somewhat larger in this study compared to Jorgenson (2001). Due to data limitations we do not consider capital services from land, inventories and residential buildings. We also do not impute services from consumer durables, part of which consists of IT goods.

GRAPH 5.3: Contribution to capital service growth by type of capital



Source: Author's calculations.

TABLE 5.1: Capital services (average annual growth rate) and capital compensation (share in total capital compensation) by type of capital

	European Union			United States		
	1990–95	**1995–2000**	**1995–2000 over 1990–95**	**1990–95**	**1995–2000**	**1995–2000 over 1990–95**
			Capital services growth			
Total capital services	**3.2**	**3.5**	**0.3**	**3.2**	**5.2**	**2.0**
IT capital services	8.8	13.9	5.1	9.0	15.2	6.2
Computers	10.2	23.5	13.3	11.3	22.9	11.6
Communications equipment	6.1	8.1	2.0	3.5	8.2	4.7
Software	10.0	11.3	1.3	12.5	14.5	1.9
Non-IT capital services	2.6	2.5	–0.2	2.0	3.0	1.0
Non-IT equipment	2.5	2.9	0.4	1.6	3.2	1.6
Transport equipment	1.7	3.8	2.1	3.7	6.3	2.5
Non-residential buildings and structures	2.8	2.1	–0.8	1.9	2.3	0.4
			Average share in capital compensation (percentage)			
Total capital services	**100.0**	**100.0**	**0.0**	**100.0**	**100.0**	**0.0**
IT capital services	9.2	9.3	0.1	17.4	18.2	0.8
Computers	3.6	2.9	–0.7	6.6	5.8	–0.7
Communications equipment	2.9	3.1	0.2	5.8	5.8	0.0
Software	2.7	3.3	0.6	5.0	6.6	1.5
Non-IT capital services	90.8	90.7	–0.1	82.6	81.8	–0.8
Non-IT equipment	26.0	24.6	–1.4	25.1	24.9	–0.2
Transport equipment	8.6	8.4	–0.3	7.7	8.9	1.3
Non-residential buildings and structures	56.2	57.7	1.5	49.8	48.0	–1.8

Source: Author's calculations.

5.4. Growth accounting

To assess the contribution of growth in IT and non-IT capital services to aggregate GDP growth, a growth accounting framework is used. Gross domestic product (Y) is produced from aggregate factor input X, consisting of capital services (K) and labor services (L). Productivity is represented as Hicks-neutral augmentation of aggregate input (A). The aggregate production function takes the form:

$$Y = A * X(L, K_n, K_{it}) \tag{5.5}$$

with subscript n indicating services from non-IT capital and subscript it indicating services from IT capital (including office and computing equipment, communications equipment and software). Under the assumption of competitive factor markets and constant returns to scale, growth accounting expresses the growth of output as a share weighted growth of inputs and TFP, denoted by A which is derived as a residual.

$$\Delta \ln Y = \bar{v}_L \Delta \ln L + \bar{v}_{Kn} \Delta \ln K_n + \bar{v}_{Kit} \Delta \ln K_{it} + \Delta \ln A \tag{5.6}$$

where v denote the average shares in total factor income and because of constant returns to scale: $v_L + v_{Kn} + v_{Kit} = 1$. GDP is taken from the OECD *National Accounts* and exclude imputed and actual rents paid as our capital measures excludes residential capital.[15] Labor input is measured as hours worked, unadjusted for changes in the composition of the labor force in terms of age, sex and/or skills. Hence contributions from changes in labor quality to GDP growth are included in the contribution of TFP. The share of labor in total factor income is calculated on the basis of compensation for employees plus an imputation for self-employed.[16] The share of capital is derived as the residual and further subdivided on the basis of rental prices as discussed in section 5.3.

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[15] As for investment series, measurement practices for deflating GDP also differ between the U.S. and many European countries. Ideally, GDP deflators should be harmonized using hedonic deflators for investment and flexible weight index formulae. The quantitative impact of these adjustments on GDP volume change depends on the size of the price adjustment, the share of IT products in domestic output and in imports. Schreyer (2002) shows that for the major European countries this effect is likely to be positive, but small.

[16] This adjustment is made under the assumption that wages of employees are similar to the compensation for self-employed persons.

Table 5.2 shows the contribution of capital and labor services to GDP growth for 1990–95 and 1995–2000. The table shows acceleration in GDP growth by 1.2 percentage points in the EU and 1.8 percentage points in the U.S. Again similar to Jorgenson (2001), the acceleration in the U.S. economy was due to higher contributions from all sources of growth which, in order of declining importance are: TFP, labor, IT and non-IT capital. In contrast, the acceleration in the EU was mainly due to faster employment growth. Although the EU labor contribution to GDP growth remained below that in the U.S., it improved from being negative (–0.73 percentage points) to positive (0.77 percentage points). When focusing on the reasons for the widening GDP growth gap between the EU and the U.S., differences in the contribution of IT capital play a minor role. It contributed 0.19 percentage points to GDP growth acceleration in the EU, and 0.40 percentage points in the U.S. Instead the major reason for the widening gap is the slowdown in European TFP growth by 0.49 percentage points vis-à-vis an acceleration in U.S. TFP growth of 0.60 percentage points.

Various studies have shown that rapid technological development in the IT producing industries play a major role in the revival of TFP growth in the U.S. (Jorgenson 2001; Oliner and Sichel 2002). A recent industry-based study by Jorgenson, Ho and Stiroh (2002) suggests that IT producing industries account for a major part of aggregate TFP growth during the period 1995–2000. On average, the GDP share of the IT producing industry is much smaller in Europe than in the United States, which may be an important reason for the much slower TFP growth in Europe. We employ Domar's aggregation model to assess the contribution of IT production to aggregate TFP growth (Domar 1961) and consider the contributions of three industries: office, accounting and computing equipment, communications equipment and electronic components.[17]

Unfortunately, reliable TFP growth estimates for IT producing industries are not available for any European country. Therefore

[17] The electronic components industry is defined as ISIC industry 321, corresponding closely to U.S. SIC (Standard Industrial Classification) industry 367. Due to a lack of output data for most European countries, the computer services industry, including software, is left out of the analysis. Jorgenson, Ho and Stiroh (2002) show that the TFP contribution of this industry in the U.S. has been small.

TABLE 5.2: **Sources of GDP growth**

	European Union			U.S.			U.S.–EU difference
	1990–95	**1995–2000**	**1995–2000 over 1990–95**	**1990–95**	**1995–2000**	**1995–2000 over 1990–95**	**1995–2000 over 1990–95**
Gross Domestic Product	**1.39**	**2.59**	**1.20**	**2.42**	**4.21**	**1.79**	**0.59**
Contribution of labor	–0.73	0.77	1.50	0.86	1.38	0.52	–0.99
Contribution of capital services	1.01	1.20	0.19	0.96	1.63	0.67	0.48
IT capital services	0.25	0.44	0.19	0.46	0.86	0.40	0.21
Non-IT capital services	0.75	0.76	0.00	0.49	0.77	0.27	0.27
Contribution of TFP	1.12	0.62	–0.49	0.61	1.21	0.60	1.09

Note: Average annual percentage rates of growth. Contributions are defined in equation (5.6). The contribution of TFP includes contribution of labor quality.
Source: Author's calculations. For updated results see Timmer and Van Ark (2005); see also http://www.ggdc.net/dseries/growth-accounting.html.

we assume that TFP growth rates in U.S. IT industries also hold for the EU. Admittedly this is a strong assumption, but so far there is no indication that would suggest that these industries, for which performance is almost entirely technology-driven and markets are highly competitive, would differ much in productivity growth across countries. In addition this assumption serves to focus ourselves on the sole effect of different output shares of IT producing industries on aggregate growth differences between the EU and the U.S. The most detailed TFP growth rates in IT production based on NIPA (National Income and Product Accounts) data are provided in Jorgenson, Ho and Stiroh (2002, Table 18), which are reproduced in Table 5.3.[18]

According to the Domar model, the contribution of a particular industry to aggregate TFP growth is obtained by weighting productivity growth for each industry by the ratio of gross output of that industry to aggregate GDP (Domar 1961). To derive the Domar weights for IT industries in each country, gross output is calculated from a mix of national accounts and manufacturing census statistics, adjusted for intra-industry deliveries using shares from input-output tables. The average weights for the EU and the U.S. in the periods 1990–95 and 1995–2000 are given in the bottom rows of Table 5.3. It is shown that all three IT industries have greater gross output shares in the U.S. than in the EU, especially the electronic components industry whose output mainly consists of semi-conductors. Only in communication equipment, the EU production almost equals the U.S. in the late 1990s, in particular because of high production shares in Finland and Sweden.

By weighting the U.S. TFP growth rates in each industry by the country-specific Domar weights, the contribution of IT production to aggregate TFP growth is calculated. Table 5.3 shows that this contribution is higher in the U.S. than in the EU and it has increased during the second half of the 1990s. For the period 1995–2000 about one third of the gap of 0.58 percentage points in aggregate TFP

[18] Alternative estimates can be obtained from Oliner and Sichel (2002) which are based on an output price deflator for semi-conductors that shows a faster decline than the one used by Jorgenson, Ho and Stiroh (2002). Consequently this would lead to higher TFP growth estimates in this industry, reinforcing the U.S. advantage in semi-conductor production.

growth between the EU and the U.S. is due to the U.S. lead in the production of IT (0.20 percentage points), in particular electronic components (0.17 percentage points). Clearly these estimates are still experimental, and await more detailed calculation of TFP growth in IT producing industries in individual countries before a definitive assessment can be made of the productivity impact of the presence of an IT producing industry.

By re-arranging equation (5.6) the results from this study can be presented in terms of average labor productivity growth defined as $y = Y/L$, the ratio of output to hours worked, $k = K/L$, the ratio of capital services to hours worked, TFP originating in the IT production industries (A_{it}) and in non-IT production (A_n).

$$\Delta \ln y = \bar{v}_{Kn} \Delta \ln k_n + \bar{v}_{Kit} \Delta \ln k_{it} + \Delta \ln A_n + \Delta \ln A_{it} \qquad (5.7)$$

Graph 5.4 shows the contribution of capital deepening (in IT and non-IT capital) and TFP growth (derived from IT production or non-IT production) to labor productivity growth. A more detailed breakdown is provided in Table 5.4. The results are in line with the conclusions above, stressing the important role for IT capital deepening and TFP growth from IT goods production in the forging ahead of labor productivity in the U.S. Together these two factors account for about two-thirds (0.54 percentage points of the 0.78 percentage points) of the difference in labor productivity growth between the EU and the U.S. in the period 1995–2000.

However, when focusing on the reasons for the widening gap in labor productivity growth between the EU and the U.S. during the 1990s, the emphasis shifts to the role of non-IT capital deepening and TFP growth in industries other than IT producing industries. In the latter half of the 1990s, EU labor productivity growth slumped from 2.45 to 1.43 percentage points, whereas U.S. growth accelerated from 1.19 to 2.21 percentage points. This turnaround in the growth differential, i.e., from faster to slower labor productivity growth in Europe vis-à-vis the U.S., adding up to 2.04 percentage points, is only partly related to bigger effects from IT technology in the U.S. Changes in the differential contributions from IT capital intensification and TFP growth in IT production accounted only for 0.34 percentage points of the U.S.–EU growth differential in labor productivity. In contrast, a much

TABLE 5.3: Sources of TFP growth

	1990–95			1995–2000		
	EU	U.S.	U.S.–EU	EU	U.S.	U.S.–EU
Aggregate TFP growth	**1.12**	**0.61**	**–0.51**	**0.62**	**1.21**	**0.58**
			Contributions to aggregate TFP growth			
IT production	**0.14**	**0.23**	**0.08**	**0.20**	**0.40**	**0.20**
Computers	0.09	0.10	0.00	0.13	0.16	0.03
Electronic components	0.03	0.11	0.08	0.07	0.24	0.17
Communications equipment	0.01	0.02	0.01	0.00	0.00	0.00
			TFP growth (percentage)			
Computers	11.9	11.9		16.8	16.8	
Electronic components	10.6	10.6		18.0	18.0	
Communications equipment	3.2	3.2		–0.4	–0.4	
			Domar weights (percentage)			
IT production	1.58	2.49	0.91	1.98	3.11	1.13
Computers	0.80	0.80	0.00	0.80	0.97	0.17
Electronic components	0.33	1.05	0.73	0.40	1.33	0.93
Communications equipment	0.45	0.63	0.17	0.78	0.81	0.03

Note: TFP growth rates for computers, semi-conductors and communications equipment for U.S. (from Jorgenson, Ho, and Stiroh 2002) are assumed applicable to the EU. Hence different contributions of IT production to aggregate TFP growth are exclusively the result of different production shares between the EU and the U.S.

Source: Author's calculations.

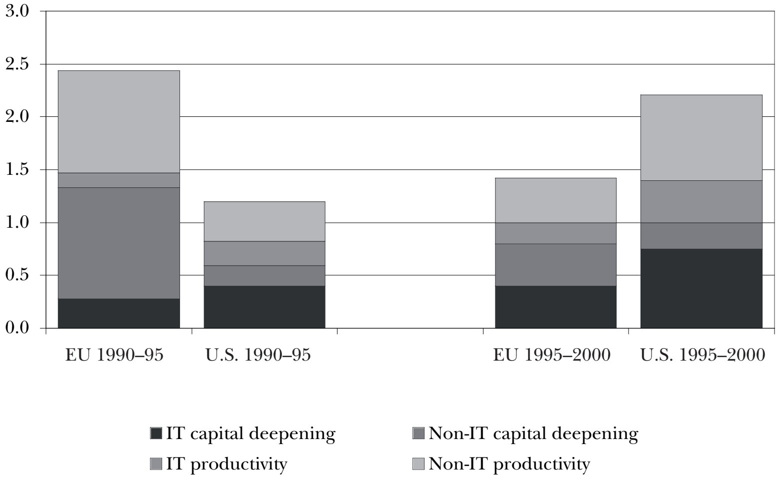
TABLE 5.4: Sources of average labor productivity growth

	1990–95			1995–2000			1995–2000 over 1990–95
	EU	U.S.	U.S.–EU difference	EU	U.S.	U.S.–EU difference	U.S.–EU difference
Average labor productivity	**2.45**	**1.19**	**–1.26**	**1.43**	**2.21**	**0.78**	**2.04**
Contribution of capital deepening	1.34	0.58	–0.75	0.80	1.00	0.20	0.95
IT	0.28	0.40	0.11	0.40	0.75	0.34	0.23
Non-IT	1.05	0.19	–0.86	0.40	0.25	–0.15	0.71
TFP	1.12	0.61	–0.51	0.62	1.21	0.58	1.09
Production of IT	0.14	0.23	0.08	0.20	0.40	0.20	0.11
Other	0.97	0.38	–0.59	0.42	0.81	0.39	0.98
Total IT contribution	**0.43**	**0.62**	**0.20**	**0.61**	**1.15**	**0.54**	**0.34**

Note: Average annual percentage rates of growth. Contributions are defined in equation (5.7). Labor productivity is measured as GDP per hour worked. Total IT contribution equals contribution of IT capital deepening and IT production.

Source: Author's calculations.

GRAPH 5.4: Sources of average labor productivity growth



Source: Author's calculations.

bigger part comes from the faster decline in the contribution from non-IT capital deepening in the EU compared to the U.S. (0.71 percentage points). Even more importantly, TFP growth in non-IT producing industries declined in the EU whereas it accelerated in the U.S., accounting for almost half (0.98 percentage points) of the change in the labor productivity growth differential.[19]

5.5. Conclusions

This paper replicates Jorgenson's (2001) IT growth accounting study for the U.S. by applying a harmonized procedure to data for twelve European Union member states, which together account for more than 95% of total EU GDP. In the 1990s, GDP growth rates accelerated in the EU, albeit at a lower pace than in the U.S.

[19] The contribution from TFP growth in the non-IT producing industries has been calculated as a residual. It is defined as the contribution of aggregate TFP growth minus the contribution of IT producing industries. Strictly speaking, this residual measure includes not only the contribution of non-IT producing industries, but also TFP gains or losses from the reallocation of factor inputs between industries. These effects are normally small.

This is partly due to the differential impact of the IT revolution. A comparison with results for the U.S., which are obtained on a similar methodological basis, shows that larger contributions from IT capital services and from TFP growth in IT producing industries account for much of the faster U.S. growth during the second half of the 1990s. Looking at the acceleration in labor productivity in the U.S. vis-à-vis the slowdown in Europe, we find that the increasing gap is in fact largely ascribed to a strong decline in non-IT capital deepening in the EU relative to the U.S., and a collapse in European TFP growth in industries which do not produce IT goods. In contrast, TFP growth outside the IT production industries in the U.S. has significantly accelerated.

Baily and Lawrence (2001) and Oliner and Sichel (2002) have stressed that the improvement in productivity in industries outside IT production in the U.S. is due—at least partly—to spillovers from IT investment in industries that are heavy users of IT. One may argue along these lines that the lacklustre TFP growth in the European non-IT production sector is related to a lack of spillovers caused by a combination of lower levels of IT investment, an insufficient degree of organizational innovations accompanying ICT, and structural impediments. For example, Brynjolfsson and Hitt (2000) argued that the benefits from the use of IT can only be reaped when IT investment is complemented by organisational changes within firms. Restrictive rules and procedures on working hours and employment protection in Europe limit flexibility in organizing the workplace and hiring and firing of workers. In addition, restrictions on labor and product markets may limit the opportunities to allocate IT to its most productive uses in Europe, in particular in services industries that are among the biggest IT investors.

Finally, the slow adoption of IT in Europe, and the slump in non-IT related investment during the second half of the 1990s cannot be seen independently from major shifts in the relation between labor and capital input prices during the 1990s. In contrast to the U.S., employment expansion in many European countries has been closely associated with a decline in capital deepening. Indeed, countries with the fastest acceleration in employment growth (like Spain, Finland, the Netherlands and

France) have shown the biggest fall in capital-labor ratios. Several of these countries have pursued active labor market policies and/or wage moderation which might have affected the relative price of capital to labor.

Further examination of these factors awaits more detailed evidence for at least two additional pieces of information. The first is an estimate of relative levels of capital deepening and wage-rental ratios in order to investigate whether the halting of convergence between the EU and the U.S. since 1995 is related to unduly high levels of capital intensity in Europe before 1995. The second type of information required is a measurement of IT and non-IT capital deepening and TFP growth by industry to detect the industries that account for Europe's slowdown in productivity growth in the 1990s.

References

BAILY, Martin N., and Robert LAWRENCE. *Do we have a New E-conomy?* NBER Working Paper no. 8243. Cambridge, MA: National Bureau of Economic Research, 2001.

BRYNJOLFSSON, Erik, and Lorin HITT. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance." *Journal of Economic Perspectives* 14, no. 4 (Autumn 2000): 23–48.

COLECCHIA, Alessandra, and Paul SCHREYER. "ICT Investment and Economic Growth in the 1990s: Is the United States a Unique Case? A Comparative Study of Nine OECD Countries." *Review of Economic Dynamics* 5, no. 2 (2002): 408–42.

DAVERI, Francesco. "The New Economy in Europe, 1992–2001." *Oxford Review of Economic Policy* 18, no. 3 (Autumn 2002): 345–62.

DOMAR, Evsey D. "On the Measurement of Technological Change." *Economic Journal* 71, no. 284 (December 1961): 709–29.

JORGENSON, Dale W. "Information Technology and the U.S. Economy." *American Economic Review* 91, no. 1 (March 2001): 1–32.

JORGENSON, Dale W., and Zvi GRILICHES. "The Explanation of Productivity Change." *Review of Economic Studies* 34, no. 3 (July 1967): 249–80.

JORGENSON, Dale W., Ho MUN, and Kevin STIROH. "Growth of U.S. Industries and Investments in Information Technology and Higher Education." Paper presented at Conference on Research in Income and Wealth, Measuring Capital in the New Economy, April 2002. Forthcoming in C. Corrado, J. Haltiwanger, and D. Sichel (eds.), *Measuring Capital in a New Economy*. Chicago: The University of Chicago Press, 2006.

JORGENSON, Dale W., and Kevin J. STIROH. "Raising the Speed Limit: U.S. Economic Growth in the Information Age." *Brookings Papers on Economic Activity* 1 (2000): 125–211.

LEQUILLER, François, Nadim AHMAD, Seppo VARJONEN, William CAVE, and Kil-Hyo

AHN. *Report of the OECD Task Force on Software Measurement in The National Accounts.* OECD Statistics Working Papers 2003/01. Paris: OECD Publishing, 2003.

OLINER, Stephen D., and Daniel E. SICHEL. “Information Technology and Productivity: Where Are We Now and Where Are We Going?” *Economic Review* 87, no. 3, Third Quarter, Federal Reserve Bank of Atlanta (2002): 15–44. Also available online at http://www.frbatlanta.org/filelegacydocs/oliner_sichel_q302.pdf.

SCHREYER, Paul. “Computer Price Indices and International Growth and Productivity Comparisons.” *Review of Income and Wealth* 48, no. 1 (March 2002): 15–31.

TIMMER, Marcel P., and Bart VAN ARK. “IT in the European Union: A driver of productivity divergence?.” *Oxford Economic Papers* 4, no. 57 (2005): 693-716.

TRIPLETT, Jack, and Barry W. BOSWORTH. “‘Baumol’s Disease’ has been Cured: IT and Multifactor Productivity in U.S. Services Industries.” Unpublished paper prepared for Brookings Workshop on Services Industry Productivity, Brookings Institution, Washington, DC, September 2002.

VAN ARK, Bart, Johanna MELKA, Nanno MULDER, Marcel TIMMER, and Gerard YPMA. *ICT Investment and Growth Accounts for the European Union, 1980–2000.* Research Memorandum GD-56. Groningen: Groningen Growth and Development Centre, 2002. Also available online at http://www.ggdc.net/.

VIJSELAAR, Focco W., and Ronald M. ALBERS. *New Technologies and Productivity Growth in the Euro Area.* ECB Working Paper no. 122. Frankfurt: European Central Bank, 2002. Also available online at http://www.ecb.int/pub/pdf/scpwps/ecbwp122.pdf.

WYCKOFF, Andrew W. “The Impact of Computer Prices on International Comparisons of Productivity.” *Economics of Innovation and New Technology* 3, nos. 3–4 (1995): 277–93.

6. ICT and Productivity Growth in the Euro Area: Sectoral and Aggregate Perspectives[1]

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IN the euro area, ALP (Average Labor Productivity) decelerated over the last two decades. In contrast, ALP accelerated in the U.S. in the second half of the 1990s. Many observers attributed this divergent pattern to differences in production and use of ICT (Information and Communication Technologies). This paper confirms the former observation. However, this paper finds that the role of ICT capital deepening is only partial. In particular, TFP (Total Factor Productivity) growth explains the largest part of the difference in ALP growth. A comparison of developments in the services sectors suggests that regulatory reforms have played a key role in TFP developments. Finally, tentative calculations suggest that problems with measurement of output in the services sector could also explain part of the difference in ALP developments.

[1] At the time of the writing the author was engaged as economist in the Euro Area Macroeconomic Developments Division, European Central Bank. The author wishes to thank, without implication, Ronald Albers, Neale Kennedy, Wolfgang Schill and participants at the Ivie (Valencian Institute of Economic Research) Workshop on "Growth, Capital Stock and New Technologies" for comments on a previous version of this paper, Heinz Dieden, Marcel Timmer, Colin Webb, and Gerard Ypma for helpful suggestions regarding several data issues and Dan Sichel for the provision of updated and detailed underlying calculations of the results in Oliner and Sichel (2002). The views expressed in this paper are those of the author and do not necessarily reflect those of the European Central Bank or its staff.

6.1. Introduction

Following a lively and prolonged debate by 2001, many economists had come round to firmly believing in a beneficial impact of the ICT on the macroeconomic performance of countries, the United States in particular. Since then, a slowdown in economic growth has cast doubt on at least some of the wilder claims of advocates of the so-called *new economy*, such as *the end of the business cycle*. Nevertheless, many observers remain convinced of the beneficial impact of new technologies in the longer run, in particular on productivity developments in the United States.

What about the euro area? As the United States is the only large economy in which an upsurge in productivity growth has been evident, one could be tempted to think that the euro area has not benefited from the new technological possibilities. However, over the past two decades as a whole, productivity growth in terms of GDP (Gross Domestic Product) per hour worked has been higher in the euro area than in the United States. And a beneficial impact of new technologies is clearly discernible in the euro area as well, as has been shown in previous work (Vijselaar and Albers 2004).

This paper provides a more rigorous comparison of productivity developments between the euro area and the United States.[2] By doing so, it closes a gap in the existing literature, as no rigorous comparison of developments in the two largest monetary areas has been made as yet.[3] The purpose is to establish comparable results for the euro area (thus not necessarily state of the art results for the United States), in order to be able to better assess productivity developments in the euro area.

[2] Throughout this paper reference will be made to the euro area aggregate. Results for individual euro area countries that make up for the respective aggregates are available upon request from the author.

[3] A recently published report by Van Ark et al. (2002) provides a rigorous growth accounting comparison for several countries and the European Union as a whole up to 2000. This paper, however, focuses on the euro area rather than the European Union. In addition, as indicated in the main text, this paper takes a different time perspective, and uses a second approach to gauge the importance of ICT by discussing sectoral developments as well.

Moreover, this paper adds to the literature by taking a different from usual time perspective. In particular, in a growth accounting exercise, this paper compares productivity developments over the last two full cycles in the euro area and the United States, respectively, rather than developments before and after 1995 as is usually done in the literature.[4, 5] The choice for this time perspective makes for a fairer comparison between the euro area and the United States for the following reasons.

Productivity is generally found to be pro-cyclical, making it desirable to cyclically adjust the data. Attempting to correct for cyclical effects is all the more important as, in the past, the United States and continental European business cycles were not fully synchronized (see e.g. Vijselaar and Albers 2001). However, in view of the difficulties of separating trend and cycle, especially over short time periods and in the absence of data for a full cycle, the focus in the literature has generally been on the latest developments. The breakpoint in productivity developments in the United States is thereby usually dated 1995–1996. Apart from some weak econometric evidence (Stiroh 2001), this point was chosen as it corresponds to an increase in the rate of decline in computer prices (e.g. Jorgenson and Stiroh 2000), and an increase of ICT capital deepening (e.g. Jorgenson and Stiroh 2000; Oliner and Sichel 2000, 2002). However, this breakpoint occurred in the middle of a business cycle and the use of 1995–1996 as a breakpoint tends to maximize both the increase in ALP growth and the contribution of ICT when comparing developments over time (see also Parham 2002). Moreover, the debate continues whether and to what extent the increase in ALP growth seen in the late 1990s in the United States will be sustainable. As long as the jury is still out on that issue, it thus seems useful to adopt a time perspective, which attempts to adjust for business cycle influences.

The growth accounting exercise in this paper points to a significant contribution of ICT capital deepening to overall ALP growth in the euro area, but at the same time to a deceleration of

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[4] Cycles are defined as running from trough to trough in the classical cycle. See also section 6.3.

[5] Moreover, the paper updates the results on the aggregate growth accounting exercise as presented in Vijselaar and Albers (2002), adding two years (2000 and 2001).

TFP in the course of the last two decades. The comparison with the results for the United States on the basis of broadly comparable data and methodologies reinforces the finding that it is not so much the difference in ICT capital deepening that is important to explain differential trends in observed ALP growth, but rather the development of other capital deepening and, in particular, of TFP (see also European Central Bank 2002).

As in Vijselaar and Albers (2004), a second (sectoral) approach is used to gauge the importance of ICT for euro area productivity growth. This is in line with the emphasis that has been put in several studies on the importance of industry-level developments (e.g. Stiroh 2001; McKinsey Global Institute 2001, 2002; Van Ark 2000, 2001). This paper adds to the approaches followed in Vijselaar and Albers (2004) in two respects.[6]

First, a *Slifman/Corrado*—type of analysis has been undertaken for the euro area. In an influential paper, Slifman and Corrado (1999) identified sectors with a particularly dismal productivity performance and calculated, for the United States, a counterfactual aggregate productivity growth, by assuming that productivity growth in sectors with negative rates of growth according to official data, had instead been zero. In this paper, similar calculations are performed for the euro area. While the present exercise does not go into much detail, it provides a reminder of the potential importance of measurement issues that severely hamper sectoral and international comparisons of productivity.

Second, the paper focuses on two services sector industries that account for almost all of the difference in observed ALP growth in the services sector between the euro area and the United States: wholesale and retail trade, and financial intermediation. While acknowledging that ICT has likely played a role here other factors, in particular demand side factors and (lack of) regulatory reforms, seem to have been more important in explaining the gap. The latter observation is reinforced by developments in the post and telecommunications sector, where the euro area outperformed the United States arguably because of a better regulatory framework.

[6] The paper also updates the previous results on the importance of the ICT producing manufacturing sectors for overall productivity developments with one extra year (1999). Again, the previous results are confirmed by the new and updated data.

While the findings in this paper suggest that factors other than ICT have been important in explaining the (relative) productivity developments in the euro area and the United States, one should not throw out the baby with the bath water. ICT capital deepening has been a major source of labor productivity growth over the last two decades. Moreover, it remains true that the pure capital deepening effect in the United States has been somewhat more important than in the euro area. And as long as Moore's Law continues to hold true, rapid productivity improvements in the ICT producing manufacturing sector are likely to be sustained. Arguably, this sector plays an important role in explaining the difference in recent productivity developments between the United States and the euro area.

The remainder of this paper is organized as follows: first, to set the stage, recent labor productivity developments in the euro area and the United States are discussed; second, the growth accounting exercise is presented; third, sectoral developments are analyzed; fourth and finally, conclusions are drawn.

6.2. Productivity developments in the euro area and the United States

Growth of real GDP per capita has, over the last decade, on average been higher in the United States than in the euro area. Table 6.1 presents a decomposition of the growth of GDP per capita. Demographic changes in population (a), changes in labor force participation (b), and changes in the employment rate (c), account for differences between the growth of GDP per capita and of GDP per person employed. Likewise, changes in the number of average hours worked per person employed (d) explain the differences between the growth of GDP per person employed and of GDP per hour worked. The Table thus highlights that the observed difference in GDP growth per capita between the United States and the euro area is due to different developments in labor utilization and not to a difference in growth of labor productivity (see also Vijselaar and Kennedy 2002).

Graphs 6.1 and 6.2 present developments in the euro area and the United States in labor productivity and employment, both measured by total hours worked, in a somewhat longer time perspective. Labor productivity is usually calculated either in terms of output per person employed or of output per hour worked. The latter measure is generally considered the more appropriate one since it corrects for the average annual number of hours worked per person. In the euro area a decline in the average annual hours worked per person occurred over the last twenty years—due to an increasing importance of part-time work and reductions in the official length of the working week—which was not matched by a similar development in the United States. The use of output per person employed would thus lead to a downward bias in productivity figures for the euro area in particular (see also Korteweg and Vijselaar 2002).

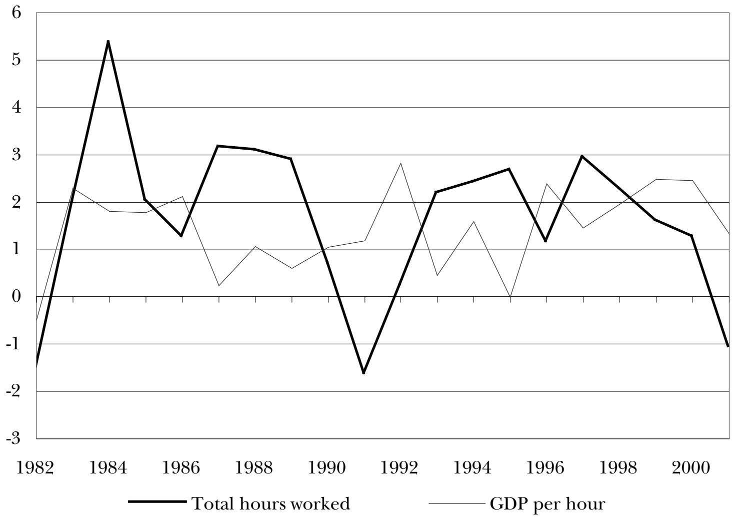
Graph 6.1 shows that ALP growth in the United States showed no particular trend over the last twenty years, but was relatively lacklustre in the period between the mid-1980s to the mid-1990s. Thereafter, in the period up to and including 2000, labor productivity accelerated again. While the rate of productivity growth attained in that latter period is in itself not without precedent, the acceleration has, in contrast to the past, been achieved with continued positive employment growth. Moreover, the acceleration has been accompanied by an increase in investment growth, to a large extent driven by strong ICT investment. This break with past experience and the role of new technologies are generally seen as the distinctive features of the recent developments in U.S. productivity growth.

TABLE 6.1: **Annual growth in GDP and its components, 1991–2001**
(percentages and percentage points respectively)

	GDP per capita	Working age population/ total population	Labor force partici- pation rate	Employment/ labor force	GDP per person employed	Average hours worked	GDP per hour worked
		(a)	(b)	(c)		(d)	
Euro area	1.7	–0.1	0.5	–0.1	1.4	–0.6	2.0
United States	1.9	0.0	0.3	0.1	1.6	–0.1	1.6

Note: Figures may not add up due to rounding.
Source: Author's calculations based on data from the European Commission, National Accounts and OECD (Organisation for Economic Co-operation and Development).

GRAPH 6.1: Growth of ALP and labor input; United States, total economy
(percentage changes)



Source: Author's calculations based on data from National Accounts and OECD.

It is still hotly debated whether and to what extent the U.S. productivity developments in the 1990s were of a structural or rather of a cyclical, non-sustainable nature (for an optimistic view see, for example, Oliner and Sichel 2002, and for a more pessimistic view Gordon 2002). No convincing conclusions can be reached yet. The recession of 2001 led to a slowdown in productivity growth, although a sharp drop in growth of total hours worked held up productivity growth to some extent. Note, in this context, that a trade-off between employment and productivity growth is a traditional phenomenon in economies and was also apparent, for example, in the recession year in the United States, 1991. Productivity developments in 2002 have been encouraging so far, but were again achieved at the expense of growth in labor input. Thus the jury is still out on the issue of whether the productivity improvements of the late 1990s are structural or largely cyclical in nature.

Graph 6.2 shows that developments in the euro area have been somewhat different from those in the United States. Although slightly downward trending, ALP growth has grown at a relatively high rate compared to the United States. In the recession periods of the first half of the 1980s and the first half of the 1990s, this

GRAPH 6.2: **Growth in ALP and labor input; euro area, total economy**
(percentage changes)

Source: Author's calculations based on data from National Accounts and OECD.

relatively high rate of productivity growth was accompanied by an adverse development in total hours worked. In the second half of the 1990s labor input accelerated again in the euro area. However, this has not been accompanied by a clear change in labor productivity developments. Overall, while ALP growth has been higher, labor input growth has been substantially lower in the euro area than in the United States.

6.3. Growth accounting

To assess the contribution of ICT capital to economic growth and to estimate the development of TFP, a standard growth accounting exercise has been carried out. The growth accounting framework was pioneered by Solow (1957) and further developed by Jorgenson and associates (e.g. Jorgenson and Griliches 1967; Jorgenson, Gollop, and Fraumeni 1987). The framework used here is similar to that used in Oliner and Sichel (2000, 2002). In a growth accounting framework, the growth rate of real output ($\dot{Y}$) is equal to the weighted growth rates of labor input ($\dot{L}$) and real capital input

($\dot{K}$), plus growth in total factor productivity ($\dot{TFP}$). The following formulas were used here:

$$\dot{Y} = \alpha_L \dot{L} + \sum_j \alpha_{Kj} \dot{K}_j + \dot{TFP} \tag{6.1}$$

which, after some rearranging, and assuming that $\sum_j \alpha_{Kj} = 1 - \alpha_L$, yields the following expression for ALP:

$$\dot{Y} - \dot{L} = \sum_j \alpha_{Kj} (\dot{K}_j - \dot{L}) + \dot{TFP} \tag{6.2}$$

Time subscripts have been suppressed for simplicity of notation. Appendix 6.1 provides a detailed overview of the data used. Labor input is measured in terms of total hours worked. The share of labor (α_L) can be calculated from the wage share in gross value added (which can be directly extracted from the national accounts) adjusted for the imputed wage income of the self-employed. Due to data limitations, no adjustment has been made for the quality of labor in this exercise.

As to capital inputs, a distinction is made between the contribution of ICT capital and of other, non-ICT capital to output. In all, six categories of capital have been distinguished. ICT capital consists of the stock of information equipment (including computers), the stock of software, and the stock of communications equipment. Non-ICT capital consists of the stocks of "Other machinery and equipment," transport equipment and non-residential construction. Capital stock estimates have been constructed using the perpetual inventory method (see also Appendix 6.1).

Note that residential dwellings were not included as part of productive capital. The factor shares were adjusted accordingly. The sum of the shares of the various types of capital is assumed to be equal to $1 - \alpha_L$, a standard assumption in this kind of exercise reflecting constant returns to scale. The shares of the different types of assets in total capital input are based on the user cost of capital, i.e. the gross rate of return that must cover the internal rate of return (assumed common to all capital),[7] the depreciation

[7] This assumption is not consistent with the views of those who argue that ICT accounts for exceptionally high returns on investment.

rate, and the capital gain/loss of the specific capital good. Tax considerations were not taken into account, but the impact of taxes on the user cost of capital is assumed to be captured by the internal rate of return.

As noted in Vijselaar and Albers (2004), there are a number of caveats to this exercise. First, the growth accounting exercise used here relies on a production function approach with constant returns to scale under the usual assumption of competitive factor markets. ICT is treated as just another capital good, one that is not different from others in terms of its impact on production. These conditions are not necessarily met in practice even though they provide a reasonable approximation in many markets (see OECD 2001).

Second, TFP growth as estimated here assumes a Hicks-neutral shift of a production possibility function over time. The estimates of TFP growth would be biased to the extent that technical progress is not neutral.

Third, the growth accounting framework assumes maintained equilibrium, which for instance guarantees that the marginal products of each factor of production exhaust their income. In periods of structural changes, this assumption may not hold. Arguably, the increased use of ICT could be seen as such a structural change. Kiley (1999), for instance, has tried for the United States to incorporate costs of adjustment and concluded that the inclusion of adjustment costs can have large effects on the growth-accounting exercise when a new investment good is introduced, such as ICT. The contribution of ICT to economic growth could consequently be constrained for a prolonged period by the large adjustment costs required to incorporate a new investment good into the economy's capital stock. Eventually, however, the impact of ICT boosts long-run growth in his model as well. This may be considered one of the reasons why some argue that, judging from historical experience, the benefits of ICT for economic growth will only feed through with a lag (e.g. David 1990).

Fourth, ideally TFP growth as derived here (i.e. as a residual term) should reflect the increase in efficiency in the economic process. Hence, any positive spill-over effects from ICT investment should result in an increase in the estimate of TFP growth.[8] However, as TFP growth is a residual term it captures all elements not included in the growth rates of capital and labor input, and thus also reflects the impact of omitted variables such as the quality of labor and any biases due for example to measurement problems.[9] It is therefore difficult to draw any firm conclusions from changes in measured TFP growth for the development of overall efficiency.

Using equation (6.2), the contribution of ICT capital to ALP growth has been determined and estimates have been made of TFP growth for the period 1982–2001. As noted in the introduction, the ICT contribution was calculated over the business cycle to implicitly filter out cyclical effects. The business cycle is defined here as the period from trough to trough in the classical cycle, in particular the periods 1982–91 and 1991–2001 for the United States, and the periods 1982–93 and 1993–2001 for the euro area. The years for the United States are chosen according to the official business cycle dates of the NBER (National Bureau of Economic Research).[10] As there exists no generally agreed upon reference cycle for the euro area, the mean dating of the cycle of the three largest euro area countries according to the ECRI (Economic Cycle Research Institute) was followed here.

For the euro area, there is a scarcity of national accounts data on ICT investment. However, the euro area estimates presented below are based on national accounts data from four euro area countries for which official data are available (Germany, France, Italy and the Netherlands) which together comprise almost 80%

[8] Some researchers suggested on the basis of U.S. data that technological change that is embodied in capital goods, which is not adequately reflected in the official price indices, would bias downward the measured growth of effective capital stock (e.g. Sakellaris and Wilson 2002). In the current analysis, the effect of such embodied technological change, which can be quite significant, is not identified and should show up in the overall estimate of TFP growth.

[9] As Triplett (2001) pointed out, "If output and computer inputs are correctly measured, the new things that computers do will not show up in economic statistics in the form of an enhanced growth of [T]FP."

[10] Note that March 2001 is the official peak month, and there is not (yet) an official trough announced by the NBER. However, given the resumption of economic growth in 2002 and the usually short period between official peaks and troughs, it seems not unreasonable to take 2001 as a trough year.

of euro area gross value added.[11] The estimates for the United States are based on BEA (Bureau of Economic Analysis) national accounts data, and follow the same methodology of construction as the euro area data in order to arrive at comparable results.

To improve comparability of the results, an attempt has been made to take into account the methodological differences with respect to certain price deflators. In particular, for the euro area estimate the U.S. deflator for information equipment was substituted for the national one corrected for relative differences in the deflator for investment in other equipment (see also Schreyer 2001). Admittedly, the adjustment is rather crude. Whilst it is true that different approaches to quality adjustment may significantly impact on information equipment deflators, a number of other factors also need to be taken into account. For instance, the price indices in each country may reflect a different mix of investment goods, which suggests that using a U.S.-based alternative deflator is far from ideal. Moreover, especially when investment goods are imported, a currency conversion could be warranted.[12]

Table 6.2 shows the decomposition of ALP into contributions from ICT capital, other capital and TFP for the euro area. Comparing the 1982–93 business cycle to the 1993–2001 business cycle, it appears that the contribution of ICT to labor productivity growth increased only slightly, while TFP growth decreased significantly in the euro area.

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[11] The euro area economic structure may differ from the structure implicit in the euro area estimate presented here, which is based on only a subset of countries. Arguably, the availability of statistics correlates positively with the degree of a country's economic development, which in turn could a priori be assumed to positively correlate with the degree of ICT penetration in the economy. This would imply that there might be an upward bias in the estimates of the contribution of ICT to ALP growth. However, here, and to a lesser extent also in the section on sectoral developments, important euro area producers of ICT (Ireland and Finland) are not taken into account—due to lack of data. Furthermore, the aggregation of gross value added is not fully harmonized across euro area countries, as use is made of both chain-weighted and fixed-weight aggregates. All this implies that there is probably a bias in the euro area estimate as presented in this study, the precise size and direction of which are however unknown.

[12] Because of the use of U.S.-based alternative deflators, theoretically real GDP growth for the euro area could be different as well from officially published figures. However, as shown in Vijselaar and Albers (2002), the impact of the use of alternative IT (Information Technology) deflators on overall euro area GDP growth is only very marginal. For a discussion of the many methodological and statistical difficulties surrounding international productivity comparisons see ECB (2001), and the measurement of the more general macroeconomic impact of ICT in the euro area in particular, see Vijselaar (2002).

TABLE 6.2: Decomposition of euro area average labor productivity growth[1]
(percentage points)

	Absolute contribution to growth	
	1982–93	**1993–2001**
ICT capital deepening	**0.27**	**0.29**
Information equipment	0.15	0.16
Software	0.06	0.08
Communications equipment	0.05	0.05
Other capital deepening	**0.43**	**0.27**
TFP	**1.86**	**1.37**
	Annual average percentage growth	
ALP	**2.6**	**1.9**

[1] Estimate based on Germany, France, Italy and the Netherlands, comprising about 79% of euro area gross value added.
Source: Author's calculations based on data from OECD and national accounts.

TABLE 6.3: Decomposition of U.S. average labor productivity growth
(percentage points)

	Absolute contribution to growth	
	1982–91	**1991–2001**
ICT capital deepening	**0.44**	**0.52**
Information equipment	0.28	0.27
Software	0.11	0.18
Communications equipment	0.05	0.07
Other capital deepening	**–0.03**	**0.13**
TFP	**0.93**	**1.02**
	Annual average percentage growth	
ALP	**1.3**	**1.7**

Source: Author's calculations based on data from OECD and national accounts.

Table 6.3 shows the same decomposition for the United States. It appears that comparing the 1982–91 business cycle with the 1991–2001 business cycle, perhaps surprisingly, the increase in ICT capital deepening was relatively modest. However, as an important difference with the euro area, the contribution of other capital increased and TFP hardly decreased.

Table 6.4 shows the difference in contribution over the cycles, comparing respectively the 1982–91 cycle in the United States with the 1982–93 cycle in the euro area (*cycle 1*) and the 1991–2001 cycle in the United States with the 1993–2001 cycle in the euro area (*cycle 2*). The table is thus constructed by simply deducting the first columns of the respective tables to yield column one in Table 6.4

and, by analogy column two. It appears that the difference in ALP growth in favor of the euro area declined significantly, from 1.2 percentage points to 0.2 percentage points from *cycle 1* to *cycle 2.* This decline can be attributed to ICT capital deepening to a very limited extent only.[13] Developments in other capital deepening and TFP are found to be more important in this respect. [14, 15]

The difference in TFP developments with the United States can be attributed to several factors, including measurement errors and sector-specific TFP developments. Factors such as spill-over effects or network externalities related to the use of ICT are other candidates which, however, are much more problematic to assess. While a quantification of the effects of the various explanations for the difference in TFP growth between the euro area and the United States is beyond the scope of this paper, it is highly

TABLE 6.4: Difference in contribution to ALP growth: euro area minus U.S.[1]
(percentage points)

	Absolute contribution to growth	
	Cycle 1	Cycle 2
ICT capital deepening	**–0.17**	**–0.23**
Information equipment	–0.13	–0.10
Software	–0.05	–0.10
Communications equipment	0.01	–0.02
Other capital deepening	**0.46**	**0.13**
TFP	**0.93**	**0.35**
	Annual average percentage growth	
ALP	**1.2**	**0.3**

[1] Estimate based on Germany, France, Italy, and the Netherlands.
Source: Author's calculations based on data from OECD and national accounts.

[13] Note that measurement of software capital differs greatly across countries, and as a consequence is generally underestimated in euro area countries compared to the United States (Lequiller 2001). This could imply a downward bias in the estimates of the contribution of software to ALP growth for the euro area compared to the United States. If so, this would further strengthen the observations as made in the main text.

[14] Note that the results shown by Van Ark et al. (2002) and Oliner and Sichel (2002) are very similar in this respect, see also Appendix 6.2.

[15] This conclusion also holds when comparing the periods 1991–95 to 1996–2001, see tables in Appendix 6.3. Indeed, comparing the periods before and after 1995 reinforces the importance of TFP for relative productivity developments in the 1990s, as noted in ECB (2002).

unlikely that biases in measured TFP growth can explain all, or most of it.[16] The sectoral composition of TFP and other structural factors which influence the use of technology could help explain at least part of the difference in TFP growth. In particular, the ICT producing manufacturing sector has shown a very strong acceleration in TFP, and this sector is substantially larger in the United States than in the euro area (see also the next section). Moreover, it is commonly believed that other business sectors in the United States are in a better position to exploit new technological opportunities due to the country's more flexible product, capital and labor markets.[17]

6.4. Sectoral developments

A picture emerging from the literature is that the ICT producing manufacturing sectors have shown clearly above average rates of production and productivity growth in the 1990s in the euro area as well as in the U.S. (Van Ark 2000, 2001; Pilat and Lee 2001; Vijselaar and Albers 2004; McGuckin and Van Ark 2001). Table 6.5 shows developments in these sectors quantitatively.[18] Note that the euro area data were adjusted for differences in the price deflator for the office, accounting and computing machinery sector, in a similar way as the investment data. From the table it is clear that even though ALP growth in the ICT producing manufacturing sectors was clearly above average in the euro area, higher productivity growth rates

[16] There is some evidence that for a number of euro area countries there has been a tendency to skill-biased employment growth in the 1990s (Scarpetta et al. 2000). This would imply that labor input growth as measured here is underestimated and, consequently, TFP is overestimated. However, also in the United States there has been an increase in labor quality over this period which is not taken into account in the above estimates. Indeed the difference between growth of total hours worked and of total labor input (adjusted for compositional change) in the United States and the euro area as a whole would be more or less the same from estimates in Bartelsman et al. (2002).

[17] In a number of OECD studies the importance of the regulatory framework for productivity developments has been addressed (see, for example, Bartelsman et al. 2002; and Scarpetta and Tressel 2002. For some considerations regarding the euro area economy specifically, see Vijselaar and Kennedy 2002).

[18] Due to data limitations, no figures are available for the period prior to 1991 and ALP refers here to value added per person employed rather than per hour worked.

TABLE 6.5: ICT producing manufacturing sectors
(annual percentage change and percentages respectively)

	Share in nominal value added		Growth in real value added		Share in employment		Growth in employment		Growth in ALP	
	1991	1999	1991–99	1995–99	1991	1999	1991–99	1995–99	1991–99	1995–99
Euro area[1]										
IT hardware	0.3	0.2	9.4	17.8	0.2	0.1	–9.6	–5.2	19.0	22.9
Communications equipment	0.6	0.6	8.5	13.0	0.6	0.5	–3.2	–0.6	11.7	13.6
United States										
IT hardware	0.5	0.4	20.0	25.8	0.2	0.2	–2.7	–2.3	22.7	28.1
Communications equipment	1.1	1.3	10.3	8.0	0.7	0.7	1.3	2.1	9.0	5.8

[1] Estimate based on Germany, France, Italy, Austria, and Finland, comprising about 80% of euro area gross value added.
Note: Due to the rapid decline of measured prices in the ICT producing manufacturing sector its share in nominal value added declined, despite high rates of growth in real value added.
Source: Author's calculations using data from STAN (Structural Analysis) OECD database, Groningen University ICT database, and BEA.

and the larger size of the ICT producing manufacturing sectors imply that the contribution to overall ALP growth from these sectors has been much more important in the United States.[19] Developments in these sectors thus explain part of the observed difference in ALP growth between the euro area and the United States.

However, in industries other than the ICT producing manufacturing sectors, the differences between the euro area and the U.S. are less clear-cut. On the one hand this relates to measurement problems. On the other hand, it relates to the nature of the differences observed, i.e. whether they are of a cyclical or otherwise non-sustainable rather than a structural nature and arguably, in some sectors excess demand has played a role in temporarily boosting their productivity performance.

As regards the first explanation, a *Slifman/Corrado* type of approach to the sectoral productivity data in the euro area and the United States was undertaken here. Basically, this approach departs from the following argument. Productivity in the services sector is notoriously hard to measure. Yet it seems implausible that over extended periods of time, productivity growth could be negative in any sector.[20] Thus it is useful to try to identify sectors that have shown a particular, persistently dismal (negative) measured productivity performance. A counterfactual overall ALP growth could subsequently be calculated by setting productivity growth at zero in sectors that show negative rates of growth over an extended period.

Productivity growth in the sectoral database used here was negative over the periods distinguished earlier in a number of sectors in the euro area and the United States. Unfortunately, the distinction in sectors is still at a rather high level of aggregation. In the euro area negative productivity growth rates were registered in the sectors “Hotels and restaurants” (ISIC [International Standard Industrial Classification] rev. 3 sector 55), and “Real estate, renting and business activities” (sectors 70–74), in the United States in these

[19] Note that the contribution to overall ALP growth cannot be easily calculated from this table for the United States because of chain-weighted volume measures.

[20] One possible explanation could be that with increasing employment and decreasing marginal productivity levels, ALP is affected negatively. This effect should then outweigh the (probably) positive effects of capital deepening and TFP growth (other than quality of labor) over an extended period of time.

two categories as well and in addition in "Communities, social and personal services" (sectors 75–99). Although productivity growth in the latter sector was slightly positive in the euro area over the 1990s, it has also been set at a counterfactual zero. The recorded ALP increase is imputed and showed a deceleration over the 1990s as wage moderation in the public sector implied a lower measured output growth. Although slightly positive, ALP growth in the public sector thus suffers from the same kind of measurement problems in the euro area as well.

National accounts guidelines recommend price and volume indices for value-added to be based on the so-called *double-deflation* method, combining deflators of gross output and intermediate inputs. In the present context, this point is of importance as many industries consume intermediate products from the above mentioned services sectors. Thus, output and input prices have to be adjusted to assess the full impact on measured value-added and on total gross value-added. Full and internally consistent estimates of inter-industry effects on input and output price and volume adjustments, and their final impact on overall value-added (or GDP) have to be assessed using detailed input-output tables. The detailed sectoral gross value-added data from the OECD STAN database were combined with information from compatible input-output tables in order to construct alternative series of gross output and inputs and thus calculate a *corrected* value-added.

Table 6.6 shows the results of the correction exercise for the euro area and the United States. Note that ALP is measured here as value-added per person employed rather than per hour worked, due to lack of data on hours worked per sector. It appears that measurement problems are also acute in the euro area, and the results would suggest that the problems have even increased over recent years in the euro area in contrast to the United States. This result provides fresh evidence that part of the difference in ALP growth developments between the euro area and the United States in the 1990s could be attributable to statistical problems rather than real differences in economic performance.[21]

[21] Note that the implicit price deflator also changes mechanically in this exercise. However, it is unclear whether or to what extent this is a genuine bias in measured prices, as difficulties in the measurement of output also apply to nominal value-added.

TABLE 6.6: **Correction for negative ALP growth (value added per person employed)**
Measured growth rate and counterfactual growth rate

	Total economy		Services sector		Business services	
	1991–99	**1995–99**	**1991–99**	**1995–99**	**1991–99**	**1995–99**
Euro area[1]	1.6	1.2	0.9	0.7	1.0	0.8
	1.8	**1.6**	**1.3**	**1.4**	**1.8**	**1.8**
United States	1.7	2.0	1.5	2.4	2.2	3.3
	2.0	**2.3**	**1.8**	**2.8**	**2.5**	**3.8**

[1] Estimate based on Germany, France, Italy, Austria, and Finland.
Source: Author's calculations using data from STAN OECD database, Groningen University ICT database and BEA.

As regards the second explanation proposed above, it turns out that only two sectors account for the difference in ALP performance in the services sector between the euro area and the United States: wholesale and retail trade and, for a smaller part, financial intermediation (Table 6.7). Unsurprisingly, these sectors belong to those singled out by the McKinsey Global Institute (2001) as being responsible for the change in productivity performance in the United States from the first to the second half of the 1990s, although on the basis of the more detailed sectoral data available to McKinsey the latter mentioned sector was narrowed down to securities. In their study, McKinsey Global Institute cites product, service and process innovations, competition, and cyclical demand factors as the most important causes for the rapid increases in productivity in the U.S.

According to McKinsey, cyclical demand factors are quite significant, explaining about half of the observed productivity boom in the securities and retail and wholesale trade sectors. The demand side factors may also have played an important role in explaining the productivity growth difference between the euro area and the United States from the middle of the 1990s onwards. In fact, one major difference between the euro area and the United States in recent years was the sustained strength of real private consumption growth in the United States. This strength was driven to an important extent by wealth effects, prompting the household savings rate to become negative, which according to many observers has given rise to unsustainable imbalances in the U.S. economy (see, for example,

TABLE 6.7: Sectoral ALP growth and average share in total employment
(annual percentage change and percentages respectively)

	Wholesale and retail		Financial intermediation		Post and Telecom.	
	1991–99	1995–99	1991–99	1995–99	1991–99	1995–99
Euro area[1]						
ALP	1.0	0.4	2.3	3.3	9.2	12.3
Employment share	15	15	3	3	2	1
United States						
ALP	3.9	6.1	2.8	4.1	3.6	2.7
Employment share	24	24	4	4	2	1

[1] Estimate based on Germany, France, Italy, Austria, and Finland.
Source: Author's calculations using data from STAN OECD database, Groningen University ICT database, and BEA.

International Monetary Fund 2001). In addition, the stock market boom in the late 1990s provides an important demand side argument for the observed increase in productivity in the financial services sector. Indeed, the fact that stock markets also boomed in the euro area, while there is also an increase discernible over the 1990s in productivity growth in the financial intermediation sector in the euro area, would suggest that it is an important factor behind the measured productivity increase.

Arguably, the supply-side factors that apply to the United States should apply to the euro area economies as well. Yet productivity showed no acceleration in the retail and wholesale trade sector in the euro area. At first sight this is puzzling. The absence of a dominating market leader setting industry standards, such as Wal-Mart in the United States, may help explain this relatively lacklustre performance in the euro area, as McKinsey suggests. Yet Wal-Mart failed, despite its alleged productivity superiority, in its attempt to penetrate continental European markets successfully, which could suggest that productivity in this sector in Europe is already relatively high. As reported in Wynne and Rodríguez Palenzuela (2002) for Germany and McKinsey Global Institute (2002) for France it could, however, also be related to the regulatory framework in the euro area, which prohibits firms to follow aggressive market penetration strategies. That would rather point to the need for further structural reforms to increase the degree of competition in euro area product markets.

As regards financial markets performance, it has been argued that the financial markets in the United States, by being more market-oriented (as opposed to bank-based) are more innovative than their continental European counterparts. ICT played an important role in this innovation process, as in many cases it was a sine qua non for those innovations (take, for example, on-line securities trading). Thus an important consideration in this respect may be the old-fashioned explanation of comparative advantage, and perhaps also geographical concentration of financial market trade following the world-wide liberalization of capital markets. Moreover, McKinsey Global Institute (2001) cites as an important driving factor of the productivity increase pro-competition regulations introduced in 1997 by the SEC (Securities and Exchange Commission) that resulted in lower equity trading costs and contributed to more trading volume by active traders. Against this background, the initiatives to stimulate financial market integration in the European Union, such as laid down in the Financial Services Action Plan and the Lamfalussy report, and indeed the advent of the euro itself, can be seen as important steps to lower barriers for cross-border competition in the euro area.

Interestingly, the post and telecommunications sector, regarded as ICT producing services sector, showed a larger ALP growth in the euro area than in the United States over the 1990s. Given the liberalization of this market segment in the euro area in the course of the last decade, this would be suggestive of the importance of structural reforms to boost productivity performance. Moreover, as McKinsey Global Institute (2002) points out, inappropriate regulation in the United States led to an overly fragmented market limiting the opportunities for telecom companies to build scale and thus maximize the benefits from innovative products and processes—in contrast to Germany and France.

6.5. Conclusion

The present paper primarily attempted to explore some of the basic facts about the productivity performance of the euro area and the role of ICT, comparing developments to those in the United States. Rather than giving definite answers to the many questions raised, the first and relatively modest purpose was to consistently examine the available evidence and try to obtain consistent results, in spite of the many complicated data issues that hamper such efforts. The main findings are summarized below.

Many observers linked the pick-up in ALP growth in the United States from the first to the second half of the 1990s with the pick-up in ICT investment, concluding that the latter caused the former. However, while ICT is an important factor in explaining productivity developments, arguably many observers have exaggerated its role in the heyday of the ICT boom. In particular, for a thorough analysis of productivity developments one needs to look into both supply side factors, as is done in growth accounting, and demand side factors, which mainly relate to cyclical developments. From this analysis, it appears that cyclical factors seem to be rather important in order to put productivity developments in a proper perspective. In particular, the contribution of ICT capital deepening to overall ALP growth seems not to have increased substantially from the cycle in the 1980s to the cycle in the 1990s in the euro area or in the United States. Note, however, that not all demand side factors are of a cyclical nature. Indeed, to the extent that productivity developments reflect comparative advantages and shifts in geographical concentration of demand, as may be the case in financial markets, differential developments may be of a more sustainable nature. However, this point needs to be studied further.

In explaining the difference in productivity performance in the 1990s between the euro area and the United States, part of the measured difference may be due to differences in statistical methodologies. Indeed, the *Slifman/Corrado* type of correction to the productivity data provides fresh evidence in this regard. However, it is unlikely that measurement issues explain all of the difference. This paper argues that rather than ICT capital, other capital deepening and in particular the development of TFP, explain the difference in productivity trends between the euro area and the United States.

The latter finding suggests that part of the difference in productivity performance between the euro area and the United States may be explained by a difference in regulatory framework, where stronger competition and more flexible labor markets imply that the U.S. economy is better able to exploit new technological opportunities. This conclusion is strengthened by an analysis of developments in the services sector, where in all three cases examined, regulatory reforms seem to have played a key role. Further research is needed to learn which specific regulatory reforms could improve the productivity performance of the euro area. In general terms, however, it is clear that as regards product market regulations, the basic assessment of many observers is that the best policy for improving the productivity performance of countries is to encourage strong competition. And as regards labor market regulations, it has been pointed out that firms must be able to adjust their workforce in a flexible manner to benefit optimally from new technological possibilities (see, for example, Brynjolfsson and Hitt 2000; Gust and Marquez 2002).

References

Bartelsman, Eric, Andrea Bassanini, John Haltiwanger, Ron Jarmin, Stefano Scarpetta, and Thorsten Schank. *The Spread of ICT and Productivity Growth. Is Europe Really Lagging Behind in the New Economy?* 2002. http://www.frdb.org/images/customer/copy_0_rdb_final_draft_1.pdf.

Brynjolfsson, Erik, and Lorin Hitt. "Beyond Computation: Information Technology, Organizational Transformation and Business Performance." *Journal of Economic Perspectives* 14, no. 4 (Autumn 2000): 23–48.

Bureau of Economic Analysis. *Fixed Reproducible Tangible Wealth in the United States, 1925–94.* Washington, DC: Bureau of Economic Analysis, 1999.

CPB. *ICT en de Nederlandse economie. Een historisch en internationaal perspectief.* Working paper no. 125. The Hague: Centraal Planbureau (CPB) – National Bureau for Economic Policy Analysis, 2000. Available online at http://www.cpb.nl/eng/pub/cpbreeksen/werkdoc/.

David, Paul A. "The Dynamo and the Computer: an Historical Perspective on the Modern Productivity Paradox." *American Economic Review* 80 (1990): 355–61.

European Central Bank (ECB). "The sensitivity of euro area growth to the measurement of ICT prices." *ECB Monthly Bulletin*, European Central Bank, Frankfurt, September 2001, 41–43.

—. "Developments in euro area labour productivity." *ECB Monthly Bulletin,* European Central Bank, Frankfurt, August 2002, 29–31.

Fagan, Gabriel, Jerome Henry, and Ricardo Mestre. *An Area-Wide Model (AWM) for the Euro Area.* ECB Working Paper no. 42. Frankfurt: European Central Bank, 2001. Available online at http://www.ecb.int/pub/pdf/scpwps/ecbwp042.pdf.

GORDON, Robert J. *Technology and Economic Performance in the American Economy.* NBER Working Paper no. 8771. Cambridge, MA: National Bureau of Economic Research, 2002.

GUST, Christopher, and Jaime MARQUEZ. *International Comparisons of Productivity Growth: The Role of Information Technology and Regulatory Practices.* International Finance Discussion Papers no. 727. Washington, DC: Board of Governors of the Federal Reserve System, 2002. Also available online at http://www.federalreserve.gov/pubs/ifdp/2002/727/ifdp727.pdf.

INTERNATIONAL MONETARY FUND (IMF). *World Economic Outlook.* Washington, DC: International Monetary Fund, 2001.

JORGENSON, Dale W., Frank M. GOLLOP, and Barbara M. FRAUMENI. *Productivity and US Economic Growth.* Cambridge, MA: Harvard University Press, 1987.

JORGENSON, Dale W., and Zvi GRILICHES. "The Explanation of Productivity Change." *Review of Economic Studies* 34, no. 3 (July 1967): 249–80.

JORGENSON, Dale W., and Kevin J. STIROH. "Raising the Speed Limit: U.S. Economic Growth in the Information Age." *Brookings Papers on Economic Activity* 1 (2000): 125–211.

KILEY, Michael T. *Computers and Growth with Costs of Adjustment: Will the Future look like the Past?* Finance and Economics Discussion Series no. 1999-36. Washington, DC: Board of Governors of the Federal Reserve System, 1999. Also available online at http://www.federalreserve.gov/pubs/feds/1999/199936/199936pap.pdf.

KORTEWEG, Gerard, and Focco W. VIJSELAAR. "A Tale of Eight Legs on a Fly." Paper prepared for the Annual Conference of the International Association for Official Statistics, August 2002. Available online at http://www.statistics.gov.uk/IAOSlondon2002/.

LEQUILLER, François. *The New Economy and the Measurement of GDP Growth.* INSEE Working Paper no. G2001/01. Paris: National Institute for Statistics and Economic Studies (France), 2001. Also available online at http://www.insee.fr/en/nom_def_met/methodes/doc_travail/docs_doc_travail/g2001-1b.pdf.

MCGUCKIN, Robert H., and Bart VAN ARK. *Making Most of the Information Age; Productivity and Structural Reform in the New Economy.* New York: The Conference Board, 2001.

MCKINSEY GLOBAL INSTITUTE. *US Productivity Growth 1995–2000: Understanding the Contribution of Information Technology relative to other Factors.* Washington, DC: Mckinsey Global Institute, 2001.

MCKINSEY GLOBAL INSTITUTE. *Reaching Higher Productivity Growth in France and Germany.* Washington, DC: Mckinsey Global Institute, 2002.

OECD. *Purchasing Power Parities and Real Expenditures: 1996 Results.* Paris: Organisation for Economic Co-operation and Development, 1999.

—. *Measuring Productivity, OECD Manual.* Paris: Organisation for Economic Co-operation and Development, 2001.

—. *Employment Outlook.* Paris: Organisation for Economic Co-operation and Development, 2002.

OLINER, Stephen D., and Daniel E. SICHEL. "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives* 14, no. 4 (2000): 3–22.

—. "Information Technology and Productivity: Where Are We Now and Where Are We Going?" *Economic Review* 87, no. 3, Third Quarter, Federal Reserve Bank of Atlanta (2002): 15–44. Also available online at http://www.frbatlanta.org/filelegacydocs/oliner_sichel_q302.pdf.

PARHAM, Dean. "Productivity Gains from Policy Reforms, ICTs and Structural Transformation." Paper prepared for the Annual Conference of the International Association for Official Statistics, August 2002. Available online at http://www.statistics.gov.uk/IAOSlondon2002/.

PILAT, Dirk, and Frank C. LEE. *Productivity Growth in ICT-Producing and ICT-Using Industries: A Source of Growth Differentials in the OECD?* STI Working Paper no. 2001/4. Paris: Organisation for Economic Co-operation and Development, Directorate for Science, Technology and Industry, 2001.

SAKELLARIS, Plutarchos, and Daniel J. WILSON. *Quantifying Embodied Technological Change*. ECB Working Paper no. 158. Frankfurt: European Central Bank, 2002. (Later published in *Review of Economic Dynamics* 7, no. 1 [2004]: 1–26.)

SCARPETTA, Stefano, Andrea BASSANINI, Dirk PILAT, and Paul SCHREYER. *Economic Growth in the OECD Area: Recent Trends at the Aggregate and Sectoral Level*. OECD Economics Department Working Paper no. 248. Paris: Organisation for Economic Co-operation and Development, 2000.

SCARPETTA, Stefano, and Thierry TRESSEL. *Productivity and Convergence in a Panel of OECD Industries: Do Regulations and Institutions Matter?* OECD Economics Department Working Paper no. 342. Paris: Organisation for Economic Co-operation and Development, 2002.

SCHREYER, Paul. "Information and Communication Technology and the Measurement of Volume Output and Final Demand – A Five Country Study." *Economics of Innovation and New Technology* 10 (2001): 339–76.

SLIFMAN, Lawrence, and Carol CORRADO. "Decomposition of Productivity and Unit Costs." *American Economic Review* 89, no. 2 (1999): 328–32.

SOLOW, Robert. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39, no. 3 (1957): 312–20.

STIROH, Kevin J. "Information Technology and the U.S. Productivity Revival: What do the Industry Data say?" *Federal Reserve Bank of New York Staff Reports* 115, (2001). (Also published by *American Economic Review* 92, no. 5 [2002]: 1559–76.)

TRIPLETT, Jack E. "Did the US have a New Economy?" Mimeo, paper prepared for 9th conference on National Accounting of the Association de Comptabilite Nationale, Paris, November 2001. Also available online at http://www.insee.fr/en/nom_def_met/colloques/acn/colloque_9/triplett.pdf.

UNITED NATIONS. *1993 System of National Accounts*, New York: United Nations, Statistics Division, 1993. Available online at http://unstats.un.org/unsd/sna1993/toctop.asp.

VAN ARK, Bart. "Issues in Measurement and International Comparison Issues of Productivity – An Overview." In OECD, ed. *Industry Productivity: International Comparison and Measurement Issues*. Paris: Organisation for Economic Co-operation and Development, 1996, 19–48.

—. "De vernieuwing van de oude economie. Nederland in een internationaal vergelijkend perspectief." In Luc Soete, ed. *ICT en de niewe economie, Preadviezen van de Koninklijke Vereniging voor Staathuishoudkunde*. Utrecht: Lemma, 2000, 21–61.

—. *The Renewal of the Old Economy: An International Comparative Perspective*. STI Working Paper no. 2001/5. Paris: Directorate for Science, Technology and Industry, OECD, 2001.

VAN ARK, Bart, Johanna MELKA, Nanno MULDER, Marcel TIMMER, and Gerard YPMA. "ICT Investment and Growth Accounts for the European Union, 1980–2000." Final report prepared for the DG Economics and Finance of the European Commission (Brussels), 2002. Also available online at http://www.eco.rug.nl/GGDC/dseries/Data/ICT/euictgrowth.pdf.

VIJSELAAR, Focco W. "Some Key Measurement Issues as seen from the Euro Area Perspective." Paper prepared for the 17th CEIES Seminar on "New Economy – Key measurement issues," Committee on Statistical Information in the Economic and Social Spheres Secretariat (Eurostat), Rome, 4–5 March 2002.

VIJSELAAR, Focco W., and Ronald M. ALBERS. "Cyclical Convergence in Europe." *Kredit und Kapital* 34 (2001): 178–96.

—. *New Technologies and Productivity Growth in the Euro Area.* ECB Working Paper no. 122. Frankfurt: European Central Bank, 2002. Also available online at http://www.ecb.int/pub/pdf/scpwps/ecbwp122.pdf. Later published in *Empirical Economics* 29 (2004): 621-46.

VIJSELAAR, Focco W., and Neale O. KENNEDY. "New Technologies: the Need for Structural Reforms." Paper prepared for the 22nd National Bank of Poland Conference "Monetary Policy in the Environment of Structural Changes" (24–25 October 2002). Also available online at http://www.nbp.pl/Konferencje/Falenty2002/pdf_en/Kennedy.pdf.

WYNNE, Mark A., and Diego RODRÍGUEZ PALENZUELA. *Measurement bias in the HICP: What do we know, and what do we need to know?* ECB Working Paper no. 131. Frankfurt: European Central Bank, 2002. Also available online at http://www.ecb.int/pub/pdf/scpwps/ecbwp131.pdf. (Later published in *Journal of Economic Surveys* 18, no. 1 [2004]: 79–112.)

Appendix 6.1. Data sources and aggregation methods

Data for sectoral developments

The main data source used is the OECD STAN database, which contains data on a detailed (two-digit ISIC rev. 3) sectoral level for gross value-added and employment. In some cases, data from this database are not available or not sufficiently detailed. In those cases, the ICT database of Groningen University (see http://www.eco.rug.nl.GGDC/) has been used as an additional source of information for euro area countries. Moreover, for the Netherlands use has been made of detailed employment accounts and supply and use tables of Statistics Netherlands. Importantly, for the United States detailed estimates for the real value-added and employment in the ICT sectors are not available from STAN. After careful comparisons of different methods and with the Groningen ICT database (which had been used in Vijselaar and Albers 2002), and BEA shipments and BLS (Bureau of Labor Statistics) employment data (some data kindly submitted on request by these agencies), it was decided to use the investment deflators to deflate nominal value-added of the ICT producing manufacturing sectors. This implied a significant upward revision of real production growth in the IT hardware producing sector. Employment includes self-employed persons in all cases.

Data for growth accounting

Labor hours: total employment data (in persons) were taken from national accounts and average working hours from OECD (2002).

Labor share: The share of labor (α_L) is calculated from the national accounts by adding to the share of the employees (which can be directly read from the national accounts) the share of the self-employed, assuming that the share of the latter is proportionally equal to the share of the employees. The measure of gross value-added is adjusted to exclude rents, as residential capital is not included as a production factor in the growth accounting exercise (see below).

Capital stocks: To construct the capital stocks the following formula has been used:

$$K_{jt} = \sum_{b=0}^{b=t} \Phi_{jtb} i_{jb}$$

where i_{ib} represents real investment at time b of capital good j, and Φ_{jtb} the economic efficiency at time t of investments at time b of capital good j. Φ_{jtb} in turn is calculated from the formula:

$$\Phi_{jtb} = \frac{\left(m_j - a_j\right)}{\left(m_j - \beta_j a_j\right)}$$

with m_j the average service lives set equal to those of the U.S. Bureau of Economic Analysis (1999), a_j being the age of the vintage, and β_j the decay parameters set equal to the depreciation rate of the type of capital under consideration. Note that the service life for software has been set at 4 years, based on assumed service lives for pre-packaged and own account software in Oliner and Sichel (2000).

The investment data necessary to build capital stocks are based on national accounts NIPA (National Income and Product Accounts) of the United States, and ESA95 (European System of Accounts 1995) of Germany, France, Italy and the Netherlands. In the case of the United States, private sector and government investment series were (chain-)aggregated to yield total economy investment series. Moreover, where appropriate, to match the distinction available for the euro area, detailed investment series were (chain-)aggregated. This implies that the IT hardware investment series is somewhat broader than in many American studies. The structural break due to German re-unification has been corrected by applying West-German growth rates to all German levels back in time. Moreover, in the case of non-ICT investment, some series had to be back-cast by applying growth rates of ESA79 (European System of Accounts 1979) data to the ESA95 time series in order to construct sufficiently long time series. The investment data were aggregated to yield estimates of euro area investment in the different types of capital goods distinguished.

Share of capital: The income share for each type of capital is calculated from the following equation:

$$\alpha_{Kjt} = \frac{c_{jt} K_{jt}}{p_{yt} Y_t}$$

where Y is real gross value-added, and c_{jt} the user costs of capital, which are calculated by using the following formula:

$$c_{jt} = (r_t + \delta_{jt} - \pi_{jt})$$

where δ_{jt} represents the depreciation rate, which is taken from the tables of the U.S. Bureau of Economic Analysis (1999) as in Oliner and Sichel (2000), π_{jt} is the expected capital gain/loss and is calculated as a three-year moving average of the annual price change of the capital good in question (following CPB 2000; Oliner and Sichel 2000), K_{jt} is the gross current cost capital stock of the respective capital good, r represents the nominal rate of return and is assumed to be equal over all types of stocks of capital goods. The depreciation rate for software has been derived in a consistent manner with BEA's depreciation estimates for the other types of capital goods. The rate of return is thus calculated for each year as the ex-post return from the equation:

$$\sum_j \frac{(r_t + \delta_{jt} - \pi_{jt}) K_{jt}}{p_{yt} Y_t} = 1 - \alpha_{Lt}$$

Aggregation methods

Where appropriate, purchasing power parities were used to compute euro area aggregates, in accordance with standard practices for cross-border comparisons of economic growth (Van Ark 1996). Purchasing power weights for 1996 as reported in OECD (1999) were applied here. In particular, the expenditure PPPs (Purchasing Power Parity) were matched to the particular sector and investment category distinguished (the so-called proxy PPP approach). This choice is motivated by the need for a conversion factor which takes cross-country differences in price levels and relative price differences among expenditure categories into account. However, the alternative of applying one common conversion factor, such as the weights used by Eurostat (Statistical

Office of European Communities) or those used in the Area-Wide model for the euro area (Fagan, Henry, and Mestre 2001), does not change the results significantly. The alternative of conversion at current exchange rates is not appropriate, as it does not allow for difference in price levels among countries. Moreover, current exchange rates are volatile and affected by a number of factors, such as capital movements, trade flows, and the sentiment of financial markets, which makes them unsuitable for comparing fluctuations in real economic activity across countries.

Appendix 6.2. Comparison with findings of other studies

From Table A.6.2.1 it emerges that in qualitative terms the estimates from this study and other related studies tend to yield a similar picture. The study by Van Ark et al. (2002) confirms that differences in relative productivity trends between the euro area and the United States are explained for the largest part by TFP developments. However, the following caveats should be borne in mind in interpreting the quantitative estimates, which differ somewhat from one study to the other.

1. The study by Van Ark et al. covers a somewhat different timeframe (decades rather than cycles) and relates to the European Union rather than the euro area.
2. This study focuses on growth rates of real GDP, as does the paper of Van Ark et al., whereas Oliner and Sichel use real non-farm business sector output. Moreover, the definition of IT hardware in this study is relatively broad, as in Van Ark et al. but unlike Oliner and Sichel, and includes the categories "Photocopy and related equipment" and "Office and accounting equipment" besides "Computers and Peripheral equipment" for the United States, to match the definition of euro area IT hardware.

TABLE A.6.2.1: Comparison of this study and other studies

Euro area/European Union

	Period	Contributions to average labor productivity growth (percentage points)				
		IT equipment	**Software**	**Comm. equipment**	**Other capital**	**TFP growth[2]**
This study	1982–93	0.15	0.06	0.05	0.43	1.86
	1993–2001	0.16	0.08	0.05	0.27	1.37
Van Ark et al.	1980–90	0.16	0.07	0.04	0.55	1.46
	1990–2000	0.16	0.10	0.06	0.59	1.04

United States

	Period	Contributions to average labor productivity growth (percentage points)				
		IT equipment	**Software**	**Comm. equipment**	**Other capital**	**TFP growth[2]**
This study	1982–91	0.28	0.11	0.05	–0.03	0.93
	1991–2001	0.27	0.18	0.07	0.13	1.02
Van Ark et al.	1980–90	0.27	0.09	0.06	0.14	0.92
	1990–2000	0.23	0.17	0.06	0.18	1.07
Oliner and Sichel[1]	1982–91	0.27	0.15	0.07	0.07	1.20
	1991–2001	0.37	0.28	0.09	0.06	1.19

[1] Non-farm business sector output per hour worked.
[2] Including labor quality.

Appendix 6.3. Comparing 1990–95 to 1995–2001

TABLE A.6.3.1: Decomposition of euro area average labor productivity growth[1]

	Absolute contribution to growth (percentage points)	
	1990–95	1995–2001
ICT capital deepening	**0.18**	**0.33**
Information equipment	0.09	0.18
Software	0.04	0.10
Communications equipment	0.05	0.05
Other capital deepening	**0.48**	**0.25**
TFP	**1.71**	**1.08**
	Annual average percentage growth	
ALP	**2.4**	**1.7**

[1] Estimate based on Germany, France, Italy, and the Netherlands, comprising about 79% of euro area gross value added.
Source: Author's calculations based on data from OECD and national accounts.

TABLE A.6.3.2: Decomposition of U.S. average labor productivity growth

	Absolute contribution to growth (percentage points)	
	1990–95	1995–2001
ICT capital deepening	**0.34**	**0.66**
Information equipment	0.18	0.31
Software	0.14	0.24
Communications equipment	0.02	0.12
Other capital deepening	**0.05**	**0.29**
TFP	**0.80**	**1.04**
	Annual average percentage growth	
ALP	**1.2**	**2.0**

Source: Author's calculations based on data from OECD and national accounts.

TABLE A.6.3.3: Difference in contribution to ALP growth: euro area minus U.S.[1]

	Absolute contribution to growth (percentage points)	
	1990–95	1995–2001
ICT capital deepening	**–0.16**	**–0.33**
Information equipment	–0.10	–0.12
Software	–0.10	–0.14
Communications equipment	0.04	–0.07
Other capital deepening	**0.42**	**–0.04**
TFP	**0.90**	**0.05**
	Annual average percentage growth	
ALP	**1.2**	**–0.3**

[1] Estimate based on Germany, France, Italy, and the Netherlands.
Source: Author's calculations based on data from OECD and national accounts.

7. Information Technology and Growth: The U.S. Experience

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THIS paper reviews the major American studies on IT (Information Technology) and growth in the United States. The paper highlights the major differences in results between the earlier studies on this subject (mainly before 1994), which found no relation between various measures of IT and productivity growth in the U.S. with the later studies (after 1994 or so) which did tend to find a positive effect of IT on productivity growth. The other effects of IT are considered as well. These include IT's impact on various measures of structural change and downsizing. The paper will also include some work based on several recent papers of mine on the subject, which use pooled cross-section, time-series data for 44 industries over the decades of the 1960s, 1970s, and 1980s in the United States.

7.1. Introduction

Robert Solow was perhaps the first to point out the anomaly between productivity growth and computerization. As we shall see below, industries that have had the greatest investment in computers (namely, financial services) have ranked among the lowest in terms of conventionally measured productivity growth. Moreover, at least until recently there has been little evidence of a pay-off to computer investment in terms of productivity growth.

However, another recent phenomenon of considerable visibility has been the rapid degree of industrial restructuring among U.S. corporations. As I shall argue below, standard measures of productivity growth are only one indicator of structural change. There are others, such as changes in direct input and capital coefficients. Changes in occupational mix and the composition of inputs were greater in the 1980s than in the preceding two decades. This is coincident with the sharp rise in computerization.

Though most of the attention in the literature has focused on the connection between IT or ICT (Information and Communication Technologies) and productivity, little work has been conducted on the linkage between IT and broader indicators of structural change (with a few exceptions noted below). One purpose of this paper is to help fill this gap. Indeed, I find evidence from regression analysis that the degree of computerization has had a statistically significant effect on changes in industry input coefficients and other dimensions of structural change. For my period of analysis, the degree of computerization does not appear to be a significant determinant of industry productivity growth.

The paper begins in section 7.2 with a review of the some of the pertinent literature on the role of computerization on productivity changes. Section 7.3 introduces the accounting framework and model. Section 7.4 presents descriptive statistics on productivity trends, computerization and measures of structural change in the U.S. In section 7.5, multivariate analysis is conducted using pooled times series and industry level data. Section 7.6 presents results on the relation between IT and downsizing in manufacturing. Concluding remarks are made in section 7.7.

7.2. Review of previous literature

A substantial number of studies have now examined the linkage between computerization or IT and productivity gains. The evidence is mixed. Most of the earlier studies failed to find any excess returns to IT, over and above the fact that these investments are normally in the form of equipment investment. These include Franke (1989), who found that the installation of ATMs (Automatic Teller Machines) was associated with a lowered real return on equity; Baily and Gordon (1988), who examined aggregate productivity growth in the U.S. and found no significant contribution of computerization; Loveman (1988), who reported no productivity gains from IT investment; Parsons, Gotlieb and Denny (1993), who estimated very low returns on computer investments in Canadian banks; and Berndt and Morrison (1995), who found negative correlations between labor productivity growth and high-tech capital investment in U.S. manufacturing industries. Wolff (1991) found that the insurance industry had a negative rate of TFP (Total Factor Productivity) growth over the 1948–86 period in the U.S. even though it ranked fourth among 64 industries in terms of computer investment.

The later studies generally tend to be more positive. Both Siegel and Griliches (1992) and Steindel (1992) estimated a positive and significant relationship between computer investment and industry-level productivity growth. Oliner and Sichel (1994) reported a significant contribution of computers to aggregate U.S. output growth. Lichtenberg (1995) estimated firm level production functions and found an excess return to IT equipment and labor. Siegel (1997), using detailed industry-level manufacturing data for the U.S., found that computers are an important source of quality change and that, once correcting output measures for quality change, computerization had a significant positive effect on productivity growth. Baily and Lawrence (2001), using national accounting data, found clear evidence that there was an acceleration in productivity growth among service sectors that are major purchasers of IT such as finance and wholesale and retail trade. They argued that these gains reflect not only increased investment in IT but also complementary innovations in business organization and policy.

Brynjolfsson and Hitt (1996, 1998) found a positive correlation between firm level productivity growth and IT investment over the 1987–94 time period when accompanied by organizational changes. Lehr and Lichtenberg (1998) used data for U.S. federal government agencies over the 1987–92 period and found a significant positive relation between productivity growth and computer intensity. Lehr and Lichtenberg (1999) investigated firm level data among service industries over the 1977–93 period and also reported evidence that computers, particularly personal computers, contributed positively and significantly to productivity growth. Ten Raa and Wolff (2000), developing a new measure of direct and indirect productivity gains, found that the computer sector was the leading sector in the U.S. economy during the 1980s as a source of economy-wide productivity growth. They also found very high productivity spillovers between the computer-producing sector and sectors using computers. In their imputation procedure, these large spillovers were attributable to the high rate of productivity growth within the computer industry.

Sitroh (1998) and Jorgenson and Stiroh (1999, 2000) used a growth accounting framework to assess the impact of computers on output growth. Jorgenson and Stiroh (2000) found relatively higher growth in TFP and average labor productivity between 1958 and 1996 in manufacturing. Within manufacturing, the annual growth rates of average labor productivity for computer-producing industries are far higher than for other industries (4.1% for "Industrial Machinery and Equipment" (SIC [Standard Industrial Classification] 35) and 3.1% for "Electronic and Electric Equipment" (SIC 36), compared with 2.6% for the next highest industry, "Instruments" (SIC 38)). Jorgenson and Stiroh (1999) calculated that one sixth of the 2.4% annual growth in output could be attributed to computer outputs, compared with about zero percent over the 1948–73 period. The effect came from capital deepening rather than from enhanced productivity growth.

Triplett and Bosworth (2000) report similar findings for TFP and labor productivity growth over three periods between 1960 and 1997 as do Jorgenson and Stiroh (2000). Productivity growth by either measure is far higher in manufacturing than in other industries during the two most recent periods (1973–97 and 1987–97), and is particularly pronounced for electronic and electric equipment. That industry's TFP growth of 7.3% per year between 1987 and 1997 far exceeded the rate of 2.4% for durables goods manufacturing as a whole, 2.4% per year for total manufacturing, 0.5% for services, and 0.9% for the private economy as a whole.

A study by Oliner and Sichel (2000) provides strong evidence for a substantial role of IT in the recent spurt of productivity growth during the second half of the 1990s. Using aggregate time-series data for the U.S., they found that the use of IT in sectors purchasing computers and other forms of IT, as well as the production of computers, appear to have made an important contribution to the speed-up of productivity growth in the latter part of the 1990s. Hubbard (2001) investigated how on-board computer adoption affected capacity utilization in the U.S. trucking industry between 1992 and 1997. He found that their use improved communications and resource allocation decisions and led to a 3% increase in capacity utilization within the industry.

Atrostic, Gates and Jarmin (2000) investigated how computer may be used to organize or streamline underlying business processes. When these computers are linked into a network, they facilitate standard business process such as order taking, inventory control, accounting services, and tracking product delivery and become electronic business processes. These e-business processes occur over internal or external computer networks that allow information from processes to be exchanged readily. Shipments may be tracked on-line, inventories may be automatically monitored and suppliers notified when predetermined levels are reached. These effects are likely to occur through organizational change. Many core supply chain processes are widely cited as examples of successful e-business practices. Viewed this way, computer networks are a productivity-enhancing general purpose technology (see, for example, Bresnahan and Trajtenberg [1995]).

One other factor that will be used in the data analysis is research and development. A large literature, beginning with Mansfield (1965), has now almost universally established a positive and significant effect of expenditures on R&D (Research and Development) on productivity growth (see Griliches 1979, 1992; Mohnen 1992, for reviews of the literature).

7.3. Modelling framework

I begin with a standard neoclassical production function f_j for sector j:

$$X_j = Z_j f_j\left(K_{Cj}, K_{Ej}, K_{Sj}, L_j, N_j, R_j\right) \tag{7.1}$$

where X_j is the (gross) output of sector *j*, K_{Cj} is the input of IT related capital, K_{Ej} is the input of other machinery and equipment capital goods, K_{Sj} is the input of plant and other structures, L_j is the total labor input, N_j are total intermediate inputs, R_j is the stock of R&D capital, and Z_j is a (Hicks-neutral) TFP index that shifts the production function of sector *j* over time.[1] For convenience, I have suppressed the time subscript. Moreover, capacity utilization and adjustment costs are ignored. It then follows that

$$\begin{aligned} d\ln X_j &= d\ln Z_j + \varepsilon_{Cj} d\ln K_{Cj} + \varepsilon_{Ej} d\ln K_{Ej} + \\ &+ \varepsilon_{Sj} d\ln K_{Sj} + \varepsilon_{Lj} d\ln L_j + \varepsilon_{Nj} d\ln N_j + \varepsilon_{Rj} d\ln R_j \end{aligned} \tag{7.2}$$

where ε represents the output elasticity of each input and $d \ln Z_j$ is the rate of Hicks-neutral TFP growth. If we now impose the assumption of competitive input markets and constant returns to scale, it follows that an input's factor share (α_j) will equal its output elasticity. Let us now employ the standard measure of TFP growth π_j for sector *j*:

$$\begin{aligned} \pi_j &\equiv d\ln X_j/dt - \alpha_{Cj} d\ln K_{Cj}/dt - \alpha_{Ej} d\ln K_{Ej}/dt - \\ &- \alpha_{Sj} d\ln K_{Sj}/dt - \alpha_{Lj} d\ln L_j/dt - \alpha_{Nj} d\ln N_j/dt \end{aligned} \tag{7.3}$$

It then follows that:

$$\pi_j = d\ln Z_j/dt + \alpha_{Rj} d\ln R_j/dt \tag{7.4}$$

In particular, in the standard neoclassical model, there is no special place reserved for IT capital in terms of its effect on TFP growth.

As Stiroh (2002) argues, there are several reasons why we might expect the standard neoclassical model to fail in the case of the introduction of a radically new technology that might be captured by IT investment. These include the presence of productivity spillovers from IT, problems of omitted variables, the presence of embodied technological change, measurement error in variables and reverse causality. If for one of these reasons, the

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[1] This is a modified form of the production function used by Stiroh (2002).

output elasticity of IT ε_{Cj} exceeds its measured input share α_{Cj}, say by u_{Cj}, then:

$$\pi_j = d\ln Z_j/dt + \alpha_{Rj} d\ln R_j/dt + u_{Cj} d\ln K_{Cj}/dt \tag{7.5}$$

In other words, conventionally measured TFP growth π_j will be positively correlated with the growth in ICT capital.

A similar argument applies to labor productivity growth, *LP*, defined as:

$$LP_j \equiv d\ln X_j/dt - d\ln L_j/dt \tag{7.6}$$

If we again impose the assumption of competitive input markets and constant returns to scale, it follows that:

$$\begin{aligned} LP_j &= d\ln Z_j/dt + \alpha_{Cj} d\ln k_{Cj}/dt + \alpha_{Ej} d\ln k_{Ej}/dt + \\ &+ \alpha_{Sj} d\ln k_{Sj}/dt + \alpha_{Nj} d\ln n_j/dt + \alpha_{Rj} d\ln R_j/dt \end{aligned} \tag{7.7}$$

where lower case symbols indicate the amount of the input per worker.[2] If for the reasons cited above there is a special productivity *kick* from IT investment, then the estimated coefficient of k_{Cj}/dt should exceed its factor input share.

However, as I indicated in the literature survey in the previous section, very few studies, with the exception of Siegel and Griliches (1992), have found a direct positive correlation between industry TFP growth and IT investment. As a result, in this study, I consider other indicators of the degree of structural change in an industry. These include changes in the occupational composition of employment and changes in the input and capital composition within an industry. Productivity growth and changes in input composition usually go hand in hand. To see this, let me first introduce three new matrices:

A = 45-order matrix of technical interindustry input-output coefficients, where a_{ij} is the amount of input *i* used per constant dollar of output *j*.

The technical coefficient (A) matrices were constructed on the basis of current dollar matrices and sector-specific price deflators.

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[2] Technically, we impose the assumption of constant returns to scale of the traditional factors of production, so that: $\alpha_{Cj} + \alpha_{Ej} + \alpha_{Sj} + \alpha_{Nj} + \alpha_{Lj} = 1$.

Sectoral price indices for years 1958, 1963, and 1967 were provided by the Brandeis Economic Research Center and those for 1972 and 1977 from the Bureau of Economic Analysis worksheets. Deflators for 1982, 1987, 1992, and 1996 were calculated from the Bureau of Labor Statistics' Historical Output Data Series (obtained on computer diskette) on the basis of the current and constant dollar series. See the Appendix for details on sources and methods and a listing of the 45 industries.

C = 45-order matrix of capital coefficients, where c_{ij} is the net stock of capital of type i (in 1992 dollars) used per constant dollar of output j.

The capital matrix in constant dollars was provided by the Bureau of Economic Analysis (see the Appendix for sources) and is based on price deflators for individual components of the capital stock (such as computers, industrial machinery, buildings, etc.).

M = occupation-by-industry employment coefficient matrix, where m_{ij} shows the employment of occupation i in industry j as a share of total employment in industry j.

The employment data are for 267 occupations and 64 industries and are obtained from the decennial Census of Population for years 1950, 1960, 1970, 1980, and 1990 (see Wolff 1996, for details).

Then, since for any input I in sector j, $\alpha_{Ij} = p_I I_j / p_j X_j$, where p is the price, I can rewrite equation (7.3) as:

$$\pi_j = -\left[\sum_i p_i da_{ij} + \sum_i p_{i,c} dc_{ij} + \sum_i w_i db_{ij}\right] / p_j \qquad (7.8)$$

where p_i is the price of intermediate input i, $p_{i,c}$ is the price of capital input i, $b_{ij} = m_{ij} L_j / X_j$ is the total employment of occupation i per unit of output in industry j, and w_i is the wage paid to workers in occupation i. In this formulation, it is clear that measured TFP growth reflects changes in the composition of intermediate inputs, capital inputs and occupational employment. Using the multiplication rule for derivatives, we can rewrite equation (7.8) as:

$$\pi_j = -\left[\sum_i p_i da_{ij} + \sum_i p_{i,c} dc_{ij} + \sum_i w_i \lambda_i dm_{ij} + \sum_i w_i m_{ij} d\lambda_j\right] / p_j \quad (7.9)$$

where $\lambda_j = L_j / X_j$. From (7.5) it follows that in the circumstances enumerated above, there may be a positive correlation between measures of coefficient changes (such as da_{ij}, dc_{ij}, and dm_{ij}) and IT investment.

Though productivity growth and changes in input composition are algebraically related, there are several reasons why they may deviate. First, there are costs of adjustments associated with radical restructuring of technology, so that there may be a considerable time lag between the two (see David 1991, for example). Second, while new technology is generally used to lower costs and hence increase measured output per unit of input, new technology might be used for other purposes such as product differentiation or differential pricing. Third, in the case of services in particular, output measurement problems might prevent us from correctly assessing industry productivity growth. This problem could, of course, be partly a consequence of product differentiation and price discrimination. Measures of structural change may therefore provide a more direct and robust test of the effects of computerization on changes in technology than standard measures of productivity growth. This is particularly so in the case when a radically new technology is introduced and the consequent adjustment period is lengthy.

7.4. Descriptive statistics

Table 7.1 shows the annual rate of TFP growth over the decades of the 1950s, 1960s, 1970s and 1980s. The periods are chosen to correspond to the employment by occupation and industry matrices. Factor shares are based on period averages (the Törnqvist-Divisia index). The labor input is based on PEP (Persons Engaged in Production), the number of full-time and part-time employees plus the number of self-employed persons, and the capital input is measured by fixed non-residential net capital stock (1992 dollars).[3] See the Appendix for details on sources and methods and a listing of the 45 industries.

[3] A second index of TFP growth was also used, with FTE (Full-Time Equivalent Employees) as the measure of labor input. Results are very similar on the basis of this measure and are not reported below.

TABLE 7.1: Productivity growth and other technological change indices by decade, 1950–90

Sector	1950–60	1960–70	1970–80	1980–90	1950–90
1. TFP Growth (percent per year)					
Total Goods	2.12	1.50	0.25	2.04	1.48
Total Services	0.70	0.58	0.58	0.07	0.48
Total Economy (GDP)	1.39	0.96	0.38	0.77	0.88
2. Dissimilarity Index (DIOCCUP) of the Distribution of Occupational Employment[1]					
Total Goods	0.063	0.061	0.014	0.110	0.062
Total Services	0.022	0.056	0.026	0.077	0.045
All Industries	0.050	0.056	0.019	0.095	0.055
3. Dissimilarity Index DIACOEFF for Technical Interindustry Coefficients[2]					
Total Goods	0.020	0.017	0.024	0.029	0.023
Total Services	0.057	0.046	0.043	0.045	0.048
All Industries	0.036	0.027	0.030	0.033	0.031
4. Dissimilarity Index DIKCOEFF for Capital Coefficients[3]					
Total Goods	0.008	0.007	0.011	0.014	0.010
Total Services (except government)	0.038	0.024	0.029	0.050	0.035
Total Economy (except government)	0.020	0.014	0.018	0.028	0.020
5. Annual Investment in OCA (Office Computing, and Accounting) Equipment per PEP (1992$, period averages)[4]					
Total Goods	26.4	27.7	42.0	162.1	—
Total Services (except government)	30.4	37.8	70.0	329.4	—
Total Economy (except government)	28.2	32.6	57.0	262.7	—

[1] Computations are based on employment by occupation aggregated for each of the major sectors.
[2] Sectoral figures are based on unweighted averages of industries within the sector.
[3] Sectoral figures are based on unweighted averages of industries within the sector. Data on investment by type are not available for the government and government enterprises sectors.
[4] Data on investment in OCA are not available for the government and government enterprises sectors.

As shown in Table 7.1, the annual rate of TFP growth for the entire economy fell from 1.4% year in the 1950s to 1.0% per year in the 1960s. It plummeted to 0.4% per year in the 1970s (the productivity slowdown period) but subsequently rose to 0.8% in the 1980s.[4] TFP growth in the goods-producing industries as a whole averaged 2.1% per year in the 1950–60 period, fell to 1.5% per year in the 1960s and then collapsed to 0.3% in the 1980s before climbing back to 2.0% per year in the 1980s. TFP growth

[4] In November of 1999, the U.S. Bureau of Economic Analysis (BEA) released a major revision of the U.S. national accounts. The new BEA data showed a faster rise in real GDP (Gross Domestic Product) and hence labor productivity during the 1990s than the older data indicated. One major element of the revision is the treatment of software expenses as a capital good rather than as an intermediate purchase. However, at the time the paper was written, the BEA had not released the corresponding revised capital stock data. As a result, the statistics in this paper are based on the older BEA national accounts data.

has been much lower in the service sector than among goods-producing industries—0.48% per year over the 1950–90 period for the former compared to 1.48% per year for the latter. Overall, annual TFP growth among all services fell monotonically between the 1950s and 1980s, from 0.7% to 0.1%.

As noted above, I use three measures of structural change. The first measure is the degree to which the occupational structure shifts over time. For this, I employ an index of similarity. The similarity index for industry *j* between two time periods 1 and 2 is given by:

$$SI^{12} = \frac{\sum_i m_{ij}^1 m_{ij}^2}{\left[\sum_i \left(m_{ij}^1\right)^2 \sum_i \left(m_{ij}^2\right)^2\right]^{1/2}} \tag{7.10}$$

The index *SI* is the cosine between the two vectors s^{t1} and s^{t2} and varies from 0—the two vectors are orthogonal—to 1—the two vectors are identical. The index of occupational dissimilarity, *DI*, is defined as:

$$DIOCCUP^{12} = 1 - SI^{12} \tag{7.11}$$

Descriptive statistics for *DIOCCUP* are also shown in Table 7.1. The *DIOCCUP* index for the total economy, after rising slightly from 0.050 in the 1950–60 period to 0.056 in the 1960–70 decade, dropped to 0.019 in the 1970s but then surged to 0.095 in the 1980s, its highest level of the four decades. These results confirm anecdotal evidence about the substantial degree of industrial restructuring during the 1980s. It is also apparent that the association between the *DIOCCUP* index and industry TFP growth is quite loose. Though the degree of occupational restructuring has been somewhat greater in the goods producing industries than in services (average scores of 0.062 and 0.045, respectively, for the 1950–90 period), the difference is not nearly as marked as for TFP growth (annual rates of 1.5% and 0.5%, respectively, over the same period). The *DIOCCUP* index provides a separate and relatively independent dimension of the degree of technological change occurring in an industry.

A second index reflects changes in the technical interindustry coefficients within an industry:

$$DIACOEFF^{12} = 1 - \frac{\sum_i a_{ij}^1 a_{ij}^2}{\left[\sum_i \left(a_{ij}^1\right)^2 \sum_i \left(a_{ij}^2\right)^2\right]^{1/2}} \tag{7.12}$$

Figures, shown in Table 7.1, indicate that the *DIACOEFF* index for the total economy, after falling from 0.036 in the 1950–60 period to 0.027 in the 1960–70 decade, rose to 0.030 in the 1970s and again to 0.033 in the 1980s. The correlation between the *DIACOEFF* index and industry TFP growth is again quite small. While TFP growth was much higher in goods-producing industries than in services, *DIACOEFF* was higher for services than the goods sector. The *DIACOEFF* index provides another independent indicator of the degree of industry technological change.

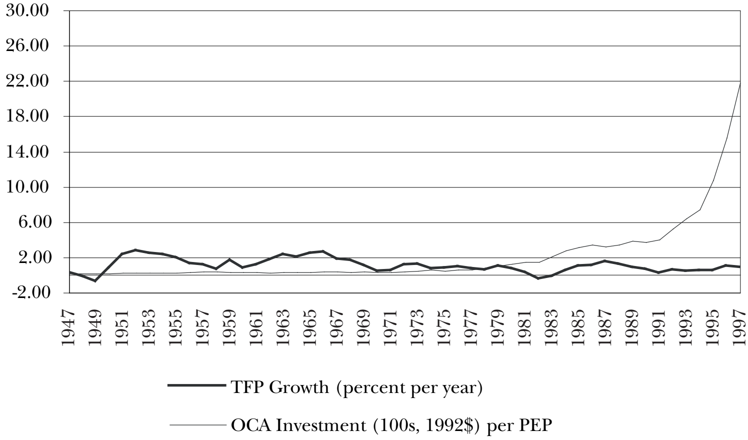
A third index measures the change in capital coefficients within an industry:

$$DIKCOEFF^{12} = 1 - \frac{\sum_i c_{ij}^1 c_{ij}^2}{\left[\sum_i \left(c_{ij}^1\right)^2 \sum_i \left(c_{ij}^2\right)^2\right]^{1/2}} \tag{7.13}$$

Table 7.1 also shows that the *DIKCOEFF* index for the total economy, after declining from 0.020 in the 1950–60 period to 0.014 in the 1960–70 decade, increased to 0.018 in the 1970s and to 0.028 in the 1980s. Here again, while TFP growth was much higher in goods than in service industries, *DIKCOEFF* was higher for the latter than the former.

My measure of IT capital is the stock of OCA equipment in 1992 dollars, which is provided in the Bureau of Economic Analysis' capital data (see the Appendix for sources). These figures are based on the BEA's hedonic price deflator for computers and computer-related equipment. As shown in Table 7.1 (also see Graph 7.1), investment in OCA equipment per PEP grew more than nine-fold between the 1950s and the 1990s, from $28 (in 1992 dollars) per PEP to $263. Indeed, by 1997, it had reached $2,178 per worker. On the whole, the overall service sector has been investing more intensively in computer equipment than the goods sector, but this was largely due to the very heavy investments made by the finance and insurance sectors. Total investment in equipment, machinery and instruments (including OCA) per PEP was more than fourteen times greater than OCA investment even in the 1980s, though by 1997 it accounted for almost exactly one-third of total equipment investment.

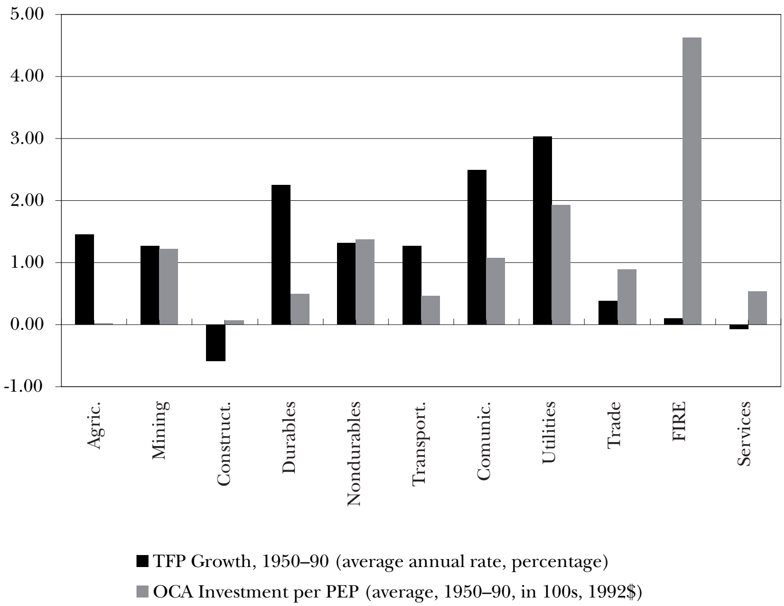
GRAPH 7.1: **Annual TFP growth (5-year running average) and OCA investment per worker, 1947–97**



On the surface, at least, there does not appear to be much relation between OCA intensity and TFP growth. While investment in OCA per worker rose almost continuously over the post-war period, TFP growth tracked downward, at least until the early 1980s (see Graph 7.1). Moreover, the sector with the highest amount of OCA investment per worker, FIRE (Finance, Insurance and Real Estate), averaged close to zero in terms of TFP growth over the post-war period (see Graph 7.2).

On the other hand, OCA investment seems to line up well with measures of structural change. As shown in Graph 7.3, the sectors with two highest rates of investment in OCA per PEP over the 1950–90 period are FIRE and utilities, which also rank in the top two in terms of the average value of *DIOCCUP* over the same period. The sector with the lowest investment

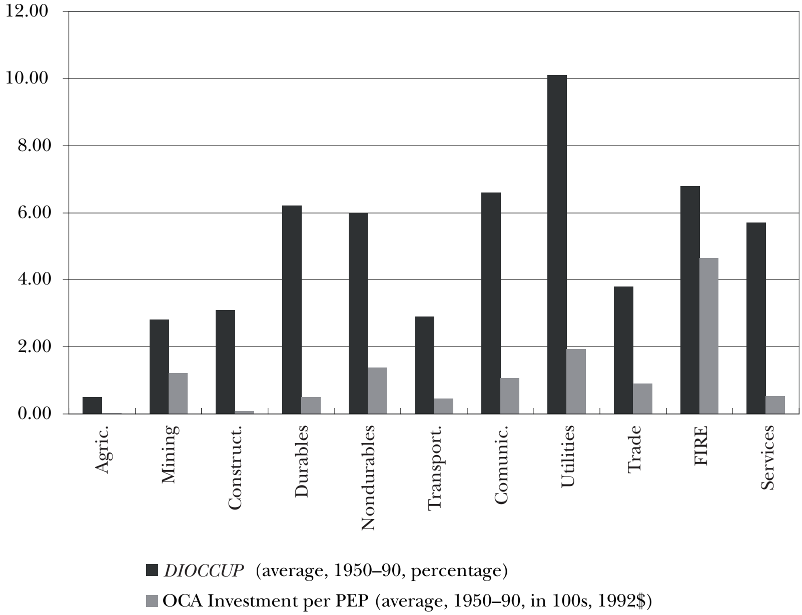
GRAPH 7.2: TFP growth and OCA investment per worker



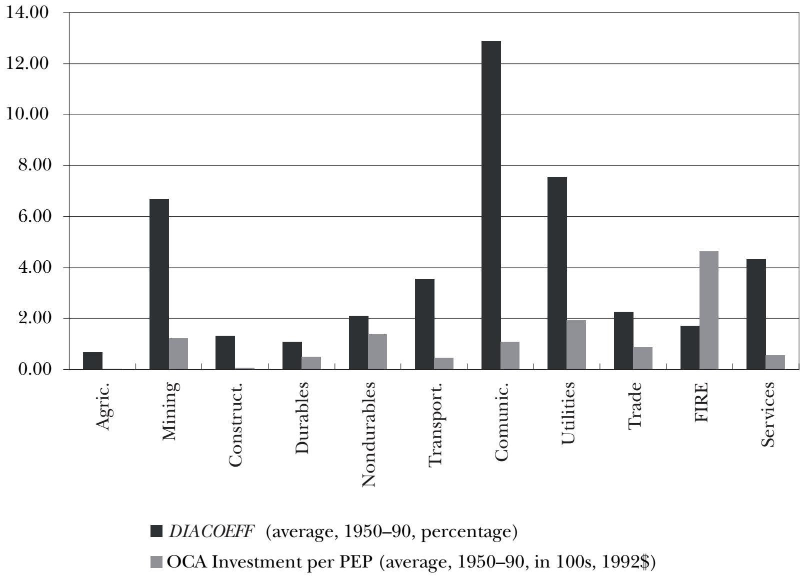
in OCA per worker is agriculture, which also ranks lowest in terms of *DIOCCUP*. Utilities ranks highest in terms of *DIACOEFF* over the 1950–90 period and second highest in terms of OCA investment per employee, while agriculture ranks lowest in both dimensions (see Graph 7.4). The association is not quite as tight between OCA investment and *DIKCOEFF* (see Graph 7.5). However, here again agriculture ranks lowest in both dimensions.

As shown in Graph 7.6, the ratio of R&D expenditures to total GDP has remained relatively constant over time, at least in comparison to the wide fluctuations in TFP growth. It averaged 2.0% in the 1960s, fell to 1.5% in the 1970s, recovered to 1.9% in the 1980s and remained at this level in the period from 1990–97. The pattern is very similar for individual industries, with the notable exceptions of industrial machinery (including OCA) and instruments, which show a continuous rise over the three periods. The ratio of R&D to sales was considerably higher in durable manufacturing than non-durables—almost a factor of three.

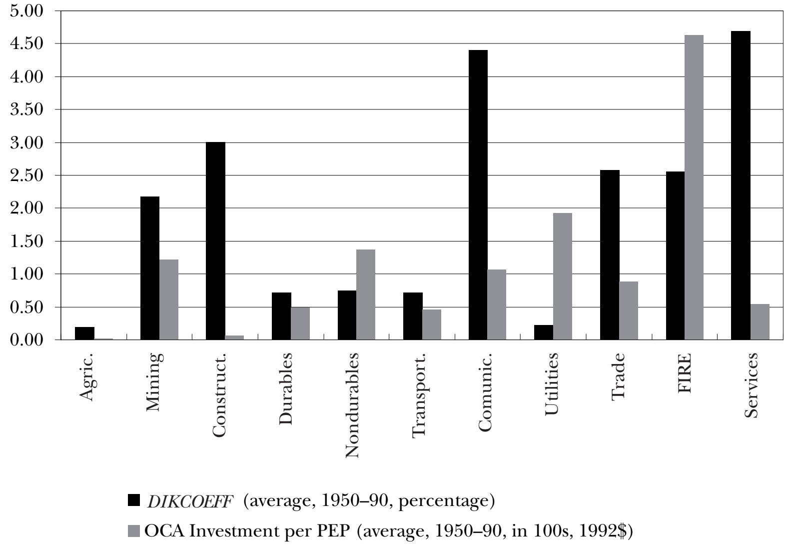
GRAPH 7.3: *DIOCCUP* and OCA investment per worker



GRAPH 7.4: *DIACOEFF* and OCA investment per worker



GRAPH 7.5: *DIKCOEFF* and OCA investment per worker

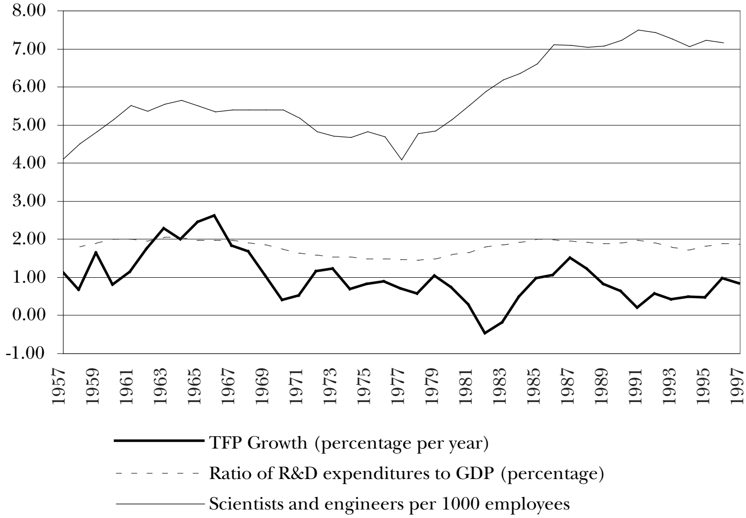


In the 1980–90 period, it ranged from a low of 0.4% in food products to a high of 18.3% in other transportation (including aircraft). The other major R&D-intensive industries, in rank order, are instruments, electric and electronic equipment, industrial machinery, chemicals and motor vehicles.

An alternative indicator of R&D activity is the number of full-time equivalent scientists and engineers engaged in R&D per 1000 full-time equivalent employees. Like the ratio of R&D expenditures to GDP, this series shows a drop between the 1960s and 1970s, from 5.4 to 4.8, and a recovery in the 1980s to 6.4 (see Graph 7.6). However, it shows a further increase to 7.3 in the 1990–96 period. This indicator also gives a very similar industry ranking. The leading industries in the 1980s, in rank order are: other transportation, chemicals, electric and electronic equipment, industrial machinery, instruments and motor vehicles.

R&D expenditures does a much better job in lining up with TFP growth than either OCA or equipment investment. Both R&D intensity and TFP growth fell between the 1960s and 1970s and then recovered in the 1980s. Moreover, there is a strong cross-industry correlation between TFP growth and R&D intensity—for example, R&D intensity and TFP growth are higher in durable manufacturing than in non-durable manufacturing.

GRAPH 7.6: Annual TFP growth (5-year running average), ratio of R&D expenditures to GDP, and scientists and engineers engaged in R&D per 1,000 employees, 1957–97



7.5. Regression analysis

In the first regression, the dependent variable is the rate of industry TFP growth. The independent variables are R&D expenditures as a percentage of net sales and the growth in the stock of OCA capital. The statistical technique is based on pooled cross-section time-series regressions on industries and for the decades that correspond with the decennial Census data. The sample consists of 45 industries and 3 time periods (1960–70, 1970–80, and 1980–90).[5] The estimating equation:

$$TFPGRTH_j = \beta_0 + \beta_1 RDSALES_j + \beta_2 OCAGRTH_j + v_j \qquad (7.14)$$

where $TFPGRTH_j$ is the rate of TFP growth in sector j, $RDSALES_j$ is the ratio of R&D expenditures to net sales in sector j, $OCAGRTH$ is

[5] The 1950–60 period cannot be included in the regression analysis because the R&D series begins fully only in 1958.

the rate of growth of the stock of OCA capital, v_j is a stochastic error term, and the time subscript has been suppressed for notational convenience. It is assumed that the v_{jt} are independently distributed but may not be identically distributed. The regression results reported below use the White procedure for a heteroscedasticity-consistent covariance matrix.

From (7.4) it follows that the constant β_0 is the pure rate of (Hicks-neutral) technological progress. From Griliches (1980) and Mansfield (1980), the coefficient of *RDSALES* is interpreted as the rate of return of R&D, under the assumption that the (average) rate of return to R&D is equalized across sectors.[6] Time dummies for the periods 1970–80 and 1980–90 are introduced to allow for period-specific effects on productivity growth not attributable to R&D or OCA investment. A dummy variable identifying the 10 service industries is also included to partially control for measurement problems in service sector output.

a. Basic regression results

Regression results for the full sample are shown in columns 1 and 2 of Table 7.2. The constant term ranges from 0.015 to 0.016. These estimates are comparable to previous estimates of the Hick-neutral rate of technological change (see Griliches 1979, for example). The coefficient of the ratio of R&D expenditures to net sales is significant at the five percent level. The estimated rate of return to R&D ranges from 0.20 to 0.21. These estimates are about average compared to previous work on the subject (see Mohnen 1992, for example, for a review of previous studies).[7]

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[6] The proof is that $RDSALES = dr / X$. From (7.2) and (7.4) it follows that:

$$\pi = \varepsilon_R (dR/R) = \varepsilon_R (dR/X)(X/R) = (\varepsilon_R X/R)(dR/X)$$

Therefore,

$$\beta_1 = (\varepsilon_R X/R) = (dX/X)(X/R)/(dR/R) = dX/dR$$

The term dX/dR is the marginal productivity of R&D capital, which is equivalent to the rate of return to R&D.

[7] The coefficient of the number of full-time equivalent scientists and engineers engaged in R&D per employee is also significant in every case, typically at the one percent level. In the tables, I present results using R&D expenditures because it is more conventional.

TABLE 7.2: Cross-industry regressions of industry TFP growth (TFPGRTH) on R&D intensity and OCA investment

Independent Variables	Specification (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	0.015 **	0.016 **	0.014 *	0.014 **	0.011	0.020	0.010	0.005
	(3.45)	(3.59)	(2.59)	(2.63)	(1.38)	(1.53)	(1.24)	(0.35)
Ratio of R&D expenditure to sales	0.203 *	0.212 *	0.199 #	0.205 #	0.338 *	0.348 #	0.171 *	0.131
	(2.17)	(2.24)	(1.89)	(1.93)	(2.28)	(2.00)	(2.26)	(1.86)
Annual growth in OCA		–0.039		–0.024	–0.053	–0.102	–0.060	–0.016
		(1.36)		(0.62)	(1.27)	(1.21)	(1.29)	(0.19)
Dummy variable for services	–0.017 **	–0.017 **			–0.018 *		–0.032 **	–0.023
	(3.47)	(3.34)			(2.47)		(3.08)	(2.10)
Dummy variable for 1970–80	–0.010 #	–0.006	–0.012 #	–0.009				
	(1.89)	(0.95)	(1.74)	(1.05)				
Dummy variable for1980–90	0.003	0.007	0.009	0.011	0.012 #	0.008	0.005	
(or 1987–97)	(0.59)	(1.13)	(1.22)	(1.37)	(1.95)	(0.80)	(0.81)	
R^2	0.195	0.205	0.127	0.131	0.216	0.145	0.232	0.187
Adjusted R^2	0.171	0.174	0.098	0.092	0.178	0.078	0.201	0.129
Standard error	0.0249	0.0251	0.0280	0.0281	0.0286	0.0289	0.0267	0.0292
Sample size	132	132	93	93	88	42	88	44
Sample	All	All	Goods	Goods	All	Goods	All	All
Period	1960–90	1960–90	1960–90	1960–90	1970–90	1970–90	1977–97	1987–97

Note: The full sample consists of pooled cross-section time-series data, with observations on each of 44 industries in 1960–70, 1970–80, and 1980–90, or in 1977–87 and 1987–97 (sector 45, public administration, is excluded because of a lack of appropriate capital stock data). The goods sample consists of 31 industries (industries 1 to 31 in Appendix Table A.7.1.1). The coefficients are estimated using the White procedure for a heteroscedasticity-consistent covariance matrix. The absolute value of the t-statistic is in parentheses below the coefficient. See the Data Appendix for sources and methods. Significance levels: # –10% level; * –5% level; ** –1% level.

The coefficient of the growth of OCA is negative but not statistically significant. The same result holds for two alternative measures of IT, the growth in the stock of computers and the stock of OCACM (OCA plus Communications Equipment). As noted above, these specifications really measure the excess returns to computer investment over and above that to capital in general, since TFP growth already controls for the growth of total capital stock per worker. The coefficient of the dummy variable for service industries is significant at the one percent level. Its value is –0.017. The coefficient of the dummy variable for the 1970–80 period is negative (significant in one of the two cases) and that for the 1980–90 period is positive (but not significant).

Because of difficulties in measuring output in many service industries, regressions were also performed separately for the 31 good producing industries (see Appendix Table A.7.1.1).[8] The coefficient values and significance levels of the constant term, R&D intensity, the dummy variable for services, and the two time period dummy variables are strikingly similar to those for the all-industry regressions (see specifications 3 and 4 of Table 7.2). The coefficient of the growth in computer stock remains negative but insignificant (specification 4).[9]

In the next two regressions, I focus on the computer age, the period from 1970 onward. Does the effect of computerization on productivity growth now show up for this restricted sample? The answer is still negative, as shown in specifications 5 and 6 of Table 7.2. The coefficients of the other two computerization variables, the rate of growth in the stock of computers and that of OCACM, are also insignificant (results not shown). R&D intensity remains significant in these regressions, and the estimated return to R&D is higher, between 34% and 35%. The same results for computerization (and R&D investment) are found when the sample is further restricted to the 1980–90 period.

The seventh specification in Table 7.2 is based on a pooled sample of observations for the 1977–87 and 1987–97 periods,

[8] Since output measurement problems are less likely to affect transportation, communications, and utilities, they are classified as goods producing industries here.

[9] Results are again similar when the sample of industries is further restricted to the 20 manufacturing industries (results not shown).

while the eighth is restricted to the 1987–97 period. As before, the coefficient of the growth of OCA per worker is negative but not significant. Likewise, the coefficients of the rate of growth in the stock of OCACM per employee, and the rate of growth of computers per employee are insignificant (results not shown). In these regressions, the coefficient of R&D intensity remains significant but is somewhat lower (a range of 0.13 to 0.17), while the coefficient of the service dummy variable also stays significant but is higher in absolute value (a range of –0.23 to –0.032).

b. Other indicators of technological activity

In the next set of regressions, shown in Table 7.3, measures of structural change are used as dependent variables. As before, the statistical technique is based on pooled cross-section time-series regressions on industries and for the decades that correspond with the decennial Census data. The sample consists of 44 industries and 2 time periods (1970–80, and 1980–90).[10] The basic estimating equation is of the same form as equation (7.14), with R&D intensity and the growth of OCA stock as independent variables. Dummy variables are also included for the service sector and the 1970–80 period. Moreover, following (7.11), I also use the growth of OCA per worker and OCA investment per worker as independent variables in place of the growth of total OCA stock.

The first of the dependent variables is the change in occupational composition (*DIOCCUP*). In contrast to the TFP regressions, the coefficient of investment in OCA per worker is positive and significant at the one percent level in the regression without the service and time period dummy variables and positive and significant at the five percent level when the dummy variables are included. The coefficients of the alternative computerization measures, the growth in OCA per employee, investment in OCACM per worker, and the rate of growth in the stock of OCACM per employee, are also significant at the one or five percent level (results not shown). However,

[10] The 1950–60 and 1960–70 periods are not included in the regression analysis because OCA investment was very small during these time periods. The government sector, moreover, cannot be included because of a lack of data on OCA investment.

TABLE 7.3: Cross-industry regressions of indicators of structural change on computer investment

Independent Variables	Dependent Variable					
	DIOCCUP	*DIOCCUP*	*DIACOEFF*	*DIACOEFF*	*DIKCOEFF*	*DIKCOEFF*
Constant	0.048 **	0.055 **	0.001	–0.02 *	0.016 **	0.008
	(7.29)	(8.00)	(0.13)	(2.24)	(2.98)	(1.02)
Ratio of R&D expenditures to sales	0.251	0.214	0.136	0.309	0.206	0.129
	(1.10)	(0.97)	(0.59)	(1.57)	(1.17)	(0.71)
Investment in OCA per worker	0.060 **	0.048 *	0.043 **	0.024 **		
	(3.07)	(2.23)	(5.24)	(2.98)		
Initial level of OCA per worker					0.032 #	0.031 #
					(1.81)	(1.66)
Dummy variable for services		0.008		0.017		0.026 **
		(0.08)		(1.51)		(2.83)
Dummy variable for 1970–80		–0.021 *		–0.001		–0.007
		(2.30)		(0.12)		(0.89)
R^2	0.112	0.145	0.250	0.271	0.135	0.165
Adjusted R^2	0.091	0.104	0.223	0.227	0.104	0.114
Standard error	0.0470	0.0457	0.0429	0.0410	0.0339	0.0341
Sample size	88	88	88	88	88	88
Industries	All	All	All	All	All	All

Note: The sample consists of pooled cross-section time-series data, with observations on each of 44 industries (excluding the government sector) in 1970–80 and 1980–90. The coefficients are estimated using the White procedure for a heteroscedasticity-consistent covariance matrix. The absolute value of the t-statistic is shown in parentheses below the coefficient estimate.

Key:

DIOCCUP: dissimilarity index for occupational coefficients.

DIACOEFF: dissimilarity index for technical interindustry coefficients.

DIKCOEFF: dissimilarity index for capital coefficients.

Significant at the 10% level. * Significant at the 5% level. ** Significant at the 1% level.

the best fit is provided by investment in OCA per worker. The results also show that R&D intensity is not a significant explanatory factor in accounting for changes in occupational composition. Nor is the dummy variable for services. However, the time period dummy variable is significant at the five percent level.[11]

The second variable is *DIACOEFF*, a measure of the degree of change in inter-industry technical coefficients. In this case computerization is also significant at the one percent level with the predicted positive coefficient. The best fit is provided by investment in OCA per worker. The coefficient of R&D intensity is positive but not statistically significant, as is the coefficient of the dummy variable for services. The coefficient of the time dummy variable is virtually zero.

The third index of structural change is *DIKCOEFF*, a measure of how much the composition of capital has changed over the period. In this case, it is not possible to use investment in OCA as an independent variable, since by construction it will be correlated with changes in the capital coefficients. Instead, I use the initial level of OCA per worker. The computerization variable has the predicted positive sign and is significant, though only at the ten percent level. The coefficient of R&D is positive but insignificant. However, the dummy variable for services is positive and significant at the one percent level. The coefficient of the dummy variable for 1970–80 is negative but not significant.

In sum, computerization is found to be strongly linked to occupational restructuring and changes in material usage and weakly linked to changes in the composition of capital. With regard to the first result, it might be appropriate to say a few words about the construction of industry OCA by the Bureau of Economic Analysis. The allocation of investment in OCA is based partly on the occupational composition of an industry. As a result, a spurious correlation may be introduced between industry-level OCA investment and the skill mix of an industry. However, there is no indication that this allocation procedure should affect the change in occupational composition and hence introduce a spurious

[11] It is not possible to use changes in skill levels or education as independent variables, since, by definition, they would be associated with shifts in occupational composition.

correlation between OCA investment and the *DIOCCUP* variable. Moreover, the time-series evidence shows a marked acceleration in the degree of occupational change between the 1970s and 1980s, when OCA investment rose substantially. Regressions of the change in occupational composition (*DIOCCUP*) on the growth of equipment per worker and the growth of total capital per worker fail to yield significant coefficients. As a result, we can surmise that this finding is on reasonably solid ground.

7.6. Additional evidence of the effects of computerization on structural change

I next investigate the so-called downsizing of American business establishments in manufacturing, which has become a noteworthy topic in the press in recent years. Some have suggested that this process is connected with the rapid diffusion of IT over the last two decades.

I use the U.S. Census of Manufacturing on establishments over the 1967–97 period. According to the Census of Manufacturing data, the average establishment size for total manufacturing has fallen rather sharply over time, from 60.5 employees in 1967 to 45.7 employees in 1992, followed by a slight increase to 46.5 employees in 1997. The change has been fairly continuous over time, though it has accelerated a bit between 1987 and 1992. Over the 1967–92 period, the average establishment size has fallen at an average annual rate of 1.12%, and between 1987 and 1992 at an annual rate of 1.54%.

I next turn to regression analysis to see how computerization has affected changes in the size distribution of employment within manufacturing industries. I use a pooled cross-sectional data set, consisting of twenty two-digit industry observations in each of the six five-year time periods. This is essentially a fixed effect model, where the average establishment size of an industry is a function of the levels of these variables and an industry-specific effect. The regression uses the first difference of this equation (actually, the percentage change in mean establishment size on the industry level), so that the industry effect should wash out. The error terms are assumed to be independently distributed but may not be identically distributed and I use the White procedure for a heteroschedasticity-consistent covariance matrix in the estimation.

Results are shown in Table 7.4. I first look at the effects of the growth in computer stock per worker on industry level TFP growth. These new results are consistent with those based on the 45-sector sample (see Table 7.2) that computerization does not have a significant effect on TFP growth. In fact, the coefficients of the contemporaneous growth in the stock of OCA per worker and the growth in OCA per worker lagged one period are negative, though not statistically significant.

In the next regression, the dependent variable is the percentage change in average establishment size as derived from the Census of Manufacturing data. There is no evidence that OCA stock per worker increased more rapidly in industries that have downsized more. While the coefficient of the growth in total OCA per worker is positive, it is not significant (specification 3). The coefficient of TFP growth is actually positive, though not significant. However, industry R&D spending as a percentage of net sales has, as expected, a negative effect on the growth in mean establishment size, and its coefficient is significant at the one percent level. The most significant variable by far is the growth in industry employment. Its coefficient is positive and uniformly significant at the 0.1% significance level. When industry employment falls, average establishment size declines, and conversely.

The next four regressions focus on changes in the dispersion of employment among size classes by two-digit industry. We use the pooled cross-sectional data set from the Census of Manufacturing for 20 industry observations in 1967–72, 1972–77, 1977–82, 1982–87 and 1987–92.[12] The first dependent variable is the change in the Gini coefficient and the second is the change in the coefficient of variation. The only significant variable in these regressions is the growth in OCA per worker. Its coefficient is negative, indicating that greater investment in OCA leads to a smaller dispersion in employment by size class within an industry.

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[12] Employment distribution by size class for two-digit SIC manufacturing industries is not yet available for 1997.

TABLE 7.4: Cross-industry regressions of the size distribution of establishments on computer investment: manufacturing industries

Independent Variables	Dependent Variable						
	TFPGRTH	TFPGRTH	CHMEAN	CHGINI	CHCV	CHG20	CHG1000
Constant	0.034 **	0.025 **	–0.003	0.001	0.009	0.003	–0.008
	(3.08)	(2.90)	(0.19)	(0.19)	(0.16)	(0.08)	(0.96)
TFP growth			0.155	–0.006	0.052	0.044	0.079
			(0.64)	(0.06)	(0.01)	(0.69)	(0.58)
Ratio of industry R&D to sales	0.207 *	0.177 #	–1.063 **	0.037	0.243	–0.076	–0.281
	(2.11)	(2.11)	(2.11)	(0.28)	(19.00)	(0.87)	(1.49)
Growth in OCA per worker	–0.061		0.065	–0.097 **	–0.678 *	0.046 *	–0.084 #
	(1.39)		(0.77)	(3.14)	(2.25)	(2.13)	(1.93)
Growth in OCA per worker (1 period lag)		–0.022					
		(0.62)					
Growth in total industry employment			2.540 **				
			(6.38)				
Period dummies	Yes	Yes	No	No	No	No	No
R^2	0.181	0.170	0.287	0.101	0.054	0.053	0.129
Adjusted R^2	0.130	0.118	0.261	0.730	0.040	0.230	0.090
Standard error	0.0342	0.0344	0.0899	0.0309	0.3014	0.0205	0.0282
Sample size	120	120	116	100	100	100	100

Note: The sample consists of pooled cross-section time-series data, with observations on each of the 20 manufacturing industries in 1967–72, 1972–77, 1977–82, 1982–1987, and 1987–92. The TFPGRTH regressions also include the 20 industries for 1992–97. The CHGMEAN regression includes 16 industries for 1992–97. The coefficients are estimated using the White procedure for a heteroscedasticity-consistent covariance matrix. The absolute value of the t-statistic is shown in parentheses below the coefficient estimates. The variables are computed from the Census of Manufacturing. Key:

1) CHMEAN: Percentage change in the mean number of employees per establishment.
2) CHGINI: Change in the Gini coefficient for the average number of employees per establishment by industry size class.
3) CHCV: Change in the coefficient of variation for the average number of employees per establishment by industry size class.
4) CHG20: Change in the percentage of employment in size classes 19 or less.
5) CHG1000: Change in the percentage of employment in size classes 1000 or more.

Significant at the 10% level. * Significant at the 5% level. ** Significant at the 1% level.

Since OCA investment is not a significant determinant of downsizing but does have a significant effect on overall dispersion, it is possible that its main effects are to reduce the share of employment in small and large establishments. However, as we see in the last two columns of Table 7.4, the growth of OCA per worker actually has a positive and significant effect on the share of total employment in establishments of 19 employees or less. On the other hand, the growth in OCA per worker is negatively and significantly associated with the share of employment in establishments of 1,000 employees or more. As in the case of changes in overall dispersion, none of the other variables is statistically significant.

7.7. Conclusion and interpretation of results

Two sets of findings emerge from the regression analysis. First, there is no evidence that computer investment is positively linked to TFP growth, at least during the periods I examine. In other words, there is no residual correlation between computer investment and TFP growth over and above the inclusion of OCA as normal capital equipment in the TFP calculation. This result holds not only for the 1960–90 period but also for the 1970–90, 1980–90, 1977–97 and 1987–97 periods. The result also holds among exclusively goods-producing industries and among exclusively manufacturing industries. This finding is not inconsistent with recent work on the subject. Oliner and Sichel (2000), for example, found a strong effect of computers on productivity growth only beginning in the mid-1990s, which is beyond my period of analysis.

Second, in contrast, computerization is strongly and positively associated with other dimensions of structural change. These include occupational restructuring and changes in the composition of intermediate inputs, as well as changes in the overall dispersion of the size distribution of establishments within manufacturing. The evidence is a bit weaker for its effects on changes in the composition of industry capital stock.

The bottom line is that the diffusion of IT appears to have shaken up the U.S. economy, beginning in the 1970s. However, it is a technological revolution that shows up more strongly in measures of structural change than in terms of productivity, if the previous literature is a good guide on the latter issue. In particular, the strongest results of the effects of OCA on productivity growth are found for the late 1990s in the U.S. My results seem to indicate that OCA had strong effects on changes in occupational composition and input structure dating from the early 1970s.

These two sets of results might reflect the high adjustment costs associated with the introduction of new technology. The paradigmatic shift from electromechanical automation to information technologies might require major changes in the organizational structure of companies before the new technology can be realized in the form of measured productivity gains (see David 1991, for greater elaboration of this argument). The results on computerization are also consistent with an alternative interpretation of its role in modern industry. The argument is that a substantial amount of new technology (particularly IT) may be used for product differentiation rather than productivity enhancement. Computers allow for greater diversification of products, which in turn also allows for greater price discrimination (e.g., airline pricing systems) and the ability to extract a large portion of consumer surplus. Greater product diversity might increase firm profits, though not necessarily its productivity. Some evidence on the product differentiation effects of computers is provided by Chakraborty and Kazarosian (1999) for the U.S. trucking industry (for example, speed of delivery versus average load).

References

ATROSTIC, Barbara K., John GATES, and Ron JARMIN. *Measuring the Electronic Economy: Current Status and Next Steps.* Working Paper CES-01-11. Washington, DC: Center for Economic Studies, U.S. Bureau of the Census, 2000.

BAILY, Martin N., and Robert J. GORDON. "The Productivity Slowdown, Measurement Issues, and the Explosion of Computer Power." *Brookings Papers on Economic Activity* 2 (1988): 347–420.

BAILY, Martin N., and Robert LAWRENCE. *Do we have a New E-conomy?* NBER Working Paper no. 8243. Cambridge, MA: National Bureau of Economic Research, 2001.

BAUMOL, William J., Sue A. BATEY BLACKMAN, and Edward N. WOLFF. *Productivity and American Leadership: The Long View.* Cambridge, MA: MIT Press, 1989.

BERNDT, Ernst R., and Catherine J. MORRISON. "High-tech Capital Formation and Economic Performance in U.S. Manufacturing Industries. An exploratory analysis." *Journal of Econometrics* 65, no. 1 (1995): 9–43.

BRESNAHAN, Timothy F., and Manuel TRAJTENBERG. "General Purpose Technologies: Engines of Growth?" *Journal of Econometrics* 65, no. 1 (1995): 83–108.

BRYNJOLFSSON, Erik, and Lorin HITT. "Computers and Productivity Growth: Firm-Level Evidence." Mimeo, MIT Sloan School, July 1996.

—. "Information Technology and Organizational Design: Evidence from Micro Data." Mimeo, MIT Sloan School, January 1998.

CHAKRABORTY, Atreya, and Mark KAZAROSIAN. "Product Differentiation and the Use of Information Technology: New Evidence from the Trucking Industry." NBER Working Paper no. 7222. Cambridge, MA: National Bureau of Economic Research, 1999.

DAVID, Paul. "Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror." In OECD, ed. *Technology and Productivity: The Challenge for Economic Policy.* Paris: Organisation for Economic Co-operation and Development 1991, 315–48.

FRANKE, Richard H. "Technological Revolutions and Productivity Decline: The Case of U.S. Banks." In Tom Forester, ed. *Computers in the Human Context: Information Technology, Productivity, and People*, Cambridge, MA: MIT Press, 1989, 281–90.

GRILICHES, Zvi. "Issues in Assessing the Contribution of Research and Development to Productivity Growth." *Bell Journal of Economics* 10, no. 1 (Spring 1979): 92–116.

—. "R&D and the Productivity Slowdown." *American Economic Review* 70, no. 2 (May 1980): 343–48.

—. "The Search for R&D Spillovers." *Scandinavian Journal of Economics* 94 (1992): 29–47.

HUBBARD, Thomas N. *Information, Decisions, and Productivity: On-Board Computers and Capacity Utilization in Trucking.* NBER Working Paper no. 8525. Cambridge, MA: National Bureau of Economic Research, 2001. (Later published in *American Economic Review* 93 [September 2003]: 1328–53.)

JORGENSON, Dale W., and Kevin J. STIROH. "Information Technology and Growth." *American Economic Review* 89, no. 2 (May 1999): 109–15.

—. "Raising the Speed Limit: U.S. Economic Growth in the Information Age." *Brookings Papers on Economic Activity* 1 (2000): 125–211.

LAWSON, Ann M. "Benchmark Input-Output Accounts for the U.S. Economy, 1992." *Survey of Current Business* 77, no. 11, Washington, DC: Bureau of Economic Analysis, (November 1997): 36–83.

LEHR, William, and Frank R. LICHTENBERG. "Computer Use and productivity Growth in US Federal Government Agencies, 1987–92." *Journal of Industrial Economics* 46, no. 2 (June 1998): 257–79.

—. "Information technology and its impact on productivity: firm-level evidence from government and private data sources, 1977–1993." *Canadian Journal of Economics* 32, no. 2 (April 1999): 335–62.

LICHTENBERG, Frank R. "The Output Contribution of Computer equipment and Personnel: A Firm Level Analysis." *Economics of Innovation and New Technology* 3, no. 4 (1995): 201–17.

LOVEMAN, Gary W. "An Assessment of the Productivity Impact of Information Technologies." In *Management in the 1990s.* Cambridge, MA: MIT Press, 1988.

MANSFIELD, Edwin. "Rates of Return from Industrial Research and Development." *American Economic Review* 55, no. 2 (May 1965): 310–22.

—. "Basic Research and Productivity Increase in Manufacturing." *American Economic Review* 70, no. 5 (December 1980): 863–73.

MINCER, Jacob A. "Schooling, Experience, and Earnings." University Microfilms, Studies in Human Behavior and Social Institutions no. 2, National Bureau of Economic Research, New York, 1974.

MOHNEN, Pierre A. *The Relationship between R&D and Productivity Growth in Canada and Other Major Industrialized Countries.* Ottawa: Canada Communications Group, 1992.

NATIONAL SCIENCE FOUNDATION. *Research and Development in Industry.* NSF96-304. Arlington: National Science Foundation, 1996.

OLINER, Stephen D., and Daniel E. SICHEL. "Computers and Output Growth Revisited: How Big is the Puzzle?" *Brookings Papers on Economic Activity* 2 (1994): 273–334.

—. "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Proceedings*, Federal Reserve Bank of San Francisco, February 2000. Also available online at http://www.frbsf.org/economics/conferences/000303/papers/resurgence.pdf. (Also published in *Journal of Economic Perspectives* 14, no. 4 [2000]: 3–22.)

PARSONS, Darrell, Calvin. C. GOTLIEB, and Michael DENNY. "Productivity and Computers in Canadian Banking." *Journal of Productivity Analysis* 4 (June 1993): 95–113.

SIEGEL, Donald. "The Impact of Computers on Manufacturing Productivity Growth: A Multiple-Indicators, Multiple-Causes Approach." *Review of Economics and Statistics* 79, no. 1 (1997): 68–78.

SIEGEL, Donald, and Zvi GRILICHES. "Purchased Services, Outsourcing, Computers, and Productivity in Manufacturing." In Zvi Griliches, ed. *Output Measurement in the Service Sector.* Chicago: University of Chicago Press, 1992.

STEINDEL, Charles. "Manufacturing Productivity and High-Tech Investment." *Quarterly Review* 17, Federal Reserve Bank of New York (December 1992): 39–47.

STIROH, Kevin J. "Computers, Productivity, and Input Substitution." *Economic Inquiry* 36, no. 2 (April 1998): 175–91.

—. "Are ICT Spillovers Driving the New Economy?" *Review of Income and Wealth* 48, no. 1 (March 2002): 33–57.

TRIPLETT, Jack E., and Barry BOSWORTH "Productivity in the Services Sector." Paper prepared for the American Economic Association meeting, January 9, 2000. Available online at http://www.brookings.edu/views/papers/triplett/20000112.pdf.

U.S. BUREAU OF ECONOMIC ANALYSIS. *Fixed Reproducible Tangible Wealth of the United States, 1925–27.* Washington, DC: Bureau of Economic Analysis, 1999. CD-ROM NCN-0229.

WOLFF, Edward N. "Productivity Growth, Capital Intensity, and Skill Levels In the U.S. Insurance Industry, 1948–86." *Geneva Papers on Risk and Insurance* 16, no. 59 (April 1991): 173–90.

—. "Technology and the Demand for Skills." *OECD Science, Technology and Industry Review* 18 (1996): 96–123.

Appendix 7.1. Data

1. NIPA (National Income and Product Accounts) employee compensation: figures are from the NIPA, available on the Internet. Employee compensation includes wages and salaries and employee benefits.
2. NIPA employment data: FTE (Full-Time Equivalent Employees) equals the number of employees on full-time schedules plus the number of employees on part-time schedules converted to a full-time basis. FTE is computed as the product of the total number of employees and the ratio of average weekly hours per employee for all employees to average weekly hours per employee on full-time schedules. PEP equals the number of full-time equivalent employees plus the number of self-employed persons. Unpaid family workers are not included.
3. Capital stock figures are based on chain-type quantity indices for net stock of fixed capital in 1992 dollars, year-end estimates. OCA investment data are available for the private (non-government) sector only. *Source:* U.S. Bureau of Economic Analysis (1999).
4. Research and development expenditures performed by industry include company, federal and other sources of funds. Company-financed R&D performed outside the company is excluded. Industry series on R&D and full-time equivalent scientists and engineers engaged in R&D per full-time equivalent employee run from 1957 to 1997. *Source:* National Science Foundation, Internet. (For technical details, see National Science Foundation, 1996).
5. The original input-output data are 85-sector U.S. input-output tables for years 1947, 1958, 1963, 1967, 1972, 1977, 1982, 1987, 1992, and 1996 (see, for example, Lawson 1997, for details on the sectoring). The 1947, 1958, and 1963 tables are available only in single-table format. The 1967, 1972, 1977, 1982, 1987, 1992, and 1996 data are available in separate make and use tables. These tables have been aggregated to 45 sectors for conformity with the other data

sources. The 1950, 1960, 1970, 1980, and 1990 input-output tables are interpolated from the benchmark U.S. input-output tables.

TABLE A.7.1.1: 45-Sector industry classification scheme

	Industry	1987 SIC Codes
1	Agriculture, forestry, and fishing	01–09
2	Metal mining	10
3	Coal mining	11, 12
4	Oil and gas extraction	13
5	Mining of nonmetallic minerals, except fuels	14
6	Construction	15–17
7	Food and kindred products	20
8	Tobacco products	21
9	Textile mill products	22
10	Apparel and other textile products	23
11	Lumber and wood products	24
12	Furniture and fixtures	25
13	Paper and allied products	26
14	Printing and publishing	27
15	Chemicals and allied products	28
16	Petroleum and coal products	29
17	Rubber and miscellaneous plastic products	30
18	Leather and leather products	31
19	Stone, clay, and glass products	32
20	Primary metal products	33
21	Fabricated metal products, including ordnance	34
22	Industrial machinery and equipment, exc. electrical	35
23	Electric and electronic equipment	36
24	Motor vehicles and equipment	371
25	Other transportation equipment	37 [exc. 371]
26	Instruments and related products	38
27	Miscellaneous manufactures	39
28	Transportation	40–42, 44–47
29	Telephone and telegraph	481, 482, 484, 489
30	Radio and TV broadcasting	483
31	Electric, gas, and sanitary services	49
32	Wholesale trade	50–51
33	Retail trade	52–59
34	Banking, credit and investment companies	60–62,67
35	Insurance	63–64
36	Real estate	65–66
37	Hotels, motels, and lodging places	70
38	Personal services	72
39	Business and repair services except auto	73,76
40	Auto services and repair	75
41	Amusement and recreation services	78–79
42	Health services, including hospitals	80
43	Educational services	82
44	Legal and other professional services and non-profit organizations	81, 83, 84, 86, 87, 89
45	Public Administration	—

8. The Contribution of ICT to Economic Activity: A Growth Accounting Exercise with Spanish Firm Level Data[1]

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THIS paper applies a well-established growth accounting framework to measure the contribution of ICT (Information and Communication Technologies) inputs to output and labor productivity growth in Spain, using a sample of 1,300 firms per year over the period 1991–2000. Firm level data are helpful to overcome the availability lags and the mis-measurement of capital stocks associated with the use of aggregate data. The main findings are: 1) The use of ICT inputs has made a positive and, relative to its cost share, significant contribution to output and productivity growth. 2) This contribution was higher in the second half of the 1990s. 3) At a sectoral level, there is a general rise in the share of ICT in total capital and a general reduction in ICT cost shares.

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[2] Soledad Núñez was working at the Bank of Spain at the time this article was written.

8.1. Introduction

Over the last decade, there has been enormous technical progress in the ICT industries. These efficiency gains have driven down the relative prices of computers, software and communications equipment and have significantly stimulated the demand for these types of goods. As a consequence, the ICT producing industries have experienced, at least in some economies, unprecedented growth rates and have contributed to the acceleration of TFP (Total Factor Productivity) growth. Furthermore, the impact of technical advances in ICT on economic activity goes beyond the direct impact on ICT producing industries. A potentially strong impact stems from the adoption and use of new technologies in most sectors of the economy. In this respect, the reduction in the prices of ICT capital goods encourages the accumulation of this type of input. Consequently, the diffusion of ICT as a capital input might have contributed significantly to output and labor productivity growth. Finally, an additional contribution of ICT to growth may arise from an acceleration of TFP growth due to efficiency enhancing effects arising from the production and adoption of ICT.

However, the empirical assessment of the role of ICT in economic activity poses considerable statistical problems. Firstly, the relevant information is not available on a timely basis. In the case of Spain, sectoral information is available only with a four-year lag. Secondly, detailed breakdowns of capital and investment are not usually accessible. Thirdly, significant measurement problems arise from the difficulty of constructing adequate price indices and of calculating economic depreciation for ICT capital goods. Given these data limitations, the use of firm level data, though they do not solve all measurement problems, represents a promising avenue and it is that which we explore in this paper.

Our objective is to examine the relationship between the use of ICT as a capital input and the recent performance of productivity growth in Spain. Therefore, rather than analyzing the contribution of ICT producing industries to economic development we adopt an input-oriented approach that focuses on the role of ICT as a capital input in all sectors of the economy. For this purpose, using a standard growth accounting framework, we estimate the contributions to output and productivity growth from the use of the different inputs, ICT among them. This analytical framework has already been used to estimate, with aggregate information, the growth contribution from the use of ICT capital in the U.S. and other industrialised economies (Oliner and Sichel [2000], Schreyer [2000], Colecchia and Schreyer [2001] and Daveri [2001]).[3] In this paper, we conduct the analysis using firm level data. More precisely, we make use of a sample of Spanish firms over the period 1991–2000 obtained from the Central Balance Sheet Office of the Bank of Spain. The final sample includes about 1,300 firms per year and it provides information for sufficiently detailed breakdowns of capital.

By conducting the analysis at the firm level, we reduce difficulties arising from mis-measurement of capital stocks. As potential additional advantages, the use of individual data would allow the distinctive features of the financial structure of technology-intensive firms to be identified and offers some pointers to the factors influencing the effect of ICT capital on productivity growth. Nevertheless, the individual data also entail some problems. Capital stock figures have to be converted from book value to market value. Next, sample coverage in terms of value-added and employment is, for a few sectors, low. Further, the sample we use is definitely biased towards large firms. Our sample does not enable us to consider labor quality as a contributing factor to growth. Given these drawbacks, our results should be viewed with some caution.

Although we use individual firm data, our main objective is to derive some general conclusions about the ICT contribution to growth for the whole non-financial market economy. For this purpose, we first obtain sectoral figures (we consider 17 sectors) by averaging firms' behavior by sector. We implicitly assume that the average performance of the firms in the sample is representative of the sector they belong to. We then obtain aggregate figures

[3] Most of the estimates of the contribution of ICT inputs to output growth concern the U.S. economy. Additional references are Jorgenson and Stiroh (2000) and Whelan (2000).

by averaging sectoral results, weighting them by their share in the whole market economy. We check that our conclusion about the ICT contribution to growth for the aggregate economy is robust with regard to alternative procedures of aggregation of the individual ICT contributions.

Our results suggest that the ICT contribution to growth and ICT capital accumulation rates have been relatively significant, although quantitatively smaller than in the U.S. According to Oliner and Sichel (2000), over the period 1996–99 ICT capital deepening explained almost one-quarter of each percentage point of U.S. output growth, while this figure was around 0.10 percentage points for the Spanish case in the second half of the nineties (1996–2000). Over the period 1996–99, these authors report U.S. annual growth rates for hardware and software of about 21% and 13%, respectively. The corresponding growth rates for the Spanish economy were 12% and 9%, respectively. These growth rates can be considered as low if we take into account that there is a most sizeable gap between U.S. and Spain in terms of ICT capital deepening.

To our knowledge, in the Spanish case only Daveri (2001) has analyzed the growth impact of ICT accumulation within a growth accounting framework. Compared with our findings, Daveri reports a similar ICT contribution for the whole period considered, but a lower one for the second half of the nineties.[4] Nevertheless, there are some substantial differences between Daveri's study and the one presented here. First, Daveri assumes perfect competition, computing the contribution to growth of factor inputs in terms of income shares, while we relax this assumption and compute these contributions in terms of cost shares. Second, he uses aggregate data from a very different data set (ICT expenditure taken from WITSA [World Information Technology and Services Alliance]/IDC [International Data Corporation] and National Accounts OECD [Organisation for Economic Co-operation and Development] series).

The rest of the paper is organized as follows: section 8.2 describes the analytical framework. Section 8.3 introduces our

[4] Thus, for the period 1991–99, Daveri reports an annual ICT contribution to output growth of 0.36 percentage points. In this paper the corresponding figure is 0.35 p.p. However, for the period 1996–99 Daveri finds an ICT contribution of 0.34 p.p., while we find a corresponding figure of 0.42 p.p.

database, paying special attention to the description of the price indices for capital inputs and to the construction of the capital stocks and the user costs of the capital inputs. A more detailed description of the sample and the definition of variables are given in Appendix 8.1. Section 8.4 presents the results for the whole economy, as well as for the 17 sectors considered. Finally, section 8.5 offers a conclusion.

8.2. The analytical framework: Neoclassical growth accounting

In this paper we apply the neo-classical growth accounting framework developed originally by Solow (1957). This framework has been extensively applied in other studies on the ICT contribution to growth, such as Oliner and Sichel (2000), Jorgenson and Stiroh (2000), Schreyer (2000), Daveri (2000), among others. Our main departures from these authors are twofold. First, we use individual firm data, and second, following R. E. Hall (1990) we do not impose perfect competition.[5]

We start from a Cobb-Douglas production function (F) that relates firm value-added (Q) to seven inputs: labor (L), software (K_{sw}), hardware (K_{hw}), non-residential buildings (K_{bld}), industrial equipment (K_{ieq}), other equipment and furniture (K_{oeq}) and transportation equipment (K_{trp}).[6] Thus:

$$Q = \theta \ F(L, K_{sw}, K_{hw}, K_{bld}, K_{ieq}, K_{oeq}, K_{trp})$$

where we assume that F displays constant returns to scale in factor inputs.

Computing growth rates:

$$\Delta q = \Delta\theta + \frac{L}{Q}\frac{\partial F}{\partial L}\Delta l + \sum_i \frac{K_i}{Q}\frac{\partial F}{\partial K_i}\Delta k_i \qquad (8.1)$$

$i = sw, hw, bld, ieq, oeq, trp$

[5] Given that we use individual data on a yearly basis, we consider this strategy more appropriate.

[6] These are the breakdowns of capital that are available in our database.

where lower case letters correspond to the logarithms of the corresponding upper-case variables. The term θ captures output growth not accounted for by changes in factor inputs, and approximates TFP.

First order conditions for cost minimization are:

$$\frac{\partial F}{\partial K_i} = \frac{r_i}{mc} \qquad \text{and} \qquad \frac{\partial F}{\partial L} = \frac{w}{mc} \tag{8.2}$$

where r_i is the rental price of capital i and w is the labor market wage. Given that, with constant returns, marginal cost (mc) is equal to average cost at the cost minimization value of inputs, we can write:

$$\frac{\partial F}{\partial L} = \frac{w\,Q}{w\,L + \sum r_i\ k_i} \tag{8.3}$$

and

$$\frac{\partial F}{\partial K_i} = \frac{r_i\ Q}{w\,L + \sum r_i\ k_i} \tag{8.4}$$

Some simple algebra leads to:

$$\frac{\partial F}{\partial L} = \frac{w\ L}{w\,L + \sum r_i\ k_i}\ \frac{Q}{L} = \alpha_L\ \frac{Q}{L} \tag{8.5}$$

$$\frac{\partial F}{\partial K_i} = \frac{r_i\ K_i}{w\,L + \sum r_i\ k_i}\ \frac{Q}{K_i} = \alpha_{K_i}\ \frac{Q}{K_i} \tag{8.6}$$

where α_i is the cost share of input i. Substituting (8.5) and (8.6) in (8.1):

$$\Delta q = \sum_i \alpha_{k_i}\ \Delta k_i\ + \alpha_L\ \Delta l + \Delta TFP \tag{8.7}$$

In equation (8.7), each input's contribution is obtained by multiplying its rate of change by each factor's share in total cost (α_i).[7] In computing the cost shares, we introduce the assumption

[7] An alternative approach would be to estimate the parameters of the production function. Although such an approach does not require the introduction of the neo-classical assumptions, it requires assuming the homogeneity of the parameters of the production function, at least, across sectors.

that all types of capital earn the same competitive rate of return at the margin, net of depreciation and capital gains or losses implied by the changes in the prices of capital goods. Thus, we are assuming that firms allocate resources efficiently. To impose the same rate of return for all capital assets implies a very high gross rate of return for ICT to offset the rapid depreciation and the capital losses arising from the decline in ICT prices.

Grouping terms in equation (8.7) yields:

$$\Delta q = c_l + c_{ITC} + c_{OTHER\,K} + \Delta TFP \tag{8.8}$$

where c_l is the contribution of the labor input to value-added growth, c_{ICT} is the contribution of ICT capital and $c_{OTHER\,K}$ is the contribution of non-ICT capital, being:

$$c_l = \alpha_l \ \Delta l \tag{8.9}$$

$$c_{ITC} = \alpha_{sw} \ \Delta k_{sw} + \alpha_{hw} \ \Delta k_{hw} \tag{8.10}$$

$$c_{OTHER\,K} = \alpha_{bld} \ \Delta k_{bld} + \alpha_{ieq} \ \Delta k_{ieq} + \alpha_{oeq} \ \Delta k_{oeq} + \alpha_{trp} \ \Delta k_{trp} \tag{8.11}$$

Alternatively, by rearranging equation (8.7) we can obtain a similar decomposition for labor productivity growth:

$$\Delta q - \Delta l = cl_{ITC} + cl_{OTHER\,K} + \Delta TFP \tag{8.12}$$

where

$$cl_{ITC} = \alpha_{sw} \ (\Delta k_{sw} - \Delta l) + \alpha_{hw} \ (\Delta k_{hw} - \Delta l) \tag{8.13}$$

$$\begin{aligned} cl_{OTHER\,K} &= \alpha_{bld} \ (\Delta k_{bld} - \Delta l) + \alpha_{ieq} \ (\Delta k_{ieq} - \Delta l) + \\ &+ \alpha_{oeq} \ (\Delta k_{oeq} - \Delta l) + \alpha_{trp} \ (\Delta k_{trp} - \Delta l) \end{aligned} \tag{8.14}$$

According to this expression, growth in labor productivity is (increase in the amount of capital per unit of labor) and by the growth rate of TFP.

The neoclassical growth accounting framework provides a simple analysis of the proximate sources of economic growth. It decomposes the growth rate of output into the sum of two factors: the rate of increase of inputs and the multifactor productivity growth.

This framework represents a limited approach to understanding the process of economic growth. It does not adequately explain the underlying factors driving the substitution processes between factors or the causes behind the growth of TFP.

In our case, we calculate each component of equations (8.8) and (8.12) (that is, the value-added growth rate, factor input contributions and the TFP growth rate) for each company in the sample. To obtain the components of equations (8.8) and (8.12) for the total non-financial market economy from the components computed at the firm level we take two additional steps.

First, we average these components by sector. For the sake of robustness, in this step we consider two alternative sectoral breakdowns (the National Accounts sectoral breakdown into 71 industries and the breakdown into 17 sectors used in Estrada and López-Salido [2001])[8] and we use two methods of aggregation: (i) we compute the sectoral contributions as simple averages of the individual ones; and (ii) we add up the individual data for value-added and productive inputs and then obtain the sectoral contributions.[9]

Second, we obtain the figures for the total non-financial market economy by taking the average of the sectors for each component, the sectors being weighted by their share in total value-added. Sectoral weights are calculated using data taken from Estrada and López-Salido (2001) in the case of the 17-sector breakdown and from the National Accounts in the case of the 71-sector breakdown.[10]

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[8] Estrada and López-Salido (2001) construct a database on a yearly basis, using National Accounts, with information on several economic variables for 17 sectors, excluding the non-market economy and financial sector, for the period 1980–99. The use of this breakdown of the market economy into 17 sectors was determined by the availability of this database.

[9] In Appendix 8.2 we discuss the choice of the aggregation method and we present the results for the alternative procedures of aggregation of the information computed at the individual level.

[10] In the case of the 71-sector breakdown, since sectoral data from ESA95 (European National Accounts 1995) is only available for the period 1995–97, we use 1995 weights for period 1992–95 and 1997 weights for the period 1996–2000. In order to obtain annual variation for these weights, we have corrected them with the weights for the 17 sectors considered in Estrada and López-Salido (2001).

8.3. The data

From the previous section, the contribution of each type of capital to output growth depends on its cost share and on its accumulation rate. The validity of this exercise depends on the accurate measurement of two elements: the capital stocks and their user costs. Before describing the method of construction of these two elements, we discuss our choice of price indices for capital inputs as these are an essential component in the computation of the capital stocks and the user costs.

Price indices for capital inputs

The choice of an appropriate deflator for capital inputs is crucial for the measurement of the capital stocks and the computation of the user costs. This task is particularly delicate in the case of ICT capital goods. Most of these ICT capital goods have undergone significant quality changes that if not properly taken into account, will lead to an overestimation of the price change in ICT capital goods and to an underestimation of the corresponding capital stocks. The use of price indices for ICT capital goods based on the application of hedonic techniques seems to be an essential tool to break down the change in the nominal capital stocks into their price and quantity components.

Given that for the Spanish economy there is no price index for ICT goods in constant quality terms,[11] we apply an indirect approach—based on Schreyer (2000)—to obtain an adequate ICT deflator. Schreyer constructs the ICT price deflator for a given country in such a way that the difference between the ICT price change and the price change in all other investment goods for that country is equal to the difference between the same price changes for the U.S. economy. We closely follow Schreyer's methodology and compute the price deflator for capital input i (P_i) by assuming that the ratio of the deflator of capital input i to the GDP (Gross Domestic Product) deflator in Spain is the same as the corresponding ratio in

[11] Izquierdo and Matea (2001) provide a series of hedonic prices for personal computers in Spain. We have not used this series because personal computers are just one product among those included in our hardware category.

the U.S. We have applied this procedure for deflation to ICT capital inputs: hardware and software.

To test the sensitivity of the results to the choice of deflator for the ICT capital inputs we have alternatively used a set of price indices for these inputs taken directly from Spanish official statistical sources. Graph 8.1 displays the time profile of the deflators for the capital inputs. In particular it provides a comparison between the two sets of deflators for the ICT inputs.[12] In the case of hardware, the index computed using U.S. deflators shows a significantly more pronounced decline. This result clearly shows to what extent failure to take into account the quality changes in these ICT goods introduces a serious bias in the estimation of their price changes. Using Spanish statistical sources, we are unable to obtain a deflator for software. As this graph makes clear, using a common deflator for hardware and software is highly misleading.

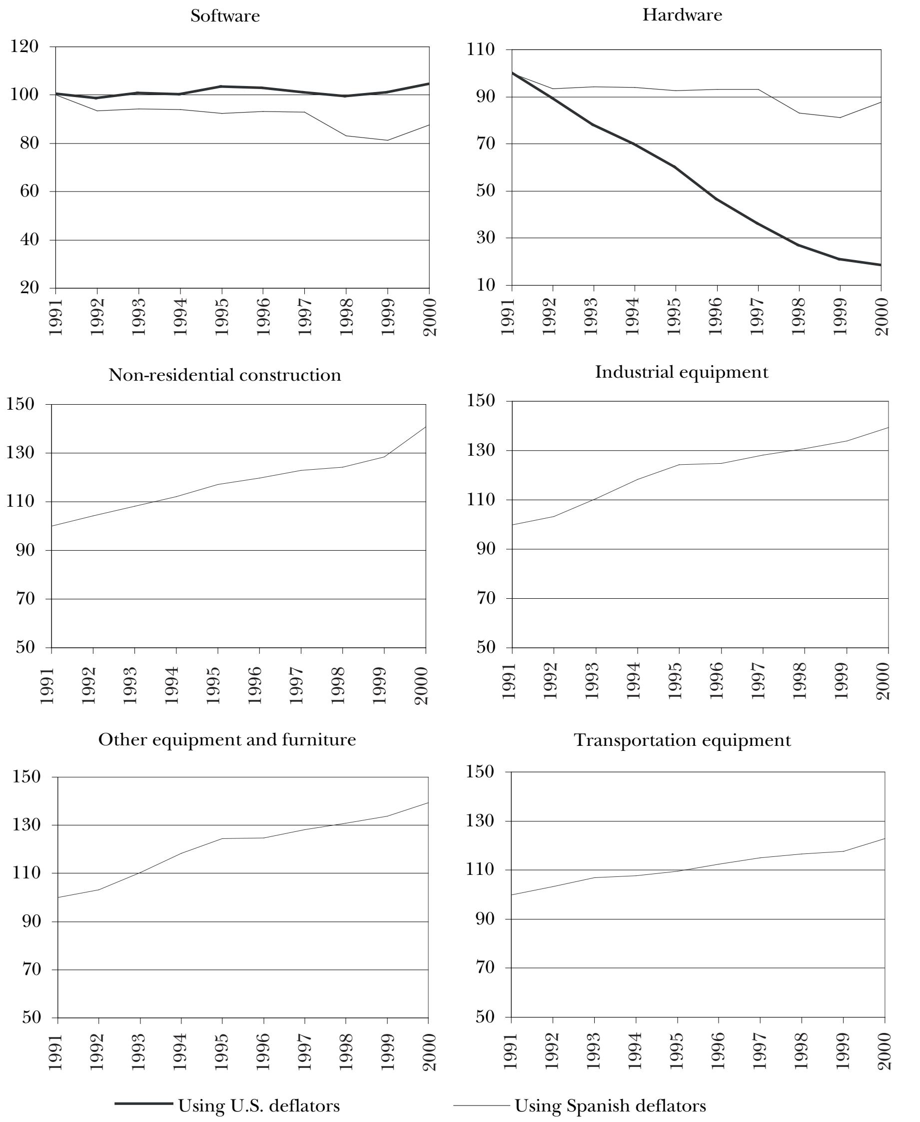
Capital stocks

Our database provides accounting data corresponding to the six types of capital assets already mentioned: software (K_{sw}), hardware (K_{hw}), non-residential buildings (K_{bld}), industrial equipment (K_{ieq}), other equipment and furniture (K_{oeq}) and transportation equipment (K_{trp}). It should be stated that in our sample, software capital comprises successful R&D (Research and Development) investment and hardware capital includes communications equipment. In this paper we construct measures of the capital stocks using this accounting information. More precisely, we have information on the net book value (at historic prices) of the six types of capital and we can construct the average age of each capital item (as the two-year average of the ratio of total accumulated depreciation to current depreciation). Using the price indices for investment goods already described, the book values of the capital stocks and their average ages, we can obtain the value of the capital stocks at constant and current prices.[13] We apply this procedure to all the observations for each firm. An alternative approach to this procedure would be the perpetual inventory method, which combines the information

[12] See Appendix 8.1 for the detailed definition of both sets of price deflators.

[13] We essentially apply the same methodology as in B. H. Hall (1990). Further details on the computation of the capital stocks are given in Appendix 8.1.

GRAPH 8.1: **Price deflators for investment goods**



on the capital stock at constant prices in an initial year with information on investment volumes for the subsequent years.[14]

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[14] Unfortunately, the lack of sufficiently detailed breakdowns of investment prevents us from adopting this standard approach in the construction of capital stocks.

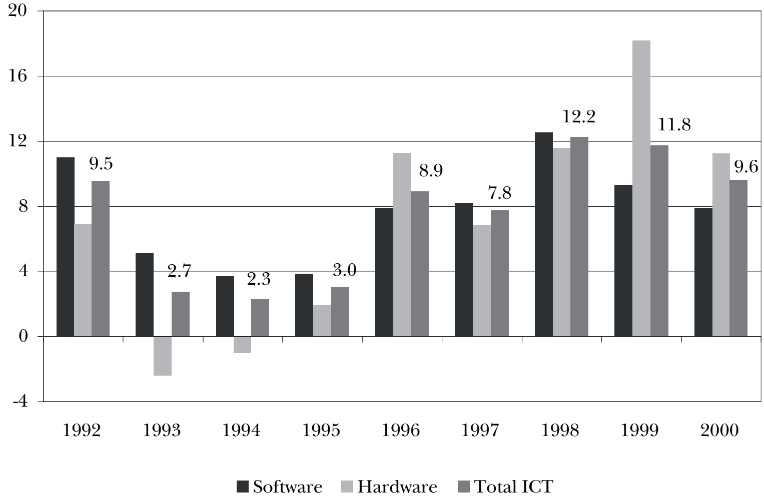
As already stated, the availability of micro-level information has undeniable advantages for the purpose of this paper. The use of accounting data to obtain measures of capital stocks also has some limitations. In particular, given that the available information is on the book value (net of economic depreciation) of fixed capital we are constrained to construct wealth measures of the capital stocks, i.e., measures of the market value of the assets of the firm. However, as is thoroughly discussed in Oliner and Sichel (2000) and Schreyer (2000), the relevant measure of capital inputs for a growth accounting exercise is that provided by the productive stocks of the inputs, that is, the productive capacity of the stock. In other words, the productive stocks take into account the physical decay of the assets whereas the wealth stocks reflect the economic depreciation. For most of the capital assets, these concepts are related but this is not the case for computers. Computers experience very little physical decay but they suffer a very high economic depreciation, as they have a very short life-cycle. As we are constrained to use a wealth measure for the capital stocks, our estimates of the growth contributions of ICT capital assets (for which the difference between the productive and the wealth stock is relevant) will be biased downwards.

Graph 8.2 shows the growth rates of the ICT (types K_{sw} and K_{hw}) capital stocks at constant prices and the changes in the ratio of ICT capital to total capital. Both these ICT capital goods have experienced much higher growth rates than those for non-ICT capital. As a consequence, the share of ICT capital goods in the total capital stock has steadily increased over the period considered and this accumulation process has substantially accelerated in the second half of the decade. The weight of ICT capital in the total capital stock was almost 11% in 2000, twice the corresponding figure for 1992 (5.2%). This process has been similarly intense for software (its weight in the total capital stock has risen from 1.5% to 3.1%) and for hardware (from 3.7% to 7.8%). These figures suggest that a strong process of substitution of ICT capital for other types of capital input has taken place, mainly driven by the sharp downward trend in the prices of ICT inputs.

GRAPH 8.2: ICT capital inputs (whole economy)

a) Growth rates of ICT capital inputs

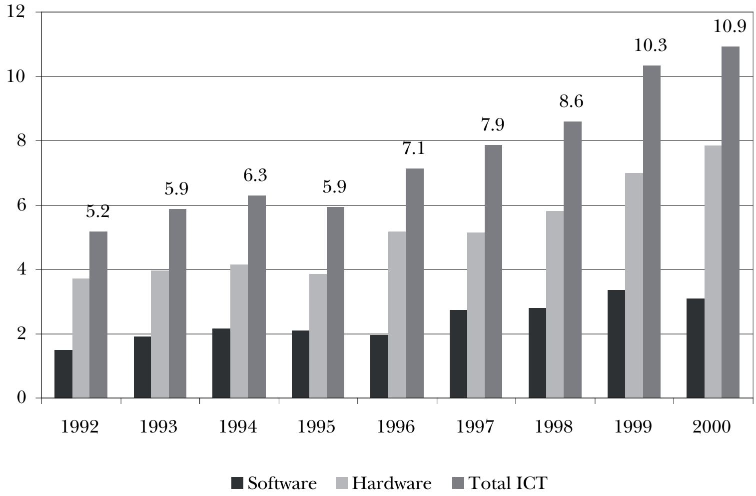
Whole economy



b) Composition of capital stock

Whole economy

(ICT capital/Total capital ratio)



Cost shares

Each factor's cost share is defined as the ratio of the cost of the input to total cost of output which, under the neoclassical assumptions, is equal to total costs. In the case of labor, its cost can be directly obtained from the accounting data. In the case of the capital inputs, its computation—given by the product of the capital stock and its rental price or user cost—is not so straightforward.

The definition of the user cost of the capital input K_i is given by the product of three terms: the acquisition price (P_i), the gross rate of return (R_i) and a fiscal correction factor (f).

$$UC_i = P_i R_i f$$

In what follows, we focus on the computation of the gross rate of return. The acquisition price has been previously discussed and the fiscal correction factor, which is constructed at a sectoral level, is described in more detail in Appendix 8.1. This fiscal correction factor, which is assumed to be common to all types of capital, reflects taxes and fiscal incentives.

The gross rate of return for capital input K_i is given by the following expression:

$$R_i = r + \delta_i - \pi_i$$

where r is the net rate of return common to all types of capital (representing the opportunity cost of the investment),[15] δ_i is the depreciation rate (which proxies the loss in market value due to ageing) and π_i is the capital price inflation, reflecting capital gains or losses.

Two factors determine the evolution of the cost share of each capital input: its user cost and its weight in total capital. Graph 8.3 displays the path in real terms[16] of the first of these factors, the rental price or user cost, for all the types of capital inputs considered. Given that the depreciation rates and the fiscal correction factor have remained quite stable over the sample period, the time profile is mostly explained by the capital price inflation and by the opportunity cost of investment. Provided that

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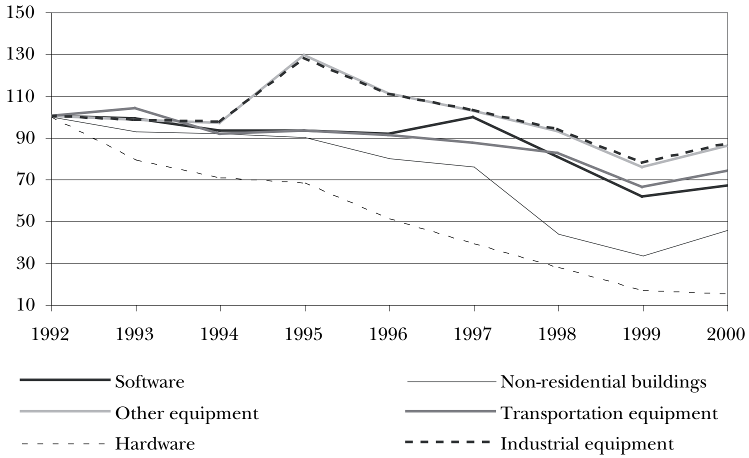
[15] In the construction of the net rate of return r, which has been assumed to be common for all firms within the same sector, we have not taken into account the composition of financing.

[16] That is $(r + \delta_i - \pi_i)\frac{P_{it}K_{it}}{P_{i95}K_{it}}$, where $P_{it}K_{it}$ is capital input i, in nominal terms, and $P_{i95}K_{it}$ is capital input i at constant prices.

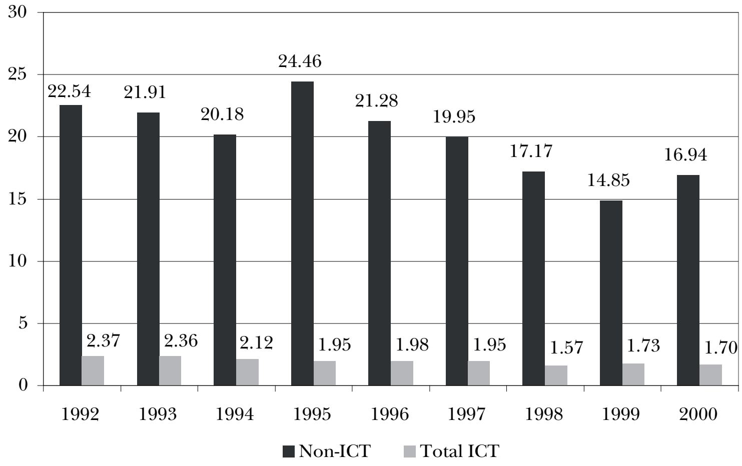
GRAPH 8.3: User costs of capital
(1992 = 100)



this last factor is assumed to be common to all types of capital, the price changes in capital goods is left as the main cause explaining differences in the changes in the cost shares across classes of capital. Especially remarkable is the fall in the user costs of ICT capital, particularly hardware, relative to the user costs of other types of capital input. This relative behavior of user costs is decisive in explaining the existence of strong substitution effects between different types of capital.

As Graph 8.4 shows, there has been a markedly different time profile for the cost shares of ICT and non-ICT capital inputs. On the one hand, in the case of non-ICT capital inputs, their cost share has shown a significant downward trend throughout the sample period, mainly driven by the declining weight of non-ICT capital in total fixed capital. On the other hand, the cost share of ICT capital goods has exhibited a slight downward trend that is the result of two effects of large magnitude but of opposite sign: the increasing weight of ICT capital inputs and the sharp decline in their rental price. This declining trend in the cost share of total ICT capital is mostly explained by the behavior of the cost share of hardware. In the case of software, the decline in its rental price has not been so sharp as to cancel out the increase in its weight in total fixed capital. Thus we observe a slightly growing cost share for software.

GRAPH 8.4: **Cost shares of ICT capital inputs**
Whole economy
(percentage)



8.4. Growth contribution from the use of ICT as a capital input

Once the information on the rates of growth of different inputs and their costs shares is available, using equations (8.8) and (8.12) we can easily approximate the breakdown of output and labor productivity growth. Given that our analysis is performed at the firm level, we report three types of results. First, we provide a breakdown of output growth for the whole market economy. As already stated, we compute this breakdown in three steps. In the first step we compute each element of equations (8.8) and (8.12) at the individual level. Next, by taking sectoral averages for each of these components, we obtain a breakdown of output growth at the sectoral level.[17] Using value-added weights, we aggregate these sectoral results. Second, we provide a discussion of the results at

[17] As already mentioned, in this step we have considered two alternative sectoral breakdowns and we have computed both simple and weighted averages. In what follows, we present the results corresponding to the case of the 17-sector breakdown and where the sectoral figures are computed, as simple averages of the individual ones. This aggregation method is the one that best approximates the growth rates observed for several economic variables with National Accounts data. Nevertheless, the results are robust to the alternative procedures of aggregation (see Appendix 8.2 for detailed results).

the sectoral level. Finally, we report the distribution of individual ICT capital contributions to growth.

8.4.1. Aggregated market economy results

Table 8.1 presents the breakdown of output growth. The first column reports the results for the overall period, 1992–2000. During these years, value-added for the non-financial market economy rose at an annual average rate of 2.9%. The contribution of ICT capital (line 5) represented 0.38 percentage points, of which 0.16 was explained by computer software and 0.22 by hardware. The ICT contribution to growth was small during the 1990s, being around half of the contribution accounted for by other fixed capital. Nevertheless several comments should be made.

First, over the period under study the ICT capital stock increased at an annual average rate of 7.5%, while non-ICT capital rose at a rate of 0.9%. Consequently, the contribution of ICT capital to growth was moderate because ICT capital still represents a very modest fraction of total capital stock (7.6%) and its share in total cost is rather small (2.0%). In other words, relative to its share in total cost or in the total fixed capital stock, the contribution of ICT capital to growth has been considerable (see lines 26 and 30 of Table 8.1).

Second, throughout the period analyzed the ICT contribution has been increasing (see columns 2 and 3 of Table 8.1). For the period 1996–2000, the ICT contribution to annual value-added growth reached 0.45 percentage points, 55% higher than the average contribution for the period 1992-95. Conversely, non-ICT capital contribution has significantly decreased.

Third, the rise in the ICT contribution to growth during the second half of the 1990s is explained by an acceleration in ICT accumulation rates, since the ICT cost share declined slightly between these two periods. Thus, annual growth rates for new technology equipment rose from 4.4% during 1992–95 to 10.1% during 1996–2000. Given these growth rates, which were also considerable in nominal terms, the reduction in the ICT cost share is explained, as already stated, by the exceptional decline in ICT capital goods prices.

TABLE 8.1: ICT contribution to VA (Value added) growth
Results for the whole non-financial market economy[1]

	Total period	1992–95	1996–2000
1. VA growth rate	**2.85**	**0.97**	**4.35**
Contribution from:			
2. Labor (in hours)	0.57	–1.59	2.30
3. Software	0.16	0.11	0.20
4. Hardware	0.22	0.18	0.25
5. ICT (3 + 4)	**0.38**	**0.29**	**0.45**
6. Rest of capital	0.80	1.04	0.61
7. TFP	1.10	1.23	0.99
Cost shares (percentage)[2]			
8. Software	0.77	0.67	0.86
9. Hardware	1.20	1.53	0.93
10. ICT (8 + 9)	1.97	2.20	1.79
11. Rest of capital	19.92	22.27	18.04
Growth rate of capital stocks (percentage)[2]			
12. Software	7.74	5.93	9.18
13. Hardware	7.18	1.37	11.83
14. ICT	7.54	4.40	10.06
15. Rest of capital	0.92	0.26	1.44
Ratio of ICT capital to total fixed capital (percentage)[2]			
20. Software	2.39	1.91	2.78
21. Hardware	5.18	3.91	6.19
22. ICT	7.57	5.82	8.97
23. Rest of capital	92.43	94.18	91.03
Contribution to VA growth relative to cost shares			
24. Software (3/8)	21.05	17.34	24.01
25. Hardware (4/9)	20.44	11.53	27.56
26. ICT (5/10)	19.84	13.06	25.27
27. Rest of capital (6/11)	4.04	4.63	3.56
Contribution to VA growth relative to total fixed capital share			
28. Software (3/20)	6.95	6.39	7.39
29. Hardware (4/21)	4.26	4.59	4.00
30. ICT (5/22)	5.08	5.11	5.05
31. Rest of capital (6/23)	0.87	1.10	0.68

[1] Computed by averaging sectoral results, weighted by their share in total value-added. Sectoral results correspond to the average for individual firms in the corresponding sector.
[2] Note that the product of average cost share by average capital growth rates is not the same as the average contribution to growth.

Finally, it should be mentioned that there are some differences between the contributions to growth of computer software and hardware. While the contribution of computer software to growth rose significantly between 1992–95 and 1996–2000, the contribution of computer hardware increased moderately. Nevertheless, the growth rate of computer hardware accelerated considerably more than that of computer software. In spite of this, the sharp decline in user costs of computer hardware explains the moderate increase of its contribution to output growth.

Table 8.2 presents a breakdown of labor productivity growth. For the overall period, labor productivity grew at an average annual rate of 2.22%. The process of ICT capital deepening showed an average contribution to productivity growth of 0.35 percentage points. Furthermore, this contribution surged in the second half of the 1990s, when the average annual ICT contribution reached 0.38 percentage points, up from 0.31 in the period 1992–95. In relative terms, this increase in the ICT contribution is even sharper. While in the period 1992–95 the ICT contribution accounted for on average 0.11 of each percentage point of labor productivity growth, this figure was 0.23 in the period 1996–2000. By contrast, the contribution of non-ICT capital to labor productivity growth declined over the period considered. These results suggest that the slowdown in labor productivity growth during the second half of the 1990s was mostly explained by a reduction in non-ICT capital deepening growth rate, since the slowdown in TFP growth was not as sharp as that in labor productivity growth.

TABLE 8.2: **ICT contribution to labor productivity growth**
Results for the whole non-financial market economy[1]

	Total period	**1992–95**	**1996–2000**
Labor productivity growth[(2)]	**2.22**	**2.90**	**1.67**
Contribution from:			
1. Software	0.14	0.12	0.17
2. Hardware	0.20	0.19	0.21
3. ICT (1 + 2)	**0.35**	**0.31**	**0.38**
4. Rest of capital	0.77	1.36	0.30
5. TFP	1.10	1.23	0.99
Memorandum items:			
Growth rate of labor	*0.63*	*–1.93*	*2.68*
Capital-labor ratio[3]			
Software	*0.13*	*0.10*	*0.17*
Hardware	*0.17*	*0.09*	*0.24*
ICT	*0.31*	*0.19*	*0.40*
Rest of capital	*21.24*	*22.84*	*19.95*

[1] Computed by averaging sectoral results, weighted by their share in total value-added. Sectoral results correspond to the average for individual firms in the corresponding sector.
[2] In hours.
[3] Capital stock (in millions of pesetas) per 1,000 hours of labor.

8.4.2. Sectoral results

Table 8.3 shows the sectoral breakdown we have considered together with each sector's share in value-added, the number of observations in the sample, its coverage (in terms of value-added and employment) and the number of firms in the sample for which the ICT capital stock is zero. For most sectors, sample coverage can be considered as relatively high, although for six of them it is lower than 15% in terms of value-added. Hence results for these sectors should be viewed with more caution.

Graph 8.5 presents sectoral ICT cost shares, ICT shares in total fixed capital, ICT capital growth rates and the contribution of ICT capital to growth. These sectoral variables have been computed by averaging firm values within the sector. Therefore, the results presented here correspond to the average firm behavior in the sample, and we take them to be representative of the corresponding sector. The results at the industry level can be summarised as follows:

First, all sectors, except "Other Market Services,"[18] display a small ICT capital share in total fixed capital (see panel *a)*) of Graph 8.5), ranging from 2.2% ("Rubber and Plastic products") to 8.1% ("Communication Services"). Consequently, cost shares are also small. Throughout the period covered, all sectors experienced a significant ICT capital growth rate, contrasting with that for non-ICT capital (see panel *c)*). Given the modest fraction of new technology capital, the average ICT contribution to output growth was small, ranging from 0.15 percentage points for "Building and Construction" to 1.4 percentage points for "Communication Services." However, for all sectors this contribution was, relative to cost shares much higher than that of the non-ICT capital stock (see panel *d)*).

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[18] "Other Market Services," which include real estate, business services and computer services activities, presents an average ICT capital share of 15.5%, far above that of the other sectors.

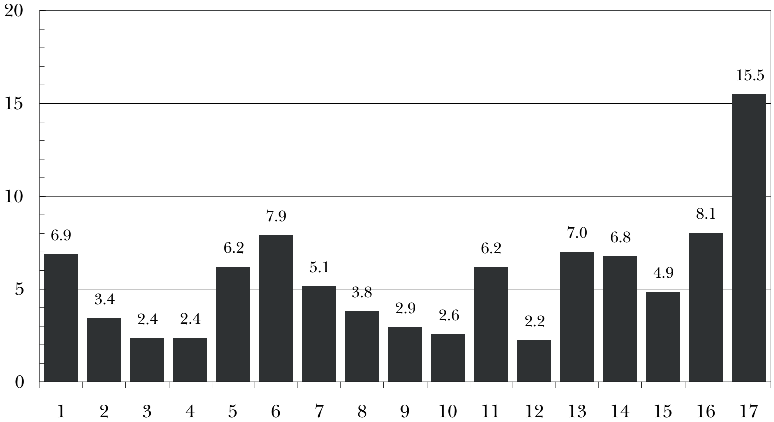
TABLE 8.3: **Sectoral classification and final sample coverage**

Sector	Correspondence NACE[1]/93 (2 digit classif.)	Share in total value-added[2] (percentage)	Total No. Obs.	Sample description: Value-added sample coverage	Sample description: Employment sample coverage	Sample description: Value-added per firm (1995 ESP m)	Sample description: Employees per firm	Sample description: Percentage of firms with ICT = 0
				Annual averages				
1. Agric., forestry and fishery	01, 02, 05	6.8	138	0.5	1.6	1,157.5	415.9	27.3
2. Fuel and power products	10, 14, 23, 40-41	5.4	623	60.8	52.7	25,665.2	1,040.4	5.3
3. Ferric and non-ferric and metals	27-28	3.1	561	18.5	11.4	4,979.3	574.4	6.8
4. Non metal minerals and mineral prod.	26	1.9	396	16.4	9.5	3,950.1	367.4	7.3
5. Chemical products	24	2.3	896	34.6	28.5	4,321.4	383.2	5.8
6. Machinery	29-33	3.3	886	24.0	18.1	4,524.7	566.2	2.7
7. Transport equipment	34-35	2.7	526	50.1	40.0	12,636.6	1,726.8	6.2
8. Food, beverages and tobacco	15-16	4.2	957	21.3	14.1	4,563.2	505.5	6.5
9. Textiles, clothing, leather and footwear	17-19	2.0	472	7.0	4.8	1,473.1	305.5	12.3
10. Other manufacturing products	20,36	1.7	290	6.1	3.2	1,751.1	251.4	2.0
11. Paper and printing products	21-22	2.1	316	15.2	9.1	5,125.7	466.5	5.1
12. Rubber and plastic products	25	1.2	198	21.9	17.7	6,613.9	789.6	3.3
13. Building and construction	45	9.9	769	8.0	6.2	4,879.0	800.8	10.1
14. Repair, wholesale, retail and host.	50-52	24.7	2,078	8.0	8.9	4,702.6	788.0	6.8
15. Transport	60-63	7.1	786	24.4	24.0	10,929.6	1,265.2	4.4
16. Communication services	64	3.7	62	64.0	52.9	194,154.5	13,591.5	2.0
17. Other market services	70-74	18.1	1,561	5.8	6.4	3,400.7	553.8	12.7

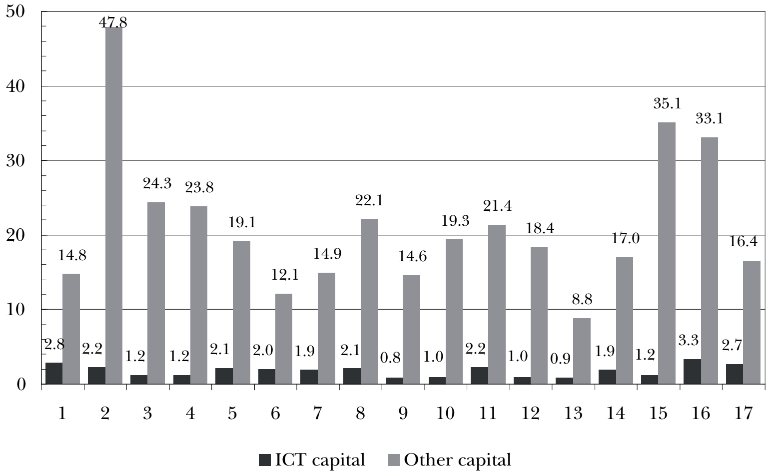
[1] Nomenclature Générale des Activités Ëconomiques dans les Communautés Européennes.
[2] Taken from Estrada and López-Salido (2001).

GRAPH 8.5: ICT capital inputs (sectoral decomposition)

a) ICT capital share in total capital by sector. Average 1992–2000
(percentage)



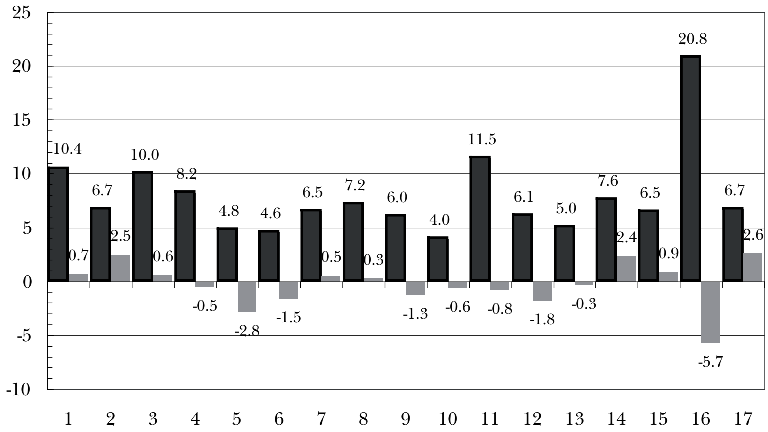
b) ICT capital cost share in total cost by sector. Average 1992–2000
(percentage)



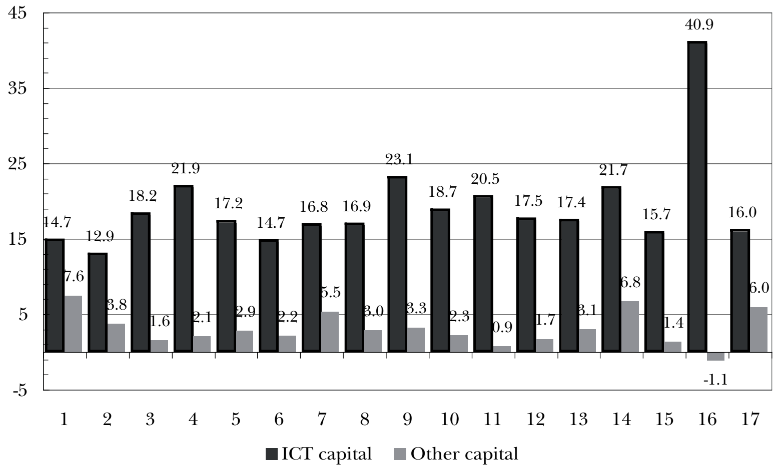
Sectors:
1. Agricultural, forestry and fishery
2. Fuel and power products
3. Ferric and non-ferric ind. and metals
4. Non-metallic minerals and mineral products
5. Chemical products
6. Machinery
7. Transport equipment
8. Food, beverages and tobacco
9. Textiles, clothing, leather and footwear
10. Other manufacturing products
11 Paper and printing products
12. Rubber and plastic products
13. Building and construction
14. Repair, wholesale, retail and hosting
15. Transport and related services
16. Communication services
17. Other market services

GRAPH 8.5 *(cont.):* **ICT capital inputs (sectoral decomposition)**

c) ICT capital growth rates by sector. Average 1992–2000
(percentage)



d) ICT capital contribution relative to cost share. Average 1992–2000
(percentage)

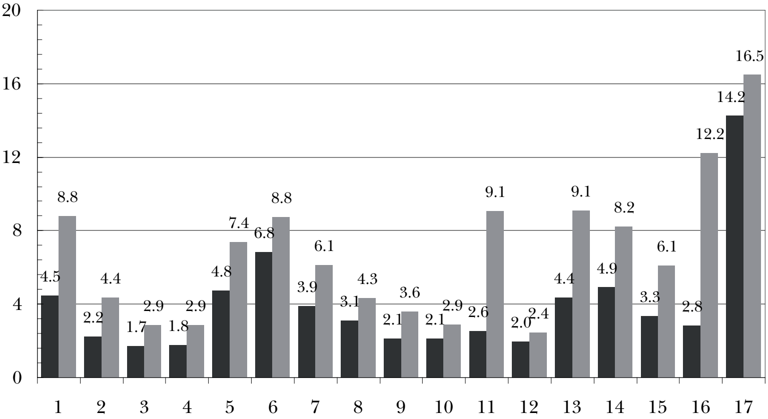


Sectors:
1. Agricultural, forestry and fishery
2. Fuel and power products
3. Ferric and non-ferric ind. and metals
4. Non-metallic minerals and mineral products
5. Chemical products
6. Machinery
7. Transport equipment
8. Food, beverages and tobacco
9. Textiles, clothing, leather and footwear
10. Other manufacturing products
11 Paper and printing products
12. Rubber and plastic products
13. Building and construction
14. Repair, wholesale, retail and hosting
15. Transport and related services
16. Communication services
17. Other market services

GRAPH 8.5 *(cont.):* **ICT capital inputs (sectoral decomposition)**

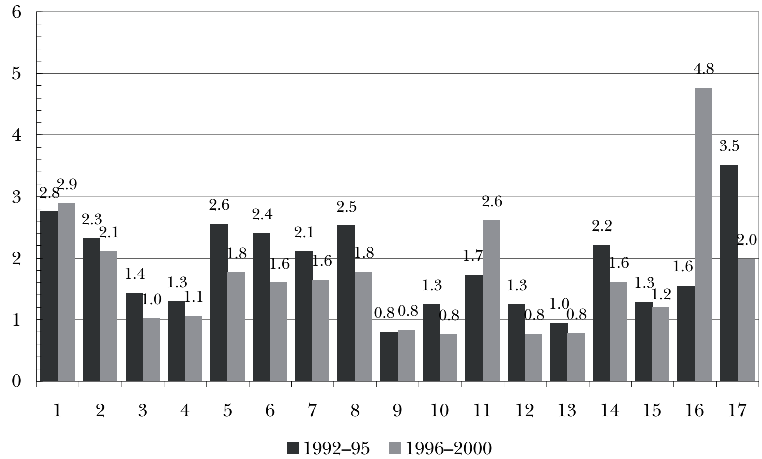
e) ICT capital/Total capital ratio

(period averages)



f) ICT capital cost share

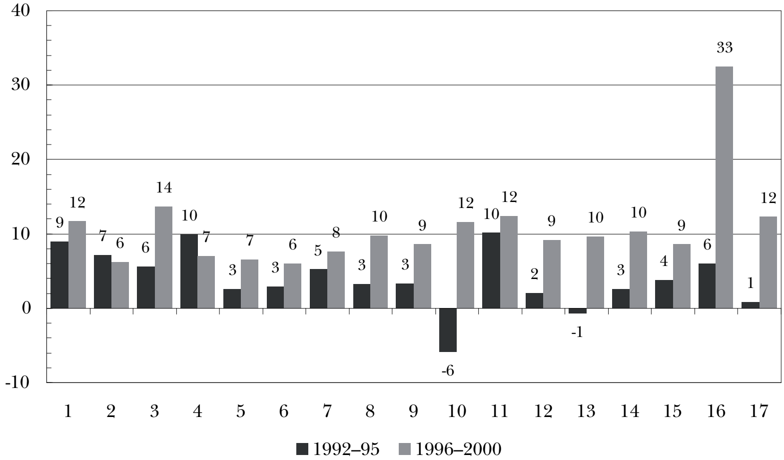
(period averages)



Sectors:
1. Agricultural, forestry and fishery
2. Fuel and power products
3. Ferric and non-ferric ind. and metals
4. Non-metallic minerals and mineral products
5. Chemical products
6. Machinery
7. Transport equipment
8. Food, beverages and tobacco
9. Textiles, clothing, leather and footwear
10. Other manufacturing products
11 Paper and printing products
12. Rubber and plastic products
13. Building and construction
14. Repair, wholesale, retail and hosting
15. Transport and related services
16. Communication services
17. Other market services

GRAPH 8.5 *(cont.)*: **ICT capital inputs (sectoral decomposition)**

g) ICT capital growth rates
(period averages)



Sectors:
1. Agricultural, forestry and fishery
2. Fuel and power products
3. Ferric and non-ferric ind. and metals
4. Non-metallic minerals and mineral products
5. Chemical products
6. Machinery
7. Transport equipment
8. Food, beverages and tobacco
9. Textiles, clothing, leather and footwear
10. Other manufacturing products
11 Paper and printing products
12. Rubber and plastic products
13. Building and construction
14. Repair, wholesale, retail and hosting
15. Transport and related services
16. Communication services
17. Other market services

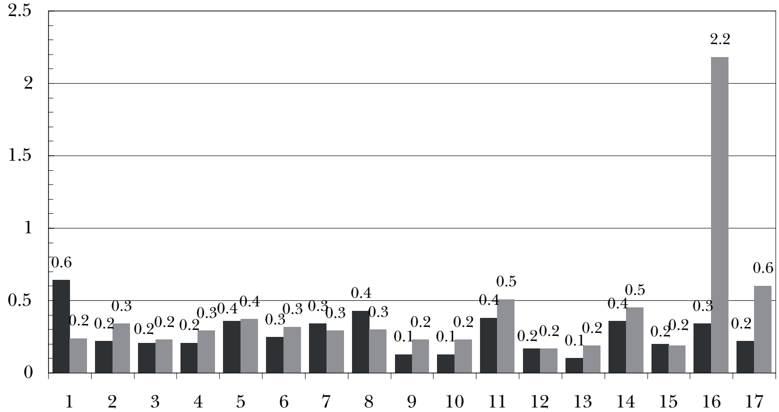
Second, all sectors have experienced a rise in the share of ICT capital in total fixed capital throughout the period considered. In most sectors, this substitution of ICT capital for non-ICT capital, explained by relative price developments, has accelerated in the second half of the period considered. Thus, for 15 sectors, annual ICT growth rates were higher during 1996–2000 than during 1992–95 (see panel *g)* of Graph 8.5), this acceleration being especially remarkable for "Communication Services" and "Other Market Services." In spite of these accumulation rates, cost shares were lower in the second half of the period analyzed for most sectors (13 of them), reflecting the significant decline experienced in ICT capital good prices (see panel *f)*).

Third, for most sectors (13 of them), the ICT growth rate acceleration outweighted the decline in the cost share. Consequently the ICT contribution to output growth increased

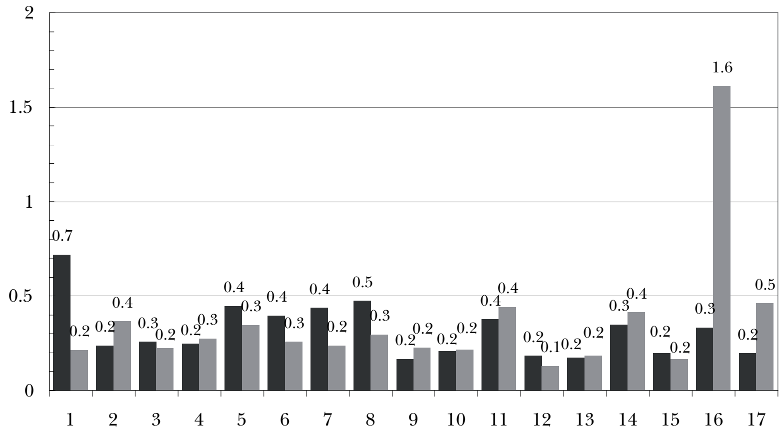
GRAPH 8.5 *(cont.)*: **ICT capital inputs (sectoral decomposition)**

h) ICT capital contribution to VA growth

(period averages)



i) ICT capital contribution to labor productivity growth by period

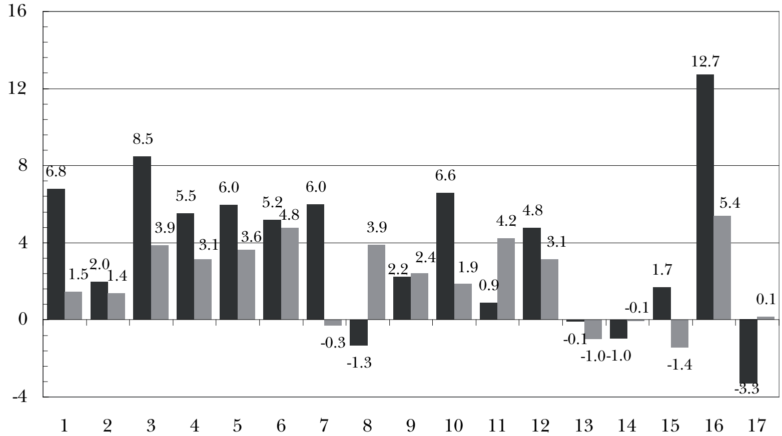


■ 1992–95 ■ 1996–2000

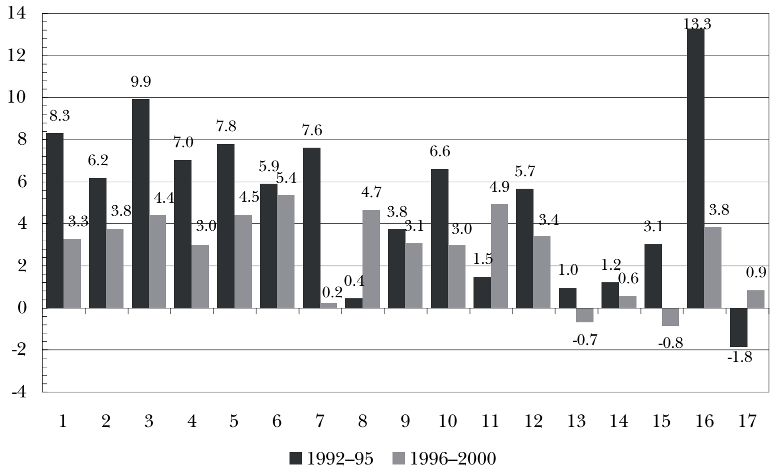
Sectors:
1. Agricultural, forestry and fishery
2. Fuel and power products
3. Ferric and non-ferric ind. and metals
4. Non-metallic minerals and mineral products
5. Chemical products
6. Machinery
7. Transport equipment
8. Food, beverages and tobacco
9. Textiles, clothing, leather and footwear
10. Other manufacturing products
11 Paper and printing products
12. Rubber and plastic products
13. Building and construction
14. Repair, wholesale, retail and hosting
15. Transport and related services
16. Communication services
17. Other market services

GRAPH 8.5 *(cont.)*: **ICT capital inputs (sectoral decomposition)**

j) TFP growth rates



k) Labor productivity growth rates



Sectors:
1. Agricultural, forestry and fishery
2. Fuel and power products
3. Ferric and non-ferric ind. and metals
4. Non-metallic minerals and mineral products
5. Chemical products
6. Machinery
7. Transport equipment
8. Food, beverages and tobacco
9. Textiles, clothing, leather and footwear
10. Other manufacturing products
11 Paper and printing products
12. Rubber and plastic products
13. Building and construction
14. Repair, wholesale, retail and hosting
15. Transport and related services
16. Communication services
17. Other market services

in 1996–2000 relative to 1992–95 (see panel *h)* of Graph 8.5). In terms of labor productivity growth, only 9 sectors experienced a higher ICT contribution in the second half of the 1990s (see panel *i)*)[19] despite the general rise in ICT capital deepening.[20]

In short, although the ICT contribution to growth across sectors displays a degree of heterogeneity, most sectors show similar main results to those for the whole market economy. The ICT contribution to growth is small in absolute terms, but it was increasing over the period covered. This increase is mostly explained by an acceleration in ICT capital accumulation.

ICT contribution to growth in ICT producing sectors

It is often argued that the dramatic price decline in ICT capital goods over recent decades can be explained by the efficiency gains in the ICT producing sectors. Therefore, it seems worth analyzing growth developments in terms of output and productivity in those sectors producing goods and services related to ICT.[21]

We have considered three ICT producing sectors: "ICT Manufacturing," which comprises the production of ICT goods, "ICT Communications" and "ICT Computer Services."[22] It should be pointed out that we do not have value-added deflators with the required level of disaggregation. Therefore value-added, labor productivity and TFP are probably imperfectly measured. Results for the analysis performed are presented in Graph 8.6. ICT producing sectors have experienced higher ICT capital growth rates and higher ICT contributions to value-added growth than other economic sectors. This is especially the case for the second half of the sample period.

Value-added growth rates in these sectors have been significantly higher than those for the rest of the economy. Therefore, ICT producing sectors have contributed positively to output growth, although given the modest share of ICT value-added in total

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[19] Nevertheless, relative to labor productivity growth, the ICT contribution increased in 11 of the 17 sectors.

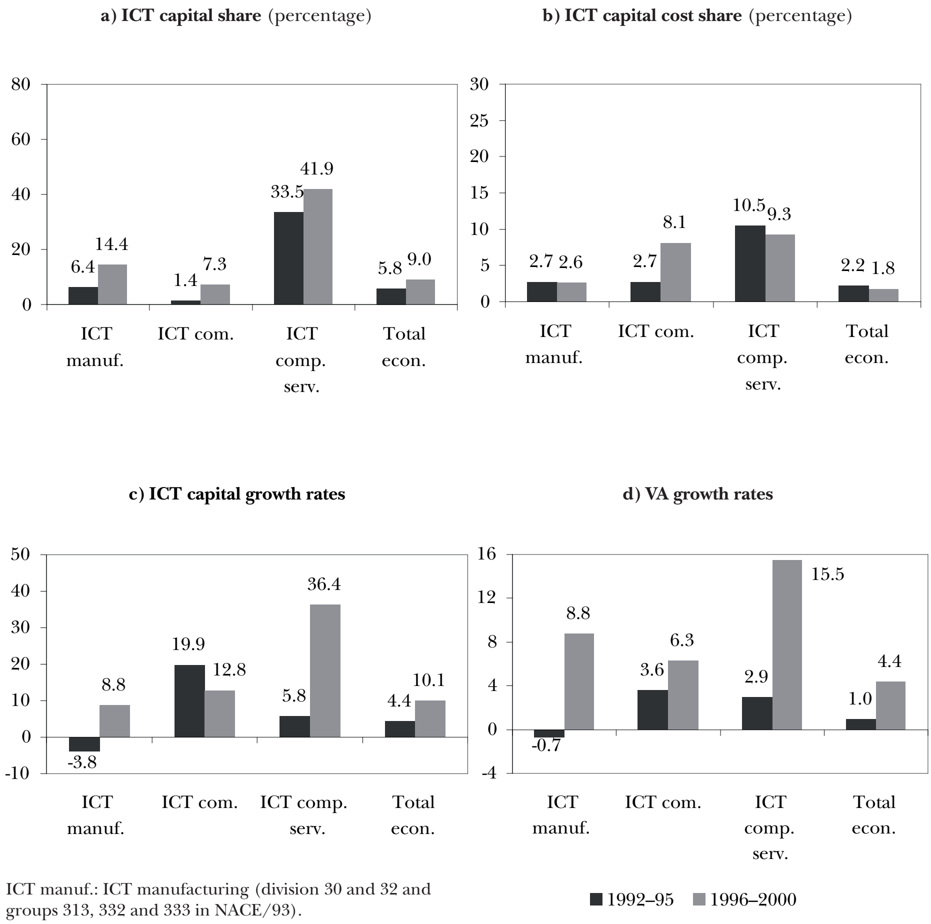
[20] The ICT capital labor ratio rose in 16 of the 17 sectors.

[21] For a more detailed study of ICT producing sectors see Núñez (2001).

[22] More specifically, using NACE/93, "ICT Manufacturing" includes divisions 30 and 31 and groups 313, 332 and 333, "ICT Communications" group 641 and "ICT Computer Services" corresponds to division 72.

economy (around 5.2%), this contribution has been small. In terms of TFP, "ICT Manufacturing" and "ICT Communications" have experienced much higher growth rates than other sectors. These growth rates accelerated in the second half of the sample period, in contrast to the slowdown in TFP growth in the whole market economy.

GRAPH 8.6: **ICT growth in ICT producing sectors**

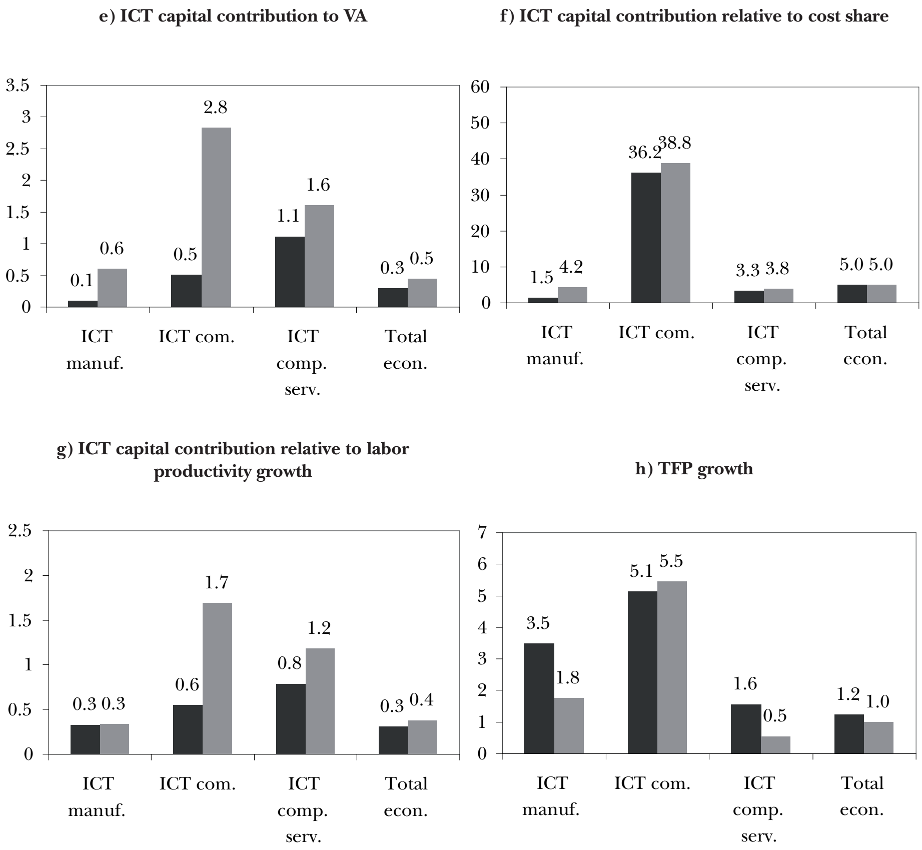


ICT manuf.: ICT manufacturing (division 30 and 32 and groups 313, 332 and 333 in NACE/93).

ICT com.: ICT Communications (group 642 in NACE/93).

ICT comp. serv.: ICT Computer Services (division 72 in NACE/93).

GRAPH 8.6 *(cont.)*: **ICT growth in ICT producing sectors**



ICT manuf.: ICT manufacturing (division 30 and 32 and groups 313, 332 and 333 in NACE/93).

ICT com.: ICT Communications (group 642 in NACE/93).

ICT comp. serv.: ICT Computer Services (division 72 in NACE/93).

■ 1992–95 ■ 1996–2000

Table 8.4 gives the contribution of ICT industries to total market economy TFP growth.[23] For the period 1992–95, this contribution was in annual average terms 0.17 percentage points, rising to 0.19 percentage points in the period 1996–2000. Relative to total economy TFP growth, these contributions were 14% and 19%, respectively, which can be considered high if we

[23] This contribution is computed as the product of TFP growth in ICT industries and the value-added weight of ICT industries (see Schreyer 2001).

TABLE 8.4: Contribution of ICT producing sectors to TFP

	1992–95				1996–2000			
	Δ TFP	**Weight in VA**	**Contribution to Δ TFP total econ.**[1]		**Δ TFP**	**Weight in VA**	**Contribution to Δ TFP total econ.**[1]	
	(percentage)	(percentage)	(p.p.)	(percentage[2])	(percentage)	(percentage)	(p.p.)	(percentage[2])
ICT manufacuring	3.48	0.88	0.03	2.5	1.77	0.87	0.02	1.6
ICT communications	5.13	2.43	0.12	10.1	5.45	3.07	0.17	16.9
Computer services	1.56	0.68	0.01	0.9	0.54	1.28	0.01	0.7
Total ICT[3]			**0.17**	**13.5**			**0.19**	**19.2**
Memorandum item:								
Total market economy	*1.23*	*100*			*0.99*	*100*		

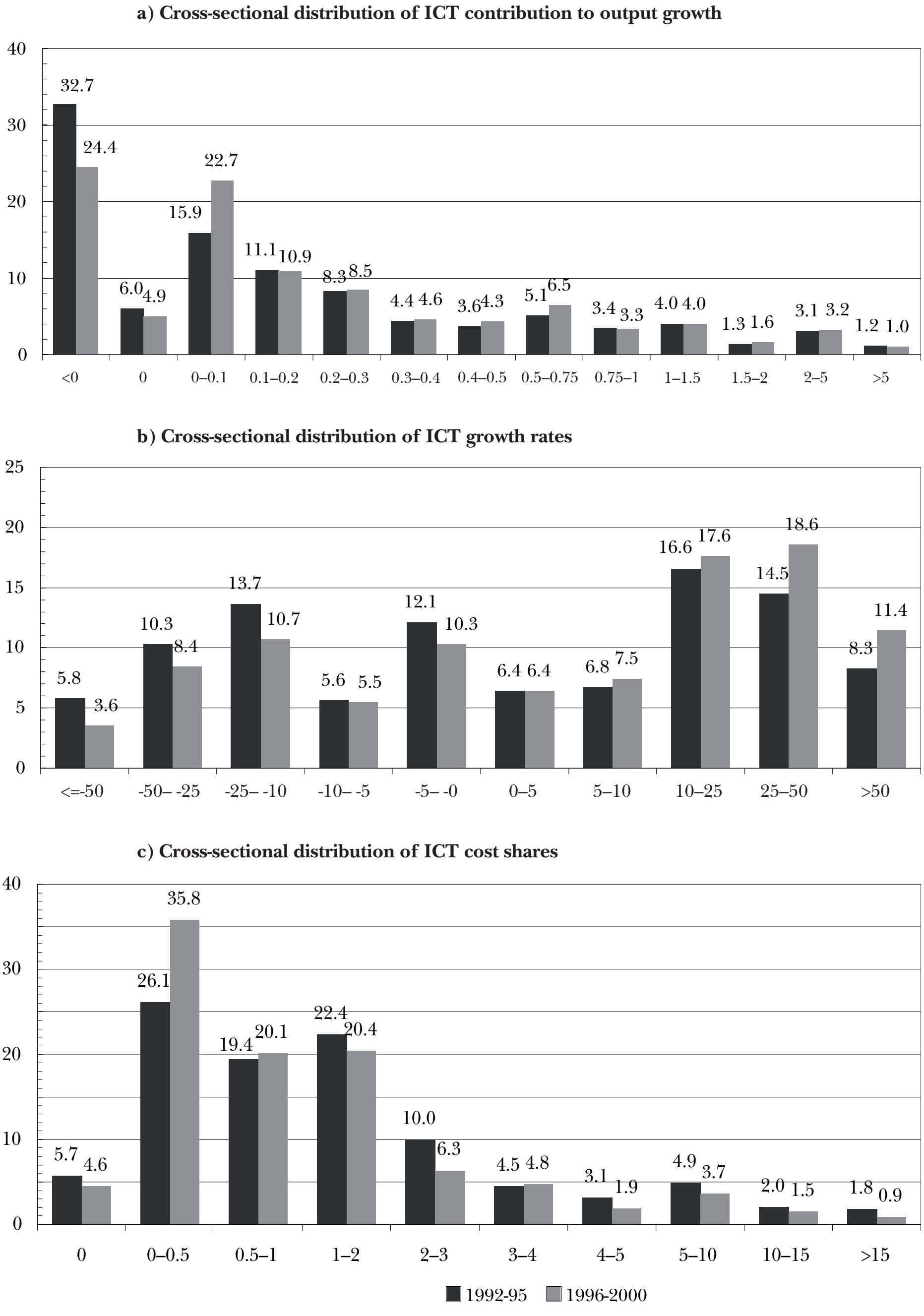
[1] Computed as the product of Δ TFP and weight in VA.
[2] Relative to Δ TFP of total market economy.
[3] Computed by adding the contributions of the 3 sectors involved.

take into account that ICT producing sectors account for only 5% of total value-added. More importantly, these high relative contributions imply that the other branches of activity, with a much higher weight, have recorded a very low and declining rate of TFP growth. These results might suggest therefore that the use of ICT has not, as yet, given rise to positive spillover effects that have translated into increases in productive efficiency for the whole economy, or, if there have been any, they have not been able to offset the negative effect of other determinants of total productivity.

8.4.3. Cross-sectional distribution of ICT contributions to value-added growth

In this section we try to provide an overview of the results obtained at the individual level. For this purpose, Graph 8.7 displays the cross-sectional distributions of ICT contributions to value-added growth and their two main determinants, the ICT cost shares and the ICT accumulation rates. These distributions are presented for the 1992–95 and 1996–2000 periods. As was already clear from the sectoral results, the average breakdown of output growth hides a very heterogeneous individual behavior. Panel *a)* of Graph 8.7 shows that the distribution of ICT contributions to output growth is highly skewed to the left. Whereas the average ICT contribution to output growth was nearly 0.40 percentage points (see Table 8.1), around 75% of the firms exhibit an ICT contribution below this average value. This contribution is even negative for a significant fraction of firms. As can be seen from panel *b)*, these negative contributions are driven by the presence of negative accumulation rates. In most cases, these negative accumulation rates arise from the fact that the gross ICT investment is not enough to offset the high depreciation rates of the installed ICT capital. Only in a small number of cases are sales of ICT capital goods observed. The cross-sectional distribution of ICT cost shares is again extremely skewed to the left (see panel *c)*). Almost 80% of the firms have ICT cost shares below the average ICT cost share (2% for the whole period). It is also noteworthy that the fraction of firms with a zero ICT cost share is very low (around 5% of the sample).

GRAPH 8.7: Cross-sectional distribution of ICT capital stock variables
(percentage)



Finally, it is interesting to analyze how these distributions have evolved over the sample period. Comparing the periods 1992–95 and 1996–2000, the rise in the average ICT contribution from 0.29 to 0.45 percentage points (see Table 8.1) is also reflected in a slight shift to the right in the distribution of ICT contributions. This shift is especially visible in the lower tail of the distribution with the reduction in the percentage of firms with negative contributions. The percentage of firms with a negative ICT contribution decreases from 33% in the early nineties to 24% in the second half of the sample period. Nevertheless, the changes of opposite sign in accumulation rates and prices of ICT goods explain the notable stability of this distribution. The small change in the distribution of ICT contributions is mostly driven by the significant shift to the right in the distribution of ICT accumulation rates that offset the shift to the left in the distribution of ICT cost shares. Again, this shift is more perceptible in the lower tail of the distribution. For example, the percentage of firms with an ICT cost share below 1% rises from 51% in the first half of the decade to 60% in the late nineties.

8.5. Conclusions

This paper examines the role played by ICT capital as an input factor and, more specifically as a factor contributing to output growth in the Spanish economy in the period 1992–2000. For this purpose, we use a standard growth accounting framework and a firm level database. In order to obtain a general conclusion regarding the ICT contribution to growth for the whole non-financial market economy, we aggregate the individual results in two steps. First, we obtain sectoral figures by averaging companies' results by sector. We implicitly assume that the average performance of the firms in the sample is representative of the sectors they belong to. We then obtain aggregate figures by averaging sectoral results, weighting them by their share in the whole market economy.

The use of firm level data is helpful to overcome some difficulties associated with the use of aggregate data, mainly the availability lags and the mis-measurement of capital stocks. However, individual data also poses some problems for the purpose in hand. In particular, the uneven coverage of the sample by sector and by size of firm, and the need to transform accounting data into information that is meaningful in economic terms, represent important limitations. Bearing in mind these drawbacks, our results should be viewed with some caution.

Our main findings may be summarised as follows. First, the use of ICT as a capital input has made a positive and, relative to its cost share, important contribution to output and productivity growth. Over the entire sample period considered, the contribution of ICT equipment amounts to about one-third of the contribution of fixed capital to output and labor productivity growth. This is especially noteworthy if we take into account that the cost share for ICT capital inputs represents around one-tenth of the cost share for the total fixed capital. Second, this contribution was higher in the second half of the 1990s, in spite of the slight decrease in the cost share of ICT capital goods. For this period we estimate that the use of ICT inputs accounted for nearly one-fourth of the labor productivity growth, representing around 55% of the entire contribution of fixed capital. Third, at a sectoral level, we find that there is a general rise in the weight of ICT in total fixed capital and a general reduction in ICT cost shares driven by the sharp downward trend in the prices of ICT products. However, the contribution of ICT inputs displays a certain sectoral heterogeneity explained by the disparity of accumulation rates of ICT inputs across sectors, although most sectors have experienced a higher contribution to growth in the second half of the 1990s. Finally, at the individual level, firms exhibit notable heterogeneity, although a majority recorded higher ICT capital growth rates in the second half of the 1990s.

Although ICT capital growth rates have been notable, they are still well below those observed in the U.S. economy. Consequently, they are not sufficiently high to narrow the gap in new technology capital observed between the Spanish and U.S. economies. A final remark concerns TFP growth. The results presented here show a slightly lower TFP growth rate for the second half of the 1990s. However, our approach does not allow us to draw any conclusion on the link between ICT growth and TFP growth rates. In other words, the growth accounting framework provides a valuable analysis of the proximate sources of economic growth, but it does not adequately explain the underlying factors driving the processes of substitution between factors or the causes that lie behind TFP growth. These are the types of issue we plan to address in future research. We think that firm level data is especially useful to deal with them, since they allow the distinctive features of technology-intensive firms and of firms displaying a high productivity growth to be identified.

References

BRYNJOLFSSON, Erik, and Lorin HITT. "Paradox lost? Firm-level evidence on the returns to information systems spending." *Management Science* 42, no. 4 (1996): 541–58.

—. "Computing Productivity: Firm-level Evidence." *Review of Economic Statistics* 85, no. 4 (2003): 793–808.

BUGAMELLI, Matteo, and Patrizio PAGANO "ICT and factor complementarities in the Italian manufacturing." Mimeo, Bank of Italy, 2001.

COLECCHIA, Alessandra, and Paul SCHREYER. *ICT investment and economic growth in the 1990s: Is the United States a unique case? A comparative study of nine OECD countries.* STI Working Paper 2001/7. Paris: Organisation for Economic Co-operation and Development, Directorate for Science, Technology and Industry, 2001. (Later published in *Review of Economic Dynamics* 5, no. 2 [2002]: 408–42.)

DAVERI, Francesco. "Information technology and growth in Europe." Mimeo, University of Parma and IGIER, May 2001.

ESTRADA, Ángel, and David LÓPEZ-SALIDO. *Accounting for Spanish productivity growth using sectoral data: new evidence.* Working Paper no. 0110. Madrid: Bank of Spain, 2001.

FRAUMENI, Barbara M. "The Measurement of Depreciation in the U.S. National Income and Product Accounts." *Survey of Current Business* 77 (July 1997): 7–23. Available online at http://www.bea.gov/bea/ARTICLES/NATIONAL/NIPAREL/1997/0797fr.pdf.

HALL, Bronwyn H. *The Manufacturing Sector Master File: 1959–1987, Documentation.* NBER Working Paper no. 3366. Cambridge, MA: National Bureau of Economic Research, 1990.

HALL, Robert E. "Invariance properties of Solow's productivity residual." In Peter Diamond, ed. *Growth Productivity and Unemployment.* Cambridge, MA: The MIT Press, 1990.

IZQUIERDO, Mario, and María de los Llanos MATEA. *Hedonic prices for personal computers in Spain during the 90s.* Estudios Económicos no. 74. Madrid: Servicio de Estudios, Bank of Spain, 2001. Also available online at http://www.bde.es/informes/be/sazul/azul74e.pdf.

JORGENSON, Dale W., and Kevin J. STIROH. "Raising the Speed Limit: U.S. Economic Growth in the Information Age." *Brookings Papers on Economic Activity* 1 (2000): 125–211.

NÚÑEZ, Soledad. "Las ramas productoras de TIC y su contribución al crecimiento." *Boletin Económico,* Bank of Spain, October 2001.

OLINER, Stephen D., and Daniel E. SICHEL. "The Resurgence of Growth in the Late 1990s: Is Information Technology the Story?" *Journal of Economic Perspectives* 14, no. 4 (2000): 3–22.

SCHREYER, Paul. *The Contribution of Information and Communication Technology to Output Growth: A Study of the G7 Countries.* OECD Science, Technology and Industry Working Paper no. 2000/2. Paris: OECD Directorate for Science, Technology and Industry, 2000.

—. *Measuring Productivity, OECD Manual.* Paris: Organisation for Economic Co-operation and Development, 2001.

SOLOW, Robert. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39, no. 3 (1957): 312–20.

WHELAN, Karl. *Computers, obsolescence and productivity.* Finance and Economics Discussion Series Paper 2000-6. Washington, DC: Division of Research and Statistics, The Federal Reserve Board, 2000. Available online at http://www.federalreserve.gov/pubs/feds/2000/200006/200006pap.pdf.

Appendix 8.1. The database

The sample

Individual balance sheet data are available over the 1991–2000 period on a yearly basis. The initial sample is an unbalanced panel containing 18,330 observations corresponding to 3,850 firms. This information has been combined with other sectoral and economy-wide data.

Cleaning of the sample

First, we have excluded those observations for which the available information was insufficient to compute some of the variables considered throughout the analysis, in particular the average life of the capital stocks. After this step the resulting sample contained 17,931 observations, corresponding to 3,789 firms (830 of them are only available for one period). Second, in order to handle outliers we have removed those observations within the upper and the lower percentiles of the distributions defined (for each year and sector) in terms of the growth rates of the different capital stocks.

Finally, as we need to compute growth rates to obtain the contribution of the different inputs we lose the first observation for each firm. The final sample is an unbalanced panel containing 11,515 observations corresponding to 2,724 firms. Table A.8.1.1 shows the composition of the final sample.

Variables and data construction

Value-added (Q): This has been deflated using sectoral value-added deflators from Estrada and López-Salido (2001).

Labor (L): For each firm, we use the average number of hours per year. This value is the result of multiplying the average number of employees per year (available at the firm level) by the average number of hours per employee (taken at a sectoral level from Estrada and López-Salido 2001).

Capital stocks (K_i): In order to convert the book value of capital into market and constant values we have proceeded as follows, following B. H. Hall (1990) and Bugamelli and Pagano (2001).[24] We

[24] A very similar procedure is also used by the Central Balance Sheet Office of the Bank of Spain to construct total capital stocks.

TABLE A.8.1.1: Final sample description

1. General		Percentiles					
	Mean	5%	10%	25%	50%	75%	90%
Number of employees	621.14	36.00	75.00	121.07	204.94	427.42	983.00
Value added (1995 millions pta)	5,345.95	257.44	401.98	698.00	1,388.78	3,220.73	8,359.02
Software capital to total capital ratio	2.72	0.00	0.00	0.00	0.26	1.82	6.23
Hardware capital to total capital ratio	4.94	0.00	0.09	0.43	1.34	3.91	12.44
Total ICT capital to total capital ratio	7.67	0.01	0.17	0.77	2.44	7.14	20.54
Total fixed capital-labor ratio[1]	18.76	0.16	0.41	1.17	2.79	6.30	15.65
Total number of firms	2,724						
Total number of observations	11,515						

2. By year Year	No. firms	No. firms with softw.= 0	No. firms with hardw.= 0	No. firms with ICT K = 0	Percentage of firms with softw.= 0	Percentage of firms with hardw.= 0	Percentage of firms with ICT K = 0
1992	1,386	785	165	137	56.6	11.9	9.9
1993	1,320	674	138	109	51.1	10.5	8.3
1994	1,310	646	122	103	49.3	9.3	7.9
1995	1,332	607	118	98	45.6	8.9	7.4
1996	1,410	594	134	109	42.1	9.5	7.7
1997	1,403	553	118	93	39.4	8.4	6.6
1998	1,307	490	110	83	37.5	8.4	6.4
1999	1,125	400	80	63	35.6	7.1	5.6
2000	922	330	65	46	35.8	7.0	5.0

[1] Capital stock (in millions of 1995 pesetas) per 100 employees.

first computed its age for each year and type of capital. We set the age of capital as the 2-year average of the ratio of total accumulated depreciation to current depreciation. We then calculated the current value of each type of capital as:

$$K_{i\,t} = [\textit{Net book value of type i capital x } P_i(t)] \,/\, P_i(t\text{-}age_{\,it})$$

where $P_i(j)$ is the price deflator for type *i* capital and year *j*, *t* is the current period and *age* is the above calculated age of capital. Capital stocks at 1995 constant prices were calculated as:

$$K_{i\,t} = \textit{Net book value of type i capital} \,/\, P_i(t\text{-}age_{\,it})$$

For these calculations we have taken into account leasing and the revaluations of book value capital made by the firm.

Price indices for capital inputs (P_i): The price indices for non-residential construction (K_{bld}) and transportation equipment (K_{trp}) are taken from the Spanish National Accounts. For industrial equipment (K_{ieq}) and other equipment and furniture (K_{oeq}) a common price index is constructed combining information from the National Accounts, IPRI (Industrial Domestic Wholesale Prices) and IVUX (Export Wholesale Prices). For software (K_{sw}) and hardware (K_{hw}), we compute the price deflators by assuming that the ratio of these deflators to the GDP deflator in Spain is the same as the corresponding ratio in the U.S. The deflators for these capital inputs in the U.S. economy are taken from U.S. Department of Commerce, Bureau of Economic Analysis (Chain-Type Price Indices for Private Fixed Investment in Equipment and Software by Type).

In section 8.3, we compare the deflators for hardware and software with an alternative price index obtained from Spanish statistical sources. This price index (common to hardware and software) is constructed combining information from the National Accounts, IPRI and IVUX.

Depreciation rates (δ_i)*:* With the exception of hardware and software, these have been calculated at a sectoral level. Hardware and software depreciation rates were equally set for all sectors. The software depreciation rate was taken from Whelan (2000) and all others from Fraumeni (1997).

Net rate of return (r): is measured as the average (by year and sector) of the apparent interest rate obtained from the accounting data. The apparent interest rate is defined as the ratio of interest and similar charges to gross debt.

Fiscal correction factor (f): Defined at the sectoral level as: $f = \frac{(1 - itc_t - \tau_t z_{st})}{(1 - \tau_t)}$ where z represents the present value of depreciation expenses, τ represents the corporate tax-rate and *itc* represents the investment tax credit. z changes by sector and over time and τ and *itc* over time only.

Appendix 8.2. The aggregation method

In this paper, the growth accounting exercise is implemented at the firm level. Each component of equations (8.8) and (8.12) (that is, the value-added growth rate, factor inputs contributions and the TFP growth rate) is computed for each firm in the sample. To obtain the components of equations (8.8) and (8.12) for the total non-financial market economy from the components computed at the firm level we take two additional steps. First, we average these components by sector. Second, we obtain the figures for the total non-financial market economy by averaging the sectoral variables involved, weighting the sectors by their share in total value-added.

For the sake of robustness, in the first step we consider two alternative sectoral breakdowns (the National Accounts sectoral breakdown into 71 industries and the breakdown into 17 sectors used in Estrada and López-Salido [2001]) and we follow two alternative procedures to go from the individual components to the sectoral ones. In the first one, we compute the sectoral component as the simple average of the individual ones, and in the second one for each sector we aggregate the individual data for value-added and inputs. We then implement the growth accounting exercise at the sectoral level.

The sectoral weights used in the second step are then calculated from data taken from Estrada and López-Salido (2001), in the case of the 17-sector breakdown, and directly from the National Accounts, in the case of the 71-sector breakdown.

Table A.8.2.1 displays growth rates for some basic variables (value-added, employment, labor productivity, TFP and capital stock)[25] computed using the four alternative aggregation methods implemented and compares them with these in the Estrada and López-Salido (2001) sectoral database, which is taken as a benchmark. As can be observed from this table, the method that

[25] Since the growth rates of these variables are compared with the corresponding growth rates in Estrada and López-Salido (2001), the capital stock for this table has been constructed using the deflators directly obtained from Spanish statistical sources. This accounts for the slight differences in the figures for TFP growth rates between this table and Table A.8.2.1.

gives growth rates for the basic variables closest to the benchmark is that based on the 17-sector breakdown and where the sectoral figures are computed as simple averages of the individual ones. We discuss the results corresponding to this case in the main text. Nevertheless, our conclusion regarding the ICT contribution to growth for the aggregate economy is robust to the alternative procedures of aggregation of the ICT contributions (see Table A.8.2.2).

TABLE A.8.2.1: Comparing results of different aggregation methods*

Variable	Period	Growth rates					Differences with benchmark			
		Bench-mark ELS (1)	Adding firms NA industries (2)	Adding firms 17 sectors (3)	Averaging firms NA industries (4)	Averaging firms 17 sectors (5)	Adding firms NA industries (2)	Adding firms 17 sectors (3)	Averaging firms NA industries (4)	Averaging firms 17 sectors (5)
Value added	1991–95	1.14	1.25	0.70	1.11	0.97	0.12	–0.43	–0.03	–0.17
	1996–2000	3.70	5.50	5.93	5.03	4.35	1.80	2.23	1.34	0.65
Employment (hours)	1991–95	–1.43	–1.40	–1.60	–1.81	–1.93	0.02	–0.18	–0.38	–0.50
	1996–2000	2.78	3.40	2.26	2.75	2.68	0.62	–0.52	–0.03	–0.10
Labor productivity	1991–95	2.56	2.66	2.31	2.92	2.90	0.10	–0.26	0.36	0.34
	1996–2000	0.92	2.09	3.67	2.29	1.67	1.18	2.75	1.37	0.75
TFP	1991–95	1.23	1.78	0.77	1.20	1.29	0.55	–0.46	–0.03	0.06
	1996–2000	0.63	1.86	3.09	1.72	1.08	1.23	2.46	1.09	0.45
Capital stock	1991–95	2.22	1.99	3.35	0.53	0.49	–0.23	1.13	–1.69	–1.73
	1996–2000	3.53	2.08	1.08	2.72	2.72	–1.44	–2.45	–0.81	–0.80

(1) Taken from Estrada and López-Salido (2001).

(2) For each of the 71 NA (National Accounts) industries, variables involved are obtained by aggregating individual values.

(3) For each of the 17 sectors considered by Estrada and López-Salido (2001), variables involved are obtained by aggregating individual values.

(4) For each of the 71 NA (National Accounts) industries, variables involved are obtained by aggregating individual values.

(5) For each of the 17 sectors considered by Estrada and López-Salido (2001), variables involved are obtained by aggregating individual values.

* For all of the aggregation methods, total market non-financial economy values are obtained by averaging sectoral figures weighted by their share in total value added.

Smallest difference with benchmark

Second smallest difference with benchmark

TABLE A.8.2.2: ICT contribution to VA growth

Results for the whole market economy with different aggregation methods[1]

	Adding firms				Averaging firms			
	17 sectors[2]		NA industries[3]		17 sectors[4]		NA industries[5]	
Period	**1992–95**	**1996–2000**	**1992–95**	**1996–2000**	**1992–95**	**1996–2000**	**1992–95**	**1996–2000**
Value added growth rate	**1.25**	**5.50**	**0.70**	**5.93**	**0.97**	**4.35**	**1.11**	**5.03**
Contribution from:								
Labor	–0.73	2.98	–1.19	2.18	–1.59	2.30	–1.44	2.32
Software capital	0.04	0.15	0.07	0.14	0.11	0.20	0.11	0.18
Hardware capital	0.05	0.21	0.12	0.20	0.18	0.25	0.18	0.25
ICT capital	**0.09**	**0.36**	**0.19**	**0.34**	**0.29**	**0.45**	**0.29**	**0.42**
Non-ICT capital	0.21	0.38	1.03	0.39	1.04	0.61	1.15	0.65
TFP	1.68	1.79	0.67	3.02	1.23	0.99	1.11	1.64

[1] For all of the aggregation methods, total market non-financial economy values are obtained by averaging sectoral figures weighted by their share in total value added.

[2] For each of the 17 sectors considered, variables involved are obtained by aggregating individual values.

[3] For each of the 71 NA industries, variables involved are obtained by aggregating individual values.

[4] For each of the 17 sectors considered, variables involved are obtained by aggregating individual values.

[5] For each of the 71 NA industries, variables involved are obtained by aggregating individual values.

9. Growth Accounting and Labor Quality in France, 1982–2001

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THIS paper aims at assessing the contribution of ICT (Information and Communication Technologies) to growth in France at the macro-economic level. On the labor side, the paper also provides evidence of the role played by hours worked, by stressing the contributions of various factors to labor quality and the way they affected labor productivity over the 1995–2001 period. In France, the contribution of ICT to hourly labor productivity growth accelerated quite strongly over 1995–2001 relative to the previous period. This acceleration was indeed accompanied by a rise in multi-factor productivity, even larger than in the U.S., but not by an increase in labor quality due to the fall in hours worked by older labor (+54 years old) and the rise in hours worked by less well-paid younger workers.

9.1. Introduction

ICT, considered as general purpose technologies, are viewed as a third industrial revolution in most studies. Since they are likely to increase the growth potential, they give way to productivity gains, contributing in turn to improve the welfare of countries. However, some studies question the ability of ICT to involve major innovations inducing technological change (Gordon 2003).

These observations have been voiced from the American case, as the acceleration in productivity growth was associated with the strong contribution of ICT over the second half of the nineties.

Various estimates have been produced in the growth accounting framework, which rests on the Solow model.[1] Over the later period (1995–2001), the contribution of ICT capital deepening in the United States would have fluctuated in a 0.70 to 1 percentage point bracket whereas hourly labor productivity growth would have moved by 2% to 3% and multi-factor productivity by 0.40 to 0.99 points according to period and methodological choices (Oliner and Sichel 2002; Van Ark, Timmer, and Ypma 2003; Council of Economic Advisers 2002; Jorgenson, Ho, and Stiroh 2004; Jorgenson 2003).

Europe seems to be imbedded in the same dynamics as the United States but with a gap that it has not managed to fill. Over the six last years, the contribution of ICT capital deepening to hourly labor productivity growth would have accelerated by 0.13 points against the last five years but hourly labor productivity and MFP gains would have decelerated by 1.07 points and by 0.67 points respectively (Van Ark, Timmer, and Ypma 2003).

In this article, ICT contribution to growth in France is assessed at the aggregate level over 1982–2001. Labor input has been focused, inasmuch as it exists a complementarity between ICT assets and qualifications. Contributions of labor characteristics to labor quality are identified. Labor quality is essential to explaining composition effects that intervene at the aggregate level.

Results obtained in the growth accounting framework are then compared with those of some big European countries and with the United States.

[1] In this framework, the growth rate of hourly productivity is explained by the growth rate of capital services per hour that can be broken down into the growth rate of ICT and other ICT assets, by labor quality and by MFP (Multifactor Productivity) gains. MFP is calculated as a residual, reflecting events related to economic fluctuations (adjustment costs, rate of inputs use, etc.) or to structural factors (free externalities), measurement errors (chiefly upon the factor share in income considered to be equal to the elasticity of inputs in production), omitted variables (R&D [Research and Development] investment, etc.), and all deviations to the hypotheses underlying the neo-classical production function (increasing returns to scale, imperfect competition, etc.).

9.2. Methodology

The method initiated by Dale Jorgenson and described at length in Jorgenson, Gollop and Fraumeni (1987) is implemented in order to assess the ICT contribution to growth. After a presentation of the analysis framework (section 9.2.1), the methodologies used to build capital and labor services will be described (sections 9.2.2 and 9.2.3).

9.2.1. Analysis

The accounting method used to assess the contribution of the new economy to value-added and labor productivity growth in France is standard. The methodology applied is the one of Jorgenson and Griliches (1967) whose objective is to trace the quality of inputs to labor and capital composition changes.

The translog function, contrary to the one of Cobb-Douglas, allows the interaction of different effects to be enhanced. But some assumptions relating to these production functions may appear strong and deviations from them may bias results, namely the residual of the function. By assuming that production inputs are properly compensated against the services they render, they must be interpreted with caution. These limitations will be explained further in section 9.3.

9.2.2. Capital services

The construction of capital services (or the like) requires that the efficiency of each type of asset is taken into account.

In that respect, each type of asset i at time t can perfectly be substituted for another asset i at time t–1. It is assumed that data on investment at constant prices allow for differences in the performance of the various assets. This means that price series used to deflate the investment series at current prices reflect the efficiency of assets. For some assets like computers and some parts of communications equipment, hedonic prices are used (for instance in the U.S. and France). The asset price is regressed upon a set of related qualitative characteristics in order to retain quality and construct a constant quality price index. This roughly consists of extrapolating series backward in order to get the missing prices for brand-new equipment or forward for older equipment.

The specificity of the approach assumed by Jorgenson and Griliches (1967) relies upon the construction of asset rental prices, i.e. the cost of capital, which reflects the cost of using the asset at a given point in time. This cost embodies the price that will be paid by an agent to use the asset (put for rent).[2]

9.2.3. Labor services

Labor services are constructed along the same lines as capital services. Hours worked must be disaggregated according to their different characteristics in order to account for quality. If this disaggregation is not performed, neither substitution between the different inputs nor productivity growth can be identified properly.

Jorgenson's method (1987) is replicated to construct a constant quality index of labor volume with a translog function. Labor quality results from the difference between labor services and the growth rate of hours worked. Labor services are measured by the growth rate of total hours worked by each individual labor category weighted by its compensation share in total labor compensation.[3]

Each component is weighted by its marginal product under the neo-classical hypothesis according to which labor is compensated at marginal productivity. Some labor categories, such as women and younger people would be less compensated than men or older workers on the productivity account.

The prolific literature[4] that documents the gender wage gap discrimination, suggests among other things that firms anticipate gaps in women's careers due to child raising, etc., allowing for this wage gap. Along the same lines, younger workers will be trained and their adaptation to the workplace will take some time before becoming operative. As firms cannot check *ex-ante* the individual characteristics of hired (female or young) workers, they tend

[2] The method is described extensively in Appendix A.9.1.1.
[3] For more details, see Appendix A.9.1.2.
[4] See for example Baldwin, Butter and Johnson (2001).

to apply an average wage to the whole category. This refers to the labor contract incompleteness theory, according to which information asymmetries arise as efforts cannot be accurately measured across all workers.

Another criticism that can be directed at the use of the translog function is that market shortcomings are not accounted for, since insider workers and trade unions can negotiate higher compensation rates than the ones suggested by productivity gains. In France, this process has been relaxed with the decrease in the bargaining power of trade unions over time.

9.3. Results

Results on the evolution of labor quality in France and the specificities of the labor and French investment markets over the last twenty years will be first highlighted before addressing the issue of ICT contribution to growth.

9.3.1. Labor

Data

Detailed data on employment, hours worked and labor compensation by type come from two sources: the DADS (*Déclarations Annuelles de Données Sociales*) and the LFS (Labor Force Surveys).[5] As diplomas are only available in the LFS, both databases have been merged after performing relevant adjustments. Totals are then controlled for with the National Accounts figures on compensation and hours.

In the final database, we have chosen to separate out three categories: gender, age and education. Gender groups two (men, women), age gathers four (–25 years old, 25–34, 35–54, +54) and education six (tertiary education + four years in college or equivalent, tertiary education + two years in college or equivalent, baccalaureate, mid-secondary leaving certificate, low vocational diploma and no formal qualifications) characteristics. Then 48 characteristics are obtained (2*4*6).

[5] For a detailed description of sources, see Melka et al. (2003).

Analysis

Graphs 9.4 to 9.11 listed in the appendix display the hourly labor compensation and hours worked from 1982 to 2001 in the new compiled database. Regressions have been run against a set of dummies: labor compensation values per hour have been regressed on gender, age and education. This means that labor compensation values per hour are corrected for differences of other characteristics. These regressions allow us to retrieve the mean with a confidence interval. The results are very significant with a confidence interval below 1%.

Men are still better paid than women in spite of a wage catch-up. The compensation discrepancy between women and men was still about 22% in 2001. The fact that unskilled women are overpaid relative to their marginal productivity balances roughly the fact that skilled women are underpaid (Crépon and Heckel 2001). This is confirmed by Graph 9.6: in terms of education, hourly wages of women graduates reached a trough in the 1991–95 period at 61% of male graduates' wages and have gone up afterwards by some 5 percentage points. In comparison, less educated women are better paid.

In terms of hours worked, people below 25 and above 54 show the most erratic moves. Over the last period, the growth rate of hours worked by labor below age 25 goes up at last. The upward trend of the 35–54 age bracket's hours is also a reflection of the funnel-shaped age pyramid.

Over all periods, the strongest wage growth rates, by age bracket, are recorded by workers above 54 but few of them remain in the working population. This could exemplify the accumulation of human capital over the whole working life, though Crépon et al. (2002) show that older workers are overpaid relative to their marginal productivity.

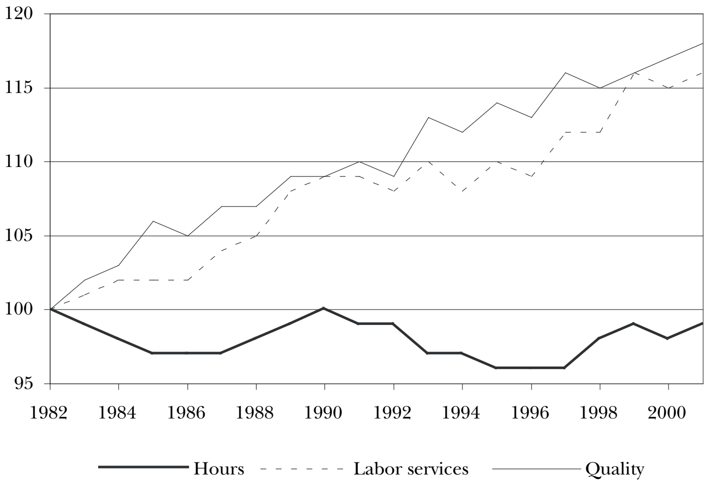
In terms of education, hours worked by those graduating at the university or equivalent level have been rising since 1982 while hours worked by unskilled workers have kept on a downward slope. This could mirror as well a general rise in education as a skill-bias of technological change. As might be suspected, workers with baccalaureate + two years at university can be second best substitutes for those with higher degrees, since the gap between wages of both categories narrows further, and specifically in ICT jobs (Graph 9.11). Moreover, the implementation of technologies can require overall higher qualifications of those who occupy a new job.

9.3.2. The evolution of labor quality in France

Graph 9.1 shows labor services, quality and non-weighted hours worked, computed on gender, age and education characteristics since 1982. Quality has increased steadily since 1982. It follows roughly the trend of labor services. Hours worked hardly meet their 1982 level at the end of the period. As the difference between labor services and hours worked is the compensation weighting scheme, this means quality has been driven up by the categories whose share in compensation increases.

As shown in Table 9.1, the growth in the labor quality index is above all due to the rise in labor services over the whole 1982–2001 period, as non-weighted hours worked show a small and negative contribution. However, the breakdown in sub-periods allows the fall in hours worked over the 1990–95 period and their rise in the 1995–2001 years to be contrasted.

GRAPH 9.1: **Labor services, hours worked and labor quality**
(1982 = 100)



Note: 1999 to 2001 are extrapolated with figures from the LFS. Labor services and quality are calculated with gender, age and education characteristics.
Source: DADS and National Accounts, INSEE (Institut National de la Statistique et des Études Économiques).

TABLE 9.1: Contributions to French quality, annual average
(percentage)

	1982–2001	1982–90	1990–2001	1990–95	1995–2001
Quality	**0.87**	**1.13**	**0.68**	**0.84**	**0.54**
Gender	–0.02	0.00	–0.04	–0.06	–0.02
Age	0.18	0.44	0.00	0.26	–0.22
Education	0.71	0.70	0.71	0.70	0.72
Σ interactions	0.00	–0.02	0.01	–0.05	0.07
Non-weighted hours	**–0.07**	**–0.04**	**0.10**	**–0.71**	**0.40**
Weighted hours (labor services)	**0.80**	**1.10**	**0.58**	**0.14**	**0.94**

Quality = Weighted hours – Non-weighted hours.
Source: DADS, LFS, National Accounts, and CEPII (Centre d'Études Prospectives et d'Informations Internationales), authors' calculations.

Contributions to labor quality show that skills and age loom large in this context. First, age plays a major role in the deterioration of quality over 1995–2001 due to the increase in unemployment of the oldest, the category with the highest compensation. This negative effect could not be cancelled out by the increase in hours worked by the youngest and by the 35–54 age bracket over this period. Second, education is a strong stimulus to labor quality. The contribution of education remains strong and has been ever growing over the whole period.

The findings for the United States (Table 9.2) contrast noticeably with French results, hours worked and quality contributing positively to labor services throughout all periods. In the 1980s, the quality index is driven up by age and education. Over the 1990s, a deterioration of the quality index is mostly due to the increase in hours worked by less educated people. The upper age brackets (35–54 and above), still the most represented in the hours worked and compensation share increase, have a positive impact on quality. Workers below age 25 see their hours increase more slowly. However, the employment status of the young is diverging between France and the United States: the American ratio of employment of the youngest to the working age population (57.8%) quite outstrips the French one (24.3%) in 2001 (*Employment Outlook,* OECD 2002).

The use of labor services or hours worked matters to the extent that labor quality in France fluctuates more according to labor services than hours. Furthermore, the strong contribution of education to labor quality leads to question the role of qualifications in the diffusion of technology.

TABLE 9.2: Contributions to American quality, annual average
(percentage)

	1982–2001	1982–90	1990–2001	1990–95	1995–2001
Quality	**0.46**	**0.49**	**0.45**	**0.55**	**0.36**
Gender	–0.08	–0.12	–0.05	–0.01	–0.08
Age	0.24	0.26	0.23	0.25	0.21
Education	0.33	0.40	0.28	0.27	0.29
Σ interactions	–0.03	–0.05	–0.01	0.03	–0.05
Non-weighted hours	**1.71**	**2.28**	**1.30**	**1.06**	**1.50**
Weighted hours (labor services)	**2.17**	**2.76**	**1.75**	**1.61**	**1.86**

Source: Data from Harvard (D. Jorgenson) and CEPII, authors' calculations.

9.3.3. Capital

Prior to the presentation of the growth accounting results in a French setting and then in an international one, we will present an analysis of the evolution of ICT price and investments in France.

9.3.3.1. Investment series

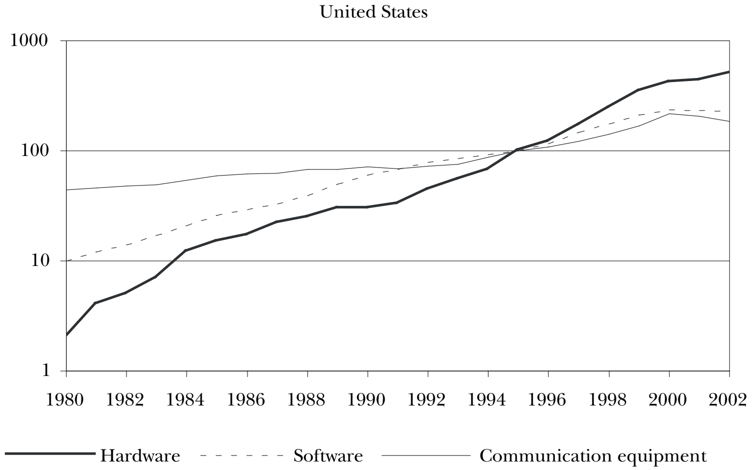
Data and analysis

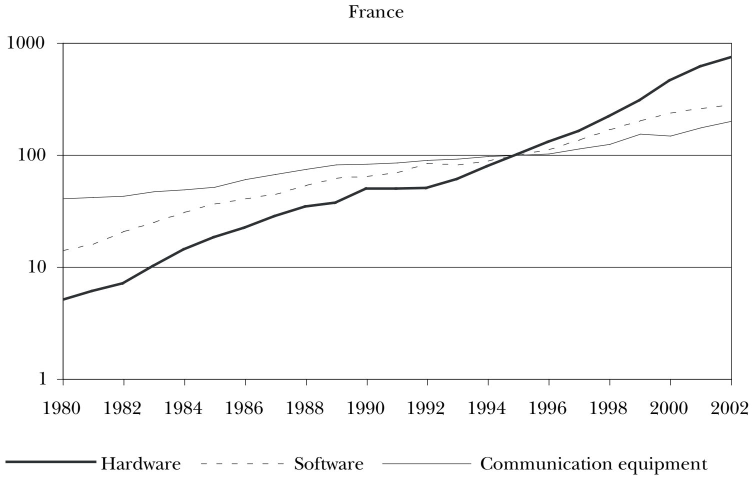
Out of six assets three are ICT assets (hardware, software, and communications equipment). The three other categories are non-residential structures and buildings, transport equipment and other machinery. Statistics used are released by INSEE. The underlying hypotheses are shown in Table 9.6.

The growth of investment in ICT at constant prices has dramatically surged over the last twenty years, due to the strong increase in hardware equipment at an annual pace of 29% over the 1982–2001 period. Investments in software have grown at the same time by 14% and those in communications equipment have increased by only 5%. Moreover, the growth in investments has mainly taken place over the last five years (1995–2001).

When comparing the evolution of ICT investments in volume in the United States and in France, it becomes evident that ICT investment growth in France was about the same as in the United States in the second half of the decade. Over 1995–2001, the growth rate of French investment in hardware and software (42% and 17% respectively) exceeded the United States (30% and 14% respectively). Conversely, the growth rate of French investments in communications equipment (2%) featured a substantial difference with the United States, which was 10%.

GRAPH 9.2: Evolution of French and American ICT investments at chained prices
Logarithmic scale
(1995 = 100)





Source: CEPII, authors' calculations.

Another difference is worth emphasising: the share of ICT investment in GDP (Gross Domestic Product) in France was well below the American level (see Table 9.7). This can cause substantial differences in terms of catch-up in a growth accounting framework.

9.3.3.2. Price series

Data

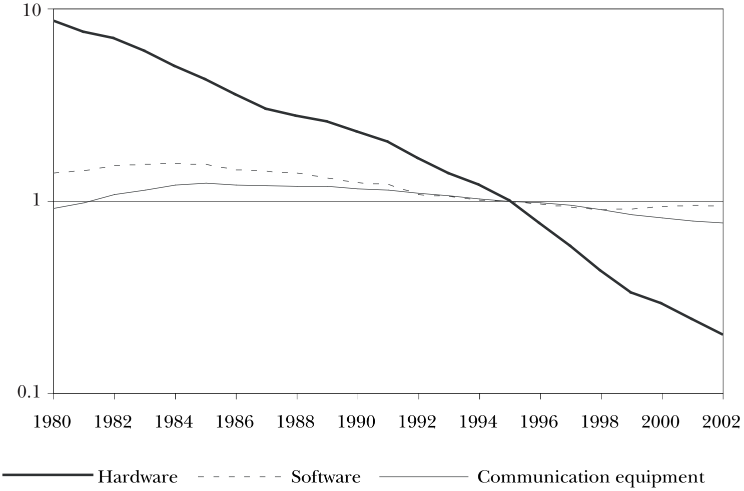
By applying the methodology suggested by Jorgenson, efficiency and substitution between assets can be taken into account. To do so, it is assumed that prices reflect the evolution of efficiency and then the quality of assets. Nonetheless, statistical offices have been constructing hedonic price series only for a short time. In France, the INSEE has been constructing such time series only for hardware (microcomputers and peripherals) since 1990. Other methods are used to construct index prices adjusted for quality of other types of assets (namely the matching method). Different approaches to elaborating methods can account for a very large gap between the U.S. and the European figures. For example, if software prices in France were estimated in the same way as in the U.S., then software investments in volume would be at least twice as high as their present figures (see Lequiller 2000; Oulton 2001).

Two ways of settling the price issue can be contemplated in order to make prices consistent with the U.S.:

- Using American ICT prices corrected for 50% of the exchange rate with the dollar. This method is chosen by Cette, Mairesse and Kocoglu (2000). With this correction, it is assumed that half of ICT equipment is imported. The growth rate of the price index is equal to the moving average over three periods of the BEA (Bureau of Economic Analysis) price index growth rate plus half the dollar/FF exchange rate change.
- Constructing new price series by applying the method devised by Schreyer (2000) that consists of applying the difference between non-ICT equipment prices and ICT prices prevailing in the U.S. to French prices of non ICT equipment.

The evolution of French hardware imports points to a significant change in the share of investments in imports over time. Thus, it cannot be assumed that this share is constant and identical for hardware and software. The Schreyer method suits us better in so far as the gap between American prices of ICT and non-ICT equipment fluctuates throughout the period and is different according to the type of ICT equipment.

GRAPH 9.3: ICT price growth in France (Schreyer's method)
Logarithmic scale
(1995 = 1)



Source: CEPII, authors' calculations.

Analysis

Firstly, the method used to construct price series greatly influences the increase in ICT investment prices, as could be expected.

A strong divergence in the evolution of ICT prices by type of asset can also be appreciated. Hardware prices fall very steeply over the period 1982–2001, whereas software and communications equipment prices increase up to the mid-1980s.

9.4. Growth accounting

9.4.1. Contributions of ICT to French economic growth

Several issues can be mooted following our estimates of the ICT contribution to French economic growth. The choice of price series is one of them. The ICT contribution to French economic growth can be estimated accordingly.

The ICT contribution to growth experiences a strong rise from 0.21 per year over the 1990–95 period to 0.40 per year over 1995–2001 (Table 9.3). Moreover, the ICT contribution has dramatically increased relative to the contribution of other equipment goods.

TABLE 9.3: Contributions to gross value added average annual growth
(percentage and percentage points)

	France				United States	
	1982–2001	**1982–90**	**1990–95**	**1995–2001**	**1990–95**	**1995–2001**
GVA[1] (percentage)	2.11	2.57	1.09	2.61	2.42	3.42
Capital services	**1.03**	**1.22**	**0.96**	**1.05**	**1.43**	**2.03**
Total ICT	0.31	0.36	0.21	0.40	0.63	1.01
Hardware	0.19	0.24	0.11	0.23	0.32	0.46
Software	0.08	0.06	0.04	0.14	0.21	0.32
Communications	0.04	0.06	0.06	0.03	0.10	0.22
Non-residential structures	0.41	0.47	0.51	0.32	0.52	0.58
Transport	0.09	0.06	0.05	0.16	0.09	0.16
Other equipments	0.22	0.33	0.15	0.17	0.19	0.29
Labor services	**0.48**	**0.71**	**0.06**	**0.62**	**1.01**	**1.16**
Total hours	–0.04	–0.05	–0.48	0.27	0.67	0.93
MFP	**0.58**	**0.63**	**0.12**	**0.94**	**–0.02**	**0.23**

[1] Gross Value Added.
Note: Non-residential investments of total economy (except household investment).
Source: CEPII, authors' calculations on data from INSEE, LFS for France; data from BEA and Harvard (D. Jorgenson) for the U.S.

Among ICT assets, communications equipment performs poorer in terms of growth and acceleration. Also, the contribution of non-residential structures continue to fall throughout the nineties.

More balanced growth over the 1995–2001 period, like in the eighties, contrasts with the 1990–95 period, when growth was almost exclusively fuelled by capital services. Just as in the 1980s, the contribution of labor services and MFP to growth is noticeably stronger.

The U.S. economy performs better than France with regard to growth. ICT contributed almost half of capital services over the 1990–95 period. What is striking when comparing French and American figures is the still buoyant capital and labor services used in the American economy over the last period. The MFP contribution is below that of France. This result stands out against most studies in which 2001, a recession year, was assessed. In this article, the NIPA (National Income and Product Accounts) figures (revised in March 2004) were used.

Analysis of multi-factor productivity

Multi-factor productivity is calculated as a residual over the sum of the different contributions of inputs. The more accurately the contribution of inputs (capital, labor) is estimated, that is to say the better it accounts for the improvement in labor and capital quality, the weaker the TFP (Total Factor Productivity) (Jorgenson and Griliches 1967). Even so, the residual is too big to be interpreted solely as mere measurement errors. It is rather "a measure of our ignorance," as pointed out by Abramovitz.[6]

It is difficult to make out in multi-factor productivity growth what share is attributable to economic fluctuations (Gordon 2002), to other factors such as deviations from the underlying hypotheses of the translog function (perfect competition…), to changes in capital shares or to structural changes such as technological and organisational innovations not captured in physical or human capital.

Any reversal in the cycle may impact multi-factor productivity. Cette, Mairesse and Kocoglu (2002) contend that more than 30% of the contribution of multi-factor productivity to value-added growth would be explained by cyclical factors over the last twenty years.

Comparison with other studies on France

Few studies besides those by Cette, Mairesse and Kocoglu. (2000, 2002) and Colecchia and Schreyer (2001) have used an accounting framework including ICT. It is not easy to compare our results with these studies in so far as the mapping is different. Contrary to our work based on the aggregate economy, the studies mentioned above assess the contribution of ICT to growth for the business sector. Ours come out with higher ICT contributions.

The main differences that stand out with other studies are the following: our study covers the whole economy whereas Cette et al. and Colecchia and Schreyer assess the contribution of ICT to French growth for the business sector. An internal rate of return is used to calculate the user cost while the two other studies take an external rate of return. Moreover, Colecchia and Schreyer assume hyperbolic depreciation rates as we use geometric ones. Cette et al. also use geometric depreciation rates but they are not the same rates and they do not compute labor services.

In other respects, the average hourly labor productivity growth in France must be considered in order to be contrasted with

[6] Quoted in Hulten (2000). For an extensive review, see Hulten (2000).

the American trend over the last ten years. The extent of the magnitude of the accumulation of ICT capital is a question worth being examined.

9.4.2. Average hourly labor productivity

French hourly labor productivity growth slows noticeably over the 1980s and 1990s (Table 9.4). Over the 1995–2001 period, it improves due to the fall in hours in the manufacturing sector (except in 2000 and 2001) and to the shift to a 35-hour-week, although some economic policy measures could have counterbalanced these effects. In fact, the French policy regarding the reduction in social contributions upon low wages and the employment of young people was started in 1993. These measures have been reinforced since 1995. They have led to a significant slow-down in labor quality, on account of a negative contribution of age to quality.

Average hourly labor productivity growth can be explained by the substitution of capital for labor *(capital deepening*) and the improvement of MFP.

A substitution of capital for labor has a positive impact on labor productivity as it makes workers more productive. The skill-biased technological change, if embodied, is accounted for in capital deepening. Thus, any increase in the substitution of capital for unskilled labor should improve labor quality through the positive effect of the contribution of education.

TABLE 9.4: **Growth sources of average hourly labor productivity**

	France				**United States**	
	1982–2001	**1982–90**	**1990–95**	**1995–2001**	**1990–95**	**1995–2001**
ALP	**2.27**	**2.60**	**1.80**	**2.21**	1.35	1.92
K/H substitution	1.10	1.21	1.13	0.91	1.03	1.46
Of which : ICT:	0.33	0.36	0.20	0.39	0.57	0.91
Hardware	0.20	0.24	0.10	0.23	0.30	0.44
Software	0.08	0.06	0.05	0.14	0.19	0.29
Communications	0.05	0.06	0.05	0.03	0.08	0.19
Labor quality	0.57	0.76	0.53	0.35	0.34	0.23
Contribution gender	–0.01	0.00	–0.04	–0.01	–0.01	–0.05
Contribution age	0.14	0.32	0.18	–0.15	0.16	0.13
Contribution education	0.44	0.43	0.42	0.45	0.17	0.18
MFP	0.59	0.63	0.12	0.94	–0.02	0.23

Note: See Table 9.3. The contribution of interactions is not shown here in the breakdown of labor quality.
Source: CEPII, authors' calculations on data from INSEE, LFS for France; data from BEA and Harvard (D. Jorgenson) for the U.S.

Over the last decade there has been a capital deepening and labor quality growth slowdown, in spite of the increasing contribution of ICT. The capital deepening acceleration is twice as high with respect to hardware and even three times as high when software is considered. This increase is accompanied by a sharp decrease in the contribution of non-ICT capital deepening (non-residential structures and to a lesser extent other non-ICT equipment). The contribution of education has managed to slow the decline of the labor quality index.

Compared with France, American labor productivity growth hinges more on capital deepening and heavily on ICT capital over the last period. Labor productivity growth is more due to the extension of factors of production (capital and labor) than to changes in the MFP. The acceleration of ICT capital intensity doubles, as in France, but departing from a much higher absolute level.

For the U.S., MFP and labor quality are below the French level. With regard to MFP, the French comply with stricter regulations in the labor market than the U.S. does and then implement strategies of capital replacement, making workers more productive. Furthermore, the labor force is younger in the U.S. than in France and labor quality turns to be lower relative to France. Composition effects cannot be ignored when both countries are compared.

International comparison

Results for the French economy can be compared with those of other OECD (Organisation for Economic Co-operation and Development) countries (Table 9.4). ICT contribution to the average hourly labor productivity growth was assessed for the United States, Germany and the United Kingdom. For these countries, an internal rate of return is used to calculate capital user costs. Also, the shares of capital income and labor compensation are adjusted in order to integrate self-employed workers' mixed income in labor compensation.

Average hourly labor productivity growth in all countries is close to 2% over the 1995–2001 period. Between 1990–95 and 1995–2001, average hourly labor productivity growth accelerates in France, in the United States and in Germany, whereas it decreases in the United Kingdom. The slump in the latter country is attributable to a fall in non-ICT investments and to a sharp decrease in the MFP contribution.

In all countries over the nineties, a steep acceleration of ICT contribution to growth is observed, greater in the United States and in the United Kingdom than in France and Germany. It should be noted that the share of capital income in value-added (37%) used for the U.S.[7] is above the one applied to the German (0.35%), French (0.33%) or British (0.32%) series over the 1995–2001 period.

The acceleration of ICT capital contribution to ALP (Average Labor Productivity) growth results from a strong increase in hardware investments, chiefly in the United Kingdom. Labor quality rises in the United Kingdom whereas it decreases in France, Germany and the United States between both periods of the nineties: in France on account of age and in Germany and the U.S. because of the greater use of hours worked by less educated workers.

To sum up, over the latest period the Anglo-Saxon countries' share as common characteristics a high level of ICT investment and weaker MFP, while the other two countries end up with less dynamic ICT investments and a stronger MFP contribution. These differences may stem from institutional patterns as the financing of investments and the degree of flexibility in the labor markets hinders business creation. Short term financing, more flexible labor markets and plainer business setup rules encourage firms to react to price and wage moves and to invest in smaller structures. The employment of the unskilled can then be promoted but at the price of productive efficiency.

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[7] Capital income (gross operating surplus or capital services in level at current prices), is the difference between GDP at current prices and total labor compensation (Taxes and subsidies are not taken into account). For the U.S., the share of capital income computed in BEA statistics gives 33% over the last period. Capital income in GDP amounts to 41% in D. Jorgenson's works, 25% in the OECD productivity database, and 30% in Van Ark, Timmer and Ypma (2003). For more details see Schreyer (2003).

TABLE 9.5: Sources of average hourly labor productivity growth
(percentage and percentage points)

	1990–95				1995–2001			
	U.S.	**G**	**UK**	**FRA**	**U.S.**	**G**	**UK**	**FRA**
GVA/H[1] (percentage)	1.35	1.87	3.19	1.80	1.92	2.05	2.22	2.21
Capital	1.03	1.08	1.89	1.13	1.46	1.09	1.41	0.91
ICT:	0.57	0.22	0.53	0.20	0.91	0.39	0.85	0.39
Hardware	0.30	0.09	0.36	0.10	0.44	0.25	0.62	0.23
Software	0.19	0.06	0.12	0.05	0.29	0.09	0.15	0.14
Communications	0.08	0.06	0.05	0.05	0.19	0.06	0.07	0.03
Other capital	0.46	0.86	1.37	0.93	0.55	0.70	0.57	0.52
Labor quality	0.34	0.95	0.14	0.53	0.23	0.28	0.35	0.35
MFP	–0.02	–0.16	1.15	0.12	0.23	0.68	0.45	0.94

[1] Gross Value Added/hours worked.
Note: 1991–95 for Germany and 1995–2000 for UK; Hardware includes all items of NACE 30 (Nomenclature Générale des Activités Ëconomiques dans les Communautés Européennes) for Germany. Non-residential investments of total economy (except household investment) for all countries.

Source: Investment: Groningen (except for France INSEE; U.S., BEA; UK, NIESR [National Institute of Economic and Social Research]) – Hours: U.S., Harvard; Germany and UK series from the University of Groningen (OECD); France from INSEE; labor quality: U.S., Harvard; France, LFS; UK, A. Colecchia (OECD); CEPII, authors' calculations.

9.5. Conclusion

ICT was focused on as it is viewed as a breeder of technological change in the economy. Its contribution to the hourly labor productivity growth should then entail an improvement in labor quality and produce an increase in the efficient combination of inputs. The acceleration of ICT capital deepening between 1990–95 and 1995–2001 was accompanied by a rise in multi-factor productivity but not by an improvement in labor quality.

French labor quality increased in the eighties by 0.8% per year. Over the last period, the fall in the French labor quality is in sync with the fall in hours worked by older workers (above age 54) and a rise in hours worked by less well-paid workers and particularly young workers. The strong education contribution to labor quality perhaps indicates that labor costs for young graduates have fallen further as the general education level has risen. This upgrading of education could have dampened the demand effects for higher skills induced by a possible technological bias towards skilled labor.

In the two other countries, the United States and the United Kingdom, more unskilled people were employed while ICT investment has dramatically risen. This points in turn to the connection between ICT and MFP. This link can be investigated in two directions. Weaker acceleration may mean that an organisational change has not taken place to a greater extent in the wake of ICT. The alternative may be that the substitution of skilled labor for unskilled labor is not so dramatic. Skill-biased technological change must then be further explored in order to determine in which sectors it occurs, namely sectors defined according to their intensity in skilled labor.

References

BALDWIN, Marjorie L., Richard J., BUTTER, and William JOHNSON. "A Hierarchical Theory of Occupational Segregation and Wage Discrimination." *Economic Inquiry* 39, no. 1 (January 2001): 94–110.

CETTE, Gilbert, Jacques MAIRESSE, and Yusuf KOCOGLU. "Croissance économique et diffusion des TIC : le cas de la France sur longue période (1980–2000)." *Revue Française d'Economie* 16 (2002): 155–92.

—. "Les technologies de l'information et des communications en France: diffusion et contribution à la croissance." *Economie et Statistique* 339-40 (September–October 2000): 117–46.

COLECCHIA, Alessandra, and Paul SCHREYER. *ICT Investment and Economic Growth in the 1990s: Is the United States a Unique Case? A Comparative Study of Nine OECD Countries.* STI Working Paper 2001/7. Paris: Organisation for Economic Co-operation and Development, Directorate for Science, Technology and Industry, 2001. (Later published as "ICT Investment and Economic Growth in the 1990s: Is the United States a Unique Case? A Comparative Study of Nine OECD Countries." *Review of Economic Dynamics* 5, no. 2 [2002]: 408–42.)

COUNCIL OF ECONOMIC ADVISERS. *Economic Report of the President.* Washington, DC: U.S. Government Printing Office, 2002.

CRÉPON, Bruno, and Thomas HECKEL. "La contribution de l'informatisation à la croissance française: une mesure à partir de données d'entreprises." *Economie et Statistique* 339–40 (2001): 93–115.

GORDON, Robert J. *Technology and Economic Performance in the American Economy.* NBER Working Paper no. 8771. Cambridge, MA: National Bureau of Economic Research, 2002.

—. "Five puzzles in the behavior of productivity, investment, and innovation," draft for the chapter written in the "Global Competitiveness report, 2003–2004." *World Economic Forum,* (September 2003).

HULTEN, Charles R. *Total Factor Productivity: A Short Biography.* NBER Working Paper no. 7471. Cambridge, MA: National Bureau of Economic Research, 2000.

HO, Mun S., and Dale W. JORGENSON. "The Quality of the US Work Force, 1948–95." Mimeo, Harvard University, Cambridge, MA, 1999.

JORGENSON, Dale W. "Information Technology and the G7 Economies." *World Economics* 4, no. 4 (October–December 2003): 139–70.

—. "Information Technology and the U.S. Economy." *American Economic Review* 91, no.

1 (March 2001): 1–32.

JORGENSON, Dale W., Frank M. GOLLOP, and Barbara FRAUMENI. "Productivity and US Economic Growth." In Jan Tinbergen, ed. *Contributions to Economic Analysis*. Amsterdam: Elsevier-North Holland, 1987.

JORGENSON, Dale W., and Zvi GRILICHES. "The Explanation of Productivity Change." *Review of Economic Studies* 34, no. 3 (July 1967): 249–80.

JORGENSON, Dale W., Mun S. HO, and Kevin J. STIROH. "Growth of US Industries and Investments in Information Technology and Higher Education." In C. Corrado, C. Hulten and D. Sichel, eds. *Measuring Capital in a New Economy*. Chicago: University of Chicago Press, 2004, 403–72. (Also published in *Economic Systems Research* 15, no. 3 [September 2003]: 279–327.)

LEQUILLER, François. "La nouvelle économie et la mesure de la croissance." *Economie et Statistique* 339–40 (2000): 45–72.

MELKA, Johanna, Laurence NAYMAN, Soledad ZIGNAGO, and Nanno MULDER. *Skills, Technology and Growth: Is ICT the Key to Success? An Analysis of ICT Impact on French Growth*. CEPII Working Paper no. 2003-04. Paris: Centre d'Études Prospectives et d'Informations Internationales, 2003. Available online at http://www.cepii.fr/anglaisgraph/workpap/pdf/2003/wp03-04.pdf.

OECD. *A New Economy? The Changing Role of Innovation and Information Technology in Growth*. Paris: Organisation for Economic Co-operation and Development, 2000.

—. *Employment Outlook*, Paris: Organisation for Economic Co-operation and Development, 2002.

—. Productivity database. Organisation for Economic Co-operation and Development, Paris. Available online at http://www.oecd.org/topicstatsportal/0,2647,en_2825_30453906_1_1_1_1_1,00.html.

OLINER, Stephen D., and Daniel E. SICHEL. "Information Technology and Productivity: Where Are We Now and Where Are We Going?" *Economic Review* 87, no. 3, Third Quarter, Federal Reserve Bank of Atlanta (2002): 15–44. Available online at http://www.frbatlanta.org/filelegacydocs/oliner_sichel_q302.pdf.

OULTON, Nicholas. *ICT and productivity growth in the United Kingdom*. Bank of England Working Paper no. 140. London: Bank of England, 2001.

PILAT, Dirk, and Frank C. LEE. *Productivity Growth in ICT–Producing and ICT-Using Industries: A Source of Growth Differentials in the OECD?* STI Working Paper no. 2001/4. Paris: Organisation for Economic Co-operation and Development, Directorate for Science, Technology and Industry, 2001.

SCHREYER, Paul. *The Contribution of Information and Communication Technology to Output Growth: A Study of the G7 Countries*. OECD Science, Technology and Industry Working Paper no. 2000/2. Paris: OECD Directorate for Science, Technology and Industry, 2000.

—. "Measuring Multi-Factor Productivity when Rates of Return are exogenous." Paper presented at the workshop on "Rethinking TFP measurement", Ottawa, October 27–28, 2003.

VAN ARK, Bart, Johanna MELKA, Nanno MULDER, Marcel TIMMER, and Gerard YPMA. "ICT Investment and Growth Accounts for the European Union, 1980–2000." Final report prepared for the DG Economics and Finance of the European Commission, Brussels, June 2002. Available online at http://www.eco.rug.nl/GGDC/dseries/Data/ICT/euictgrowth.pdf.

VAN ARK, Bart, Marcel TIMMER, and Gerard YPMA. "IT in the European Union: Driving Productivity Divergence?" GGDC Research memorandum, GD-67, Groningen Growth and Development Centre, University of Groningen, Groningen, October 2003.

Appendix 9.1. Methodology

A.9.1.1. Capital services

First step: Construction of a productive capital stock: The permanent inventory method

According to the permanent inventory method, capital stock is defined as the weighted sum of past investments. The weights are defined by the relative efficiency of capital assets of different ages.

The capital stock for the asset *i* at time *t* is defined by:

$$K_t = \sum_{\tau=0}^{\infty} d_\tau I_{t-\tau} \tag{A.9.1}$$

where K_t is the capital stock (of a given asset) at time t, d_τ represents the efficiency of capital at age τ relative to the efficiency of a new capital good bought at time $t-\tau$.

It is then necessary for the follow-up of our study to know the pattern acknowledging the loss of efficiency. The rate of depreciation chosen is a geometric rate, contrary to Colecchia and Schreyer (2001) who use a hyperbolic depreciation rate.

The capital stock is defined by:

$$K_{i,t} = K_{i,t-1}(1-d_i)+I_{i,t} = \sum_{\tau=0}^{\infty}(1-d_i)^\tau I_{i,t-\tau} \tag{A.9.2}$$

with:

d: geometric rate of depreciation,

I : investment at constant prices,

τ : age of capital,

i is the asset type and *t* is time.

Second step: Construction of the rental price of capital services (or cost of capital)

Our next objective is to construct costs of capital in the same way as Jorgenson, Gollon and Fraumeni (1987).

The cost of capital is equal to the cost of financing the asset *i* less the loss or gain in capital.

$$c_{i,t} = P_{i,t-1}(r_t - \frac{P_{i,t} - P_{i,t-1}}{P_{i,t-1}}) + P_{i,t} d_i \qquad \text{(A.9.3)}$$

$P_{i,t}$: price of the asset i at time t,

r_t : rate of return of capital at time t.

The first term reflects the cost of financing the asset i with $p_{i,t-1} r_t$ being the opportunity or the financial cost borne at the time of the acquisition of the asset.

The second term points to the gain or the loss in capital generated by the reselling of this asset after use.

The third one, $P_{i,t} d_t$, is the cost related to the declining efficiency of the asset since its acquisition.

The rental price of capital services is thus equivalent to the price of using the asset during a given period of time, under the consideration of its declining efficiency during this period and its resale at the end of the period.

Which rate of return must be chosen?

To compute the cost of capital, the alternative between ERR (External Rates of Return), such as the long rates on government bonds and an IRR (Internal Rate of Return) comes forth.

The internal rate of return is calculated on the following accounting definition:

Income from capital = GVA – labor compensation.

Capital income is then defined by the NA (National Accounts). Likewise, as capital income is the product of the capital stock in volume and the price of capital, the rate of return can be deduced from the following formula:

$$CapInc = c_t K_{t-1} = \sum_i \left\{ P_{i,t-1} \left(r_t - \frac{P_{i,t} - P_{i,t-1}}{P_{i,t-1}} \right) + P_{i,t} * d_i \right\} K_{i,t-1} \qquad \text{(A.9.4)}$$

The choice of a IRR or a ERR reveals numerous drawbacks. If a ERR is adopted, the cost of capital used as a weight (the average share of each component in the value of property compensation) to estimate capital services, is determined externally. As a result, income from capital defined by the product of the cost of capital by the capital stock is different from capital income defined in the national accounts.

As for the IRR, its use implies that the function of production has constant returns of scale and that markets are perfectly competitive. Moreover, with an internal rate of return, the cost of capital can turn out to be negative, whereas this is not the case for the ERR. As a matter of fact, due to high asset inflation rates and low depreciation rates relative to interest rates, the cost of capital can be negative.[8]

In spite of this drawback, the IRR will be chosen in order to keep consistency in the accounting framework.

We get then the following equation:

$$r_t = \frac{CapInc - \sum_i (d_i * P_{i,t} - \Pi_{i,t} * P_{i,t-1}) * K_{i,t-1}}{P_{i,t-1} * K_{i,t-1}} \qquad \text{(A.9.5)}$$

with $\Pi_{i,t} = \frac{P_{i,t}}{P_{i,t-1}} - 1$.

Third step: Construction of the aggregate index of capital services

The aggregate index of capital services for all assets is assumed to be a translog function of individual capital services (Jorgenson, Gollop, and Fraumeni 1987). The index of aggregate capital is defined by:

$$\Delta \ln K_t = \sum_i \bar{v}_i \Delta \ln K_{i,t} \qquad \text{(A.9.6)}$$

The weights are given by the average shares of each asset type in total property compensation:

$$\bar{v}_k = 0.5(v_{k,t} + v_{k,t-1})$$

$$v_{k,t} = \frac{c_{k,t} K_{k,t}}{\sum_i c_{k,t} K_{k,t}}$$

where c_i is the user cost of asset *i*.

[8] For a more extensive explanation, see Jorgenson, Ho and Stiroh (2004).

A.9.1.2. Labor services

Jorgenson's method (1987) is replicated in order to construct with a translog function a constant quality labor volume index. This index of labor services is a weighted average of the growth rate of hours worked according to labor characteristics.

$$\Delta \ln L = \sum_{l} \bar{v}_{Ll} \, \Delta \ln H_l$$

with L, labor services, H, hours worked and v, the weight. The overstrike stands for an average. The weight bears on the share of compensation of each characteristic in total compensation and is computed with a Törnqvist index, where $P_l L$ is compensation related to the considered characteristic:

$$v_l = \frac{P_l^L L_l}{\sum P_l^L L_l}$$

$$\bar{\upsilon}_{Ll} = 0.5 * \left[\upsilon_{Ll}(t) + \upsilon_{Ll}(t-1)\right]$$

The use of the translog function allows interactions of different characteristics. For each characteristic of the labor force (for example, gender, age, occupation, etc.), the growth rate of hours worked weighted by the compensation share of the considered category is computed to get first-order partial indices. For instance, the first-order index computed over gender is the growth rate of hours worked by women and men weighted by the corresponding compensation of women and men. The different characteristics are then combined with each other to get second-order indices (for example gender and age: the growth rate of hours worked by women and men that are less than 25 years old, between 25 and 34 and so on, weighted by their relative compensation rate), 3rd-order indices (the combination of gender, age and occupation), 4th-order indices (the interaction of gender, age, occupation and part-time jobs) and 5th-order indices (the combination of all characteristics). The last order will constitute the labor services as the weighted growth rates of each characteristic are summed to get the final labor services.

Contributions to labor quality

The ratio of labor services computed on the different orders to the growth rate of hours worked (that are not weighted) is designed to measure the labor input quality. The quality index is the constant that allows hours worked to be transformed into flows of labor services. This gives a measure of the contribution of substitution between components of the labor input relative to the volume of hours worked.

$L_L = Q_L * H$, or:

$Q_L = L_L / H$, L being labor services, product of Q_L, the quality of labor and H, non-weighted hours worked.

$$\Delta \ln Q^L = \sum_l \bar{v}_{Ll} \Delta \ln H_l - \Delta \ln H$$

If components of hours worked grow at the same pace, the labor quality index, Q_L, remains unchanged. The quality index increases when components generating the most labor services—workers whose marginal product is high—grow faster than the other characteristics. On the contrary, it decreases when the least efficient hours worked grow faster than the others.

Contributions to the quality index growth allow changes in the composition of hours worked by each characteristic to be captured. Contributions of the different characteristics to the quality index growth are computed from the partial indices and hours worked.

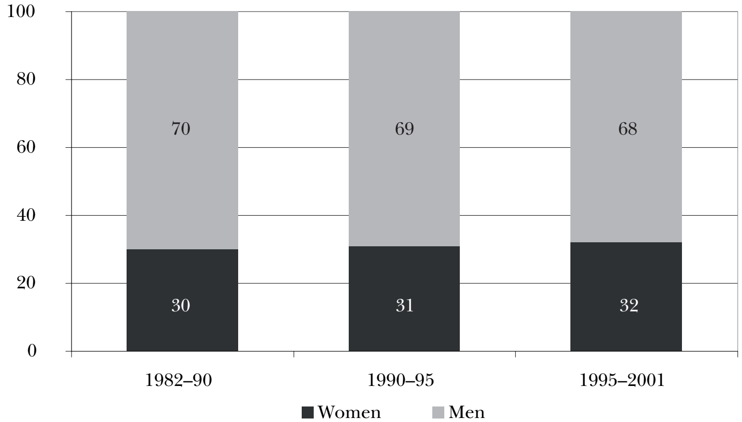
Partial first-order indices of labor input differentiated relative to the growth rate of hours worked indicate the contribution of each characteristic to the labor quality index growth. Partial second-order indices of labor input differentiated against the growth rate of hours worked reflect the interaction between two characteristics excluding the effect of all others. This calculation is continued to the last order.

Appendix 9.2. Graphs and tables

GRAPH A.9.2.1: Growth rate of hours worked by gender
(1982 = 100)

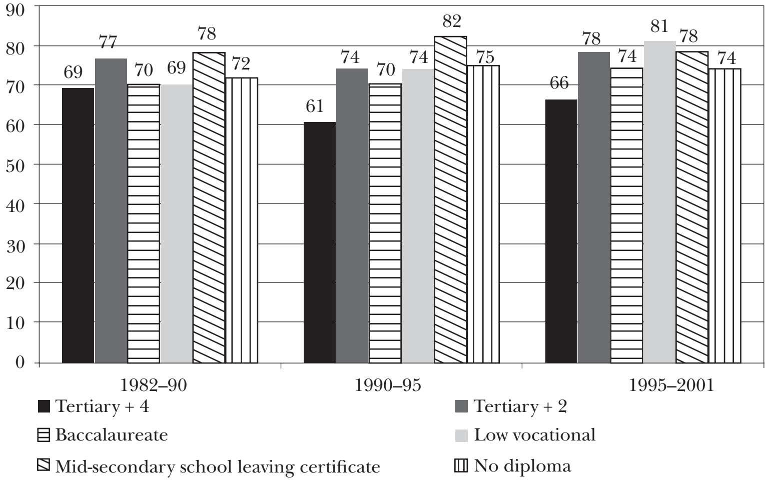
Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.2: Composition of wages by gender
(percentage)



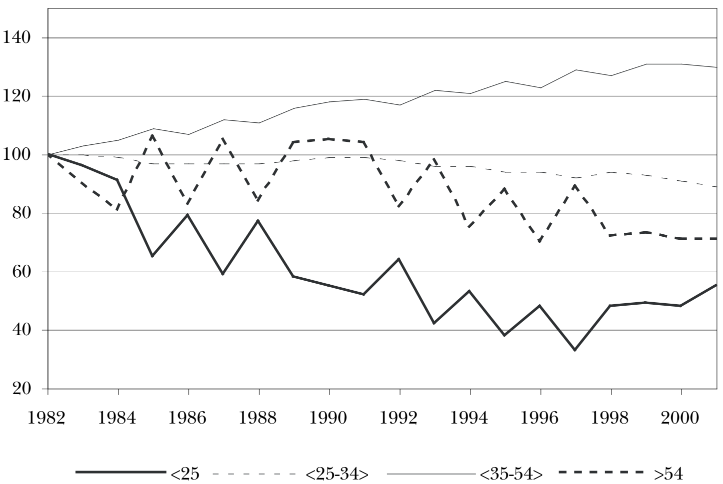
Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.3: Hourly wage of women/men by skills
Education



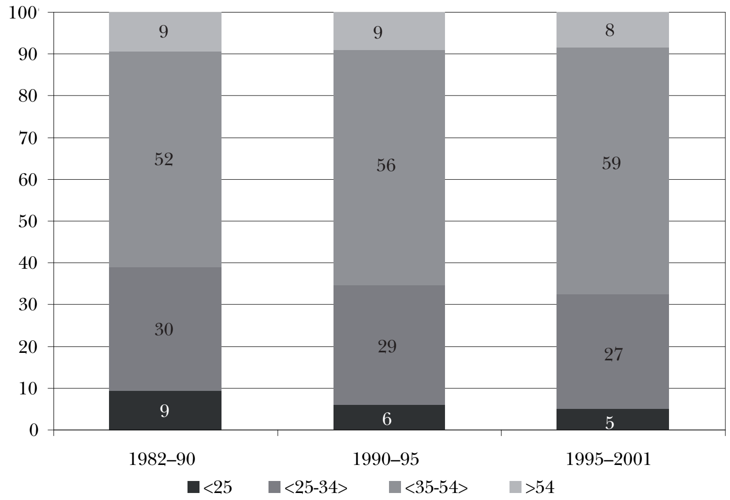
Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.4: Growth rate of hours worked by age bracket
(1982 = 100)



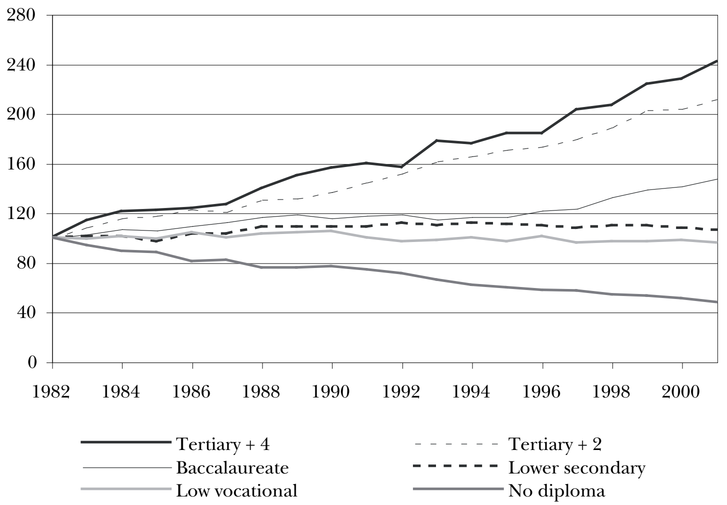
Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.5: Composition of wages by age bracket
(percentage)



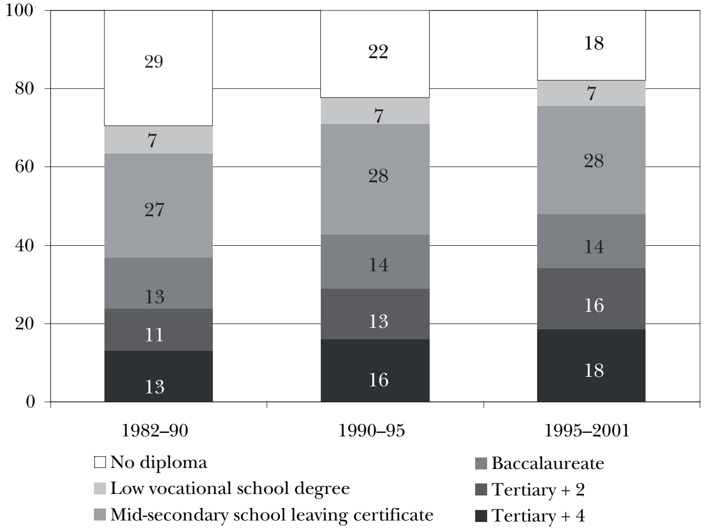
Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.6: Growth rate of hours worked by education level
(1982 = 100)



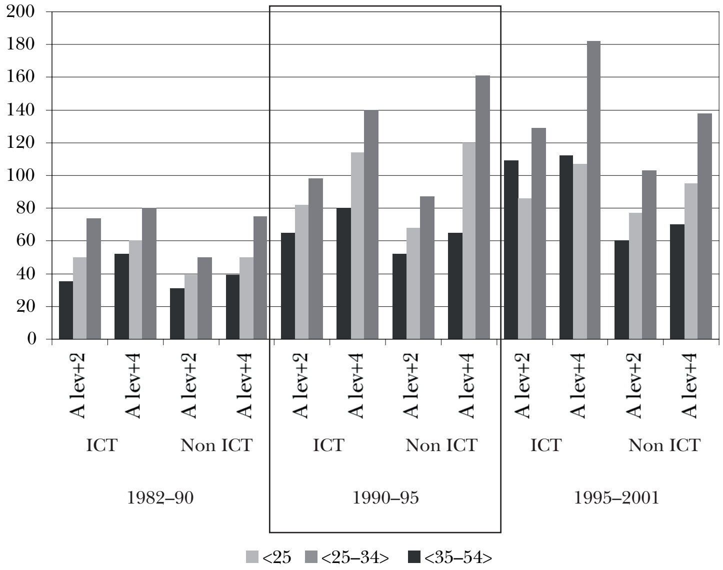
Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.7: Composition of wages by education level
(percentage)



Source: INSEE, DADS, LFS and National Accounts; CEPII, authors' calculations.

GRAPH A.9.2.8: Comparison of hourly wages of tertiary educated workers by age bracket, 1 year's service with the firm



A lev+2: baccalaureate + 2 years in college or equivalent; A lev+4: baccalaureate + 4 years in college or equivalent.
Source: LFS; CEPII, authors' calculations.

TABLE A.9.2.1: Hypotheses for the construction of capital stocks

Assets	Depreciation	Lifetime
Software	0.315	5
Hardware	0.315	7
Communications	0.11	15
Non-residential structures	0.028	60
Transport	0.1906	15
Other equipment	0.132	15

Source: M. O'Mahony (NIESR) and Marcel Timmer (University of Groningen).

TABLE A.9.2.2: Share of current ICT investment in total non-residential investment and in GDP for France and the U.S.
Total economy

	1980	1985	1990	1995	2001
Percentage non-res. investment in GDP					
France	15.4	13.6	15.8	13.0	14.3
United States	16.7	16.3	14.5	14.2	14.8
Percentage ICT in total non-res. investment					
France	6.1	9.3	8.7	9.9	14.2
United States	11.5	17.0	19.4	22.6	28.2
Percentage ICT investment in GDP					
France	0.9	1.2	1.3	1.3	2.0
United States	1.9	2.8	2.8	3.2	4.2

Source: U.S., BEA (last revision March 2004); CEPII, authors' calculations.

10 . Convergence across Countries and Regions: Empirical Results and Theoretical Implications[1]

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THIS paper surveys the recent literature on convergence across countries and regions. After briefly discussing the main convergence and divergence mechanisms identified in the literature, I review the existing empirical evidence and discuss its theoretical implications. Early optimism concerning the ability of a human capital-augmented neoclassical model to explain productivity differences across economies, has been questioned on the basis of more recent contributions that make use of panel data techniques and obtain theoretically implausible results. Some recent research in this area tries to reconcile these findings with sensible theoretical models by exploring the role of alternative convergence mechanisms and the possible shortcomings of panel data techniques for convergence analysis.

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10.1. Introduction

In the last decade and a half, growth has come to occupy an increasingly important place among the interests of macroeconomists, displacing to some extent their previous preoccupation with the business cycle. This change is largely due to two factors. The first one is the realization that in terms of medium and long-term welfare, the trend is more important than the cycle—provided the volatility of income remains as low as it has been during the last few decades (Lucas 1987). The second factor is the increasing dissatisfaction with the traditional neoclassical models that summarised the pre-existing consensus on the determinants of growth—essentially because of their perceived inability to account for such key features of the data as the observed increase in international inequality or the absence of capital flows toward less developed countries.

Dissatisfaction with the received theory has motivated the search for alternatives to the traditional neoclassical model that has driven the recent literature on *endogenous growth*. At the theoretical level, numerous authors have developed models in which departures from traditional assumptions about the properties of the production technology or the determinants of technical progress generate predictions about the evolution of international income distribution that stand in sharp contrast with those of neoclassical theory. Some of these models emphasize the role of growth factors that were ignored by previous theories and generate policy implications that are considerably more activist than those derived from the traditional models. At the empirical level, there is also a rich literature that attempts to test the validity of the different theoretical models that have been proposed, and to quantify the impact of various factors of interest on growth and on the evolution of international or interregional income disparities.

This paper provides an introduction to the empirical literature on growth and convergence across countries and regions. It is organized as follows: section 10.2 contains some general considerations on the convergence and divergence mechanisms identified in the growth literature. Section 10.3 focuses on the empirical implementation of growth models through convergence equations. Finally, sections 10.4 and 10.5 contain a brief survey of the main empirical results on convergence and a discussion of their theoretical implications. Section 10.6 concludes with a brief summary and some tentative conclusions.

10.2. Convergence and divergence in growth theory

As the reader will soon discover, the concept of *convergence* plays a crucial role in the literature we will survey. Although I will eventually provide a more precise definition of this term, we can provisionally interpret it as shorthand for the possible existence of a tendency towards the reduction over time of income disparities across countries or regions. We will say that there is convergence in a given sample when the poorer economies in it tend to grow faster than their richer neighbours, thereby reducing the income differential between them. When we observe the opposite pattern (i.e. when the rich grow faster and increase their lead) we will say that there is divergence in the sample.

Economic theory does not provide unambiguous predictions about the convergence or divergence of per capita income levels across countries or regions. It does, however, identify a series of factors or mechanisms that are capable in principle of generating either convergence or divergence. Theoretical models based on different assumptions about the existence or relative importance of such mechanisms can generate very different predictions about the evolution of income disparities across territories.

At some risk of oversimplifying, we can classify growth models into two families according to their convergence predictions. According to those in the first group, being poor is to some extent an advantage. In these models the technology is such that, other things equal, poor countries grow faster than rich ones. This does not necessarily imply the eventual elimination of inequality (other things may not be equal), but it does mean that the distribution of relative income per capita across territories will tend to stabilize in the long run, provided some key *structural* characteristics of the different economies remain unchanged over time. In the second set of models, in contrast, rich countries grow faster and inequality increases without any limits.

The source of these contrasting predictions must be sought in very basic assumptions about the properties of the production technology at a given point in time and about the dynamics of technological progress. A first necessary condition for convergence is the existence of decreasing returns to scale in capital (or more generally, in the various types of capital considered in the model). This assumption means that output grows less than proportionally with the stock of capital. This implies that the marginal productivity of this factor will decrease with its accumulation, reducing the incentive to save and the contribution to growth of a given volume of investment and creating a tendency for growth to slow down over time. The same mechanism generates a convergence prediction in the cross-section: poor countries (in which capital is scarcer) will grow faster than rich ones because they have a greater incentive to save and enjoy faster growth with the same rate of investment. This result will be reinforced by open-economy considerations as the flows of mobile factors, together with international trade, will contribute to the equalization of factor prices and domestic products per worker. Under the opposite assumption (of increasing returns in capital), the preceding neoclassical logic is inverted and we obtain a divergence prediction. In this case, the return on investment increases with the stock of capital per worker, favoring rich countries that tend to grow faster than poor ones, thereby increasing inequality further.

The second factor to consider in relation with the convergence or divergence of income per capita or productivity has to do with the determinants of technological progress. If countries differ in the intensity of their efforts to generate or adopt new technologies, their long-term growth rates will be different. One possible objection is that the persistence of such differences is not plausible. For instance, it may be argued that the return on technological capital should decrease with its accumulation, just as we would expect to find for other assets. In this case, large differences across countries in rates of technological investment would not be sustainable, and there would be a tendency towards the gradual equalization of technical efficiency levels. It is far from clear that the accumulation of knowledge should be subject to the law of diminishing returns. If the cost of additional innovations falls with scientific or production experience, the return on technological investment may not be a decreasing function of the stock of accumulated knowledge, and cross-country differences in levels of technological effort could persist indefinitely.

Technical progress could be an important divergence factor. But there are also forces that push in the opposite direction. As Abramovitz (1989a, 1989b) and other authors have pointed out, the public good properties of technical knowledge have an international dimension that tends to favor less advanced countries, provided they have the capability to absorb foreign technologies and adapt them to their own needs. The idea is simple: not having to reinvent each wheel, followers will be in a better position to grow quickly than the technological leader, who will have to assume the costs and lags associated with the development of new leading-edge technologies.[2] The resulting process of technological catch-up could contribute significantly to convergence, particularly within the group of industrialized countries that are in a position to exploit the advantages derived from technological imitation.

In addition to decreasing returns and technological diffusion, the literature identifies a third convergence mechanism that, although featured less prominently in theoretical models is likely to be of great practical importance. This mechanism works through structural change, or the reallocation of productive factors across sectors. Poorer countries and regions tend to have relatively large agricultural sectors. Given that output per worker is typically much lower in agriculture than in manufacturing or in the service sector, the flow of resources out of agriculture and into these other activities tends to increase average productivity. Since this process has generally been more intense in poor economies than in rich ones in the last few decades, it may have contributed

[2] The idea seems to be due originally to Gerschenkron (1952) and has been developed among others by Abramovitz (1989a, 1989b), Baumol (1986), Dowrick and Nguyen (1989), Nelson and Wright (1992) and Wolff (1991).

significantly to the observed reduction in productivity differentials across territories.

In conclusion, economic theory identifies forces with contrasting implications for income dynamics. Convergence mechanisms feature prominently in the neoclassical and catch-up models that dominated the literature until recently. The perceived failure of the optimistic convergence predictions of these models has motivated the search for alternatives and contributed to the development of new theories that incorporate various divergence factors (Romer [1986], and Lucas [1988, 1990], among others). Some of the pioneers of the *endogenous growth* literature (especially Romer [1986, 1987a, 1987b] focused on the possibility of non-decreasing returns to scale in capital alone, while other authors, such as Lucas (1988), Romer (1990) and Grossman and Helpman (1991), developed models in which the rate of technical progress was determined endogenously and could differ permanently across countries, reflecting differences in structural characteristics. In both cases, the theory allows for the possibility of a sustained increase in the level of international or interregional inequality.

10.3. From theory to empirics: a framework for empirical analysis and some convergence concepts

In the previous section we identified two groups of theories of growth with contrasting implications for the evolution of the international or interregional distribution of income. While traditional neoclassical models and those that incorporate the assumption of technological catch-up have relatively optimistic convergence implications, some endogenous growth models based on the assumption of increasing returns and those that emphasize the endogenous nature of the rate of technical progress can generate a tendency towards the increase of income disparities across economies.

When it comes to trying to distinguish empirically between these two families of models, the natural starting point is probably the observation that the main testable difference between them has to do with the sign of the partial correlation between the growth rate and the initial level of income per capita. While this correlation should be negative according to standard neoclassical models (that is, other things being equal, poorer countries should grow faster), in some models of endogenous growth the expected sign would be the opposite one. This suggests that a natural way to try to determine which group of models provides a better explanation of the growth experience involves estimating a *convergence equation,* that is, a regression model in which the dependent variable is the growth rate of income per capita or output per worker and the explanatory variable is the initial value of the same income indicator. The sign of the estimated coefficient of this last variable allows us in principle to discriminate between the two sets of alternative models.

The correct formulation of the empirical model requires that we control for other variables that may affect the growth rate of the economies in the sample. As we have seen in a previous section, neoclassical and catch-up models predict that poor countries will grow faster than rich ones only under certain conditions. In Solow's (1956) neoclassical model, for instance, the long-term level of income is a function of the rates of investment and population growth and can, therefore, differ across countries. In a similar vein, Abramovitz (1989a, 1989b) emphasizes that the process of technological catch-up is far from automatic. Although relative backwardness carries with it the potential for rapid growth, the degree to which this potential will be realized in a given country depends on its *social capability* to adopt advanced foreign technologies (i.e. on factors such as the level of schooling of its population and the availability of qualified scientific and technical personnel) and on the existence of a political and macroeconomic environment conducive to investment and structural change.

In short, even in models where convergence forces prevail, long-term income levels can vary across territories, reflecting underlying differences in *fundamentals.* If we do not control for such differences, the estimated relationship between growth and initial income could be very misleading. Imagine, for instance, that the Solow model (with decreasing returns and access by all economies to a common technology) is the correct one, and that richer countries display on average higher rates of investment and lower rates of population growth than poorer countries (which is why they are richer in the first place). According to the model, these two factors would have a positive effect on the growth rate (during the transition to the long-run equilibrium) that could conceivably dominate the convergence effect that makes growth a decreasing function of income, other things being constant. It is clear that if we do not include the rates of investment and population growth in the equation, we could find that the estimated coefficient of initial income is positive and erroneously conclude from this that the predictions of the Solow model fail to hold. To put it in a slightly different way, the problem would be that when we do not control for the determinants of the steady state, we are actually testing the hypothesis that all economies converge to the same long-run equilibrium. The rejection of this hypothesis has no implications for the validity of the Solow model, since this model makes no such prediction except when the economies in the sample are exactly alike.

On the basis of the preceding discussion, we can conclude that a *minimal* model for the empirical analysis of convergence would be an equation in the form:

$$\Delta y_{it} = \gamma x_{it} - \beta y_{it} + \varepsilon_{it} \tag{10.1}$$

where y_{it} is income per capita or per worker in territory i at the beginning of period t, Δy_{it} the growth rate of the same variable over the period, ε_{it} a random disturbance and x_{it} a variable or set of variables that captures the *fundamentals* of economy i, that is, all those characteristics of this territory that have a permanent effect on its growth rate.

a. Structural convergence equations

Many empirical studies of growth and convergence have proceeded by estimating some variant of equation (10.1). In early studies the empirical specification was frequently ad hoc and only loosely tied to the theory (Kormendi and Meguire 1985; Grier and Tullock 1989, Barro 1991). In recent years researchers have increasingly focused on the estimation of *structural* convergence equations derived explicitly from formal models. One of the most popular specifications in the literature is the one derived by Mankiw, Romer and Weil (M-R-W 1992) from a neoclassical model à la Solow (1956). Working with a log-linear approximation to the model around its steady state, M-R-W show that the growth rate of output per worker in territory i during the period that starts at t is given approximately by the following equation:[3]

$$\Delta y_{it} = g + \beta\left(a_{io} + gt\right) + \beta\frac{\alpha}{1-\alpha}\ln\frac{s_{it}}{\delta + g + n_{it}} - \beta\, y_{it} \qquad (10.2)$$

where

$$\beta = (1-\alpha)(\delta + g + n) \qquad (10.3)$$

g is the rate of technical progress, δ the depreciation rate, α the coefficient of capital in the aggregate production function, t the time elapsed since the beginning of the sample period, a_{io} the logarithm of the index of technical efficiency at time zero, s the share of investment in GDP (Gross Domestic Product) and n the rate of growth of the labor force.

It is important to understand that the estimation of equation (10.2) does not imply that we are literally accepting the assumptions of the underlying Solow-type model (i.e. we do not need to assume that the investment rate is exogenous or constant over time). What we are doing is simply assigning to some of the parameters of the Solow model (in particular, to s and n) the observed average values of their empirical counterparts during a given period. During

[3] Barro and Sala i Martin (1990, 1992) derive a similar expression from a variant of the optimal growth model of Cass (1965) and Koopmans (1965) with exogenous technical progress. The resulting equation is similar to (10.2) except that the investment rate (which is now endogenous) is replaced by the rate of time discount among the determinants of the steady state. The convergence coefficient, β, is now a more complicated function of the parameters of the model, but it still depends on the degree of decreasing returns to capital and on the rates of population growth, depreciation and technical progress. A second difference between the two models is that, whereas the M-R-W model can be easily extended to incorporate investment in human capital, Barro and Sala i Martin do not include this factor as an argument of the production function, although they do bring it into their empirical specification, in an ad hoc way, as a determinant of the steady state.

this period, the economy will behave approximately as if it were approaching the steady state of the Solow model that corresponds to the contemporaneous parameter values. In the next period we are likely to observe different values of the investment and population growth rates and therefore, a different steady state, but this poses no real difficulty. In essence, all we are doing is constructing an approximation to the production function that allows us to recover its parameters using data on investment flows rather than factor stocks. This is very convenient because such data are easier to come by and can be expected to be more reliable and comparable over time and across countries than most existing estimates of factor stocks. It must be kept in mind that the only information we can extract from the estimation of a convergence equation of the form (10.2) concerns the properties of the production technology. As Cohen (1992) emphasizes, the estimated equation does not, in particular, tell us anything about the actual dynamics of the economy or the position of a hypothetical long-run equilibrium—although it does allow us to make predictions about long-term income levels conditional on assumptions about the future behavior of investment and population growth rates.

The empirical implementation of equation (10.1) or (10.2) does not, in principle, raise special problems. Given time series data on income, population and investment for a sample of countries or regions, we can use (10.2) to recover estimates of the rate of convergence and the parameters of the production function. The convergence equation can be estimated using cross-section or pooled data. Most of the earlier convergence studies took the first route, averaging the variables over the entire sample period and working with a single observation for each country or region. The second possibility, which has become increasingly popular, involves averaging over shorter sub-periods in order to obtain several observations per country.

In either case, one difficulty which immediately becomes apparent is that three of the variables on the right-hand side of the equation (g, δ and a_{io}) are not directly observable. In the first two cases, the problem is probably not very important. Although these coefficients can be estimated inside the equation (and this has been done occasionally), the usual procedure in the literature is to impose *reasonable* values of these parameters prior to estimation. The standard assumption is that $g = 0.02$ and $\delta = 0.03$, but researchers report that estimation results are not very sensitive to changes in these values.

The possibility that initial levels of technical efficiency (a_{io}) may differ across countries raises a more difficult problem. Although some authors have argued that it may be reasonable to assume a common value of a_{io} because most technical knowledge is in principle accessible from everywhere, casual observation suggests that levels of technological development differ widely across countries. If this is so, failure to control for such differences will bias the estimates of the remaining parameters whenever the other regressors in the equation are correlated with them. In other words, we can only legitimately subsume technological differences across countries in the error term if they are uncorrelated with investment rates and population growth. This seems unlikely, however, as the level of TFP (Total Factor Productivity) is one of the key determinants of the rate of return on investment.

The standard solution for this problem is to turn to panel data techniques in order to control for unobserved national or regional fixed effects. The simplest procedure involves introducing country or regional dummies in order to estimate a different regression constant for each territory. It should be noted that this is equivalent to estimating the equation with the dependent and independent variables measured in deviations from their average values (computed over time for each country or region in the sample). Hence, this procedure (as most panel techniques designed for removing fixed effects), ignores the information contained in observed cross-country differences and produces parameter estimates that are based only on the time variation of the data within each territory over relatively short periods. Since what we are trying to do is characterise the long-term dynamics of a sample of economies this may be rather dangerous, particularly when the data contain an important cyclical component or other short-term noise.

The structural convergence equation methodology has some important advantages and limitations, both of which are derived from the close linkage between theory and empirics that characterizes this approach. Its most attractive feature is that it allows us to use the relevant theory to explicitly guide the formulation of the empirical model—that is, the formal model is used to determine what variables must be included in the regression and how they must enter in order to obtain direct estimates of the structural parameters of the model. It is clear that such guidance comes at a price, as our estimates at best be only as good as the underlying theoretical model. Hence, an inadequate specification of this model can yield very misleading conclusions.

Although this problem arises to some extent whenever we run a regression, there are reasons to think that it may be particularly important in the present context. In most of the recent empirical work on growth and convergence, the theoretical model of reference is some version of the one-sector neoclassical model with exogenous technical progress that underlies equation (10.2). Since the only convergence force present in this model is what we may call the neoclassical mechanism, the usual finding of a negative partial correlation between growth and initial income must be interpreted in this framework as evidence that the aggregate production function displays decreasing returns to scale in reproducible factors. In fact, this assumption is precisely what allows us to draw inferences about the degree of returns to scale from the estimated value of the convergence coefficient. The problem, of course, is that if any other convergence mechanisms are operative, the inference will not be valid, as the estimated value of the convergence parameter will also capture their effects.

As we have seen, the literature identifies at least two factors other than decreasing returns that can generate a negative partial correlation between income levels and growth rates holding investment and population growth constant: technological diffusion and structural change. Although none of these mechanisms is incompatible with the neoclassical story, the observation that this is not the only possible source of convergence suggests that it may be dangerous to accept without question an interpretation of the convergence coefficient based too literally on the preceding model. For instance, if income per capita is highly correlated with the level of technological development, the coefficient of initial income in a convergence regression could capture, at least in part, a technological catch-up effect. To avoid the danger of drawing the wrong conclusions about the properties of the technology, it may be preferable to interpret existing estimates of the convergence parameter, β, (particularly in the case of unconditional convergence equations) as summary measures of the joint effect of several possible convergence mechanisms. The value of this parameter will depend on the coefficient of capital in the production function, the speed of technological diffusion, the impact of sectoral change and the response of investment rates to rising income. It will be positive (i.e. growth will be negatively correlated with initial income) whenever the forces making for convergence dominate those working in the opposite direction.

b. Some convergence concepts

Before we review the empirical evidence, it is convenient to introduce some concepts of convergence that will feature prominently in the discussion below. Perhaps the first question that arises concerning the evolution of the distribution of income per capita is whether the dispersion of this variable (measured for instance by the standard deviation of its logarithm) tends to decrease over time. The concept of convergence implicit in this question, called *σ-convergence* by Barro and Sala i Martin (1990, 1992), is probably the one closest to the intuitive notion of convergence. It is not, however, the only possible one. We may also ask whether poorer countries tend to catch up with richer ones, or whether the relative position of each country within the income distribution tends to stabilize over time. The concepts of *absolute* and *conditional β-convergence* proposed by Barro and Sala i Martin (B&S) correspond roughly to these two questions.

To make more precise these two notions of convergence, we can use a variant of equation (10.1) in which we assume that each economy's fundamentals remains constant over time (that is, that $x_{it} = x_i$ for all t) and we interpret the variable y_{it} as relative income per capita, that is, income per capita normalized by the contemporaneous sample average. Omitting the disturbance term, the evolution of relative income in territory i is described by:

$$\Delta y_{it} = \gamma x_{it} - \beta y_{it} \tag{10.1'}$$

Setting Δy_{it} equal to zero in this expression, we can solve for the steady state value of relative income:

$$y_i^* = \frac{\gamma x_i}{\beta} \tag{10.4}$$

It is easy to check that if β lies between zero and one, the system described by equation (10.1') is stable. This implies that the relative income of territory *i* converges in the long run to the equilibrium value given by y_i*. Note that the equilibrium can differ across countries as a function of the *fundamentals* described by x_i.

In terms of this simple model, we will say that there is conditional β-convergence when β lies between zero and one, and absolute β-convergence when this is true and, in addition, x_i is the same for all economies—i.e. when all countries or regions in the sample converge to the same income per capita.

Even though they are closely related, the three concepts of convergence are far from being equivalent. Some type of β-convergence is a necessary condition for sustained σ-convergence, for the level of inequality will grow without limit when β is negative (i.e. when the rich grow faster than the poor). It is not sufficient, however, because a positive value of β is compatible with a transitory increase of income dispersion due to random shocks or to the fact that the initial level of inequality is below its steady state value (as determined by the dispersion of fundamentals and the variance of the disturbance). The two types of β-convergence have very different implications. Absolute β-convergence implies a tendency towards the equalization of per capita incomes within the sample. Initially poor economies tend to grow faster until they catch up with the richer ones. In the long run, expected per capita income is the same for all members of the group, independently of its initial value. As we know, this does not mean that inequality will disappear completely, for there will be random shocks with uneven effects on the different territories. Such disturbances will have only transitory effects, implying that in the long run we should observe a fluid distribution in which the relative positions of the different countries or regions change rapidly. With conditional β-convergence, on the other hand, each territory converges only to its own steady state but these can be very different from each other. Hence, a high degree of inequality could persist even in the long run, and we would also observe high persistence in the relative positions of the different economies. In other words, rich economies will generally remain rich while the poor continue to lag behind.

It is important to observe that, although the difference between absolute and conditional convergence is very sharp in principle, things are often much less clear in practice. In empirical studies we generally find that a number of variables other than initial income enter significantly in convergence equations. This finding suggests that steady states differ across countries or regions that convergence is only conditional. It is typically the case that so conditioning variables change over time and often tend to converge themselves across countries or regions. Hence, income may still converge unconditionally in the long run, and so convergence may reflect in part the gradual equalization of the underlying fundamentals. In this situation, a conditional and an unconditional convergence equation will yield different estimates of the convergence rate. There is no contradiction between these estimates once we recognize that they are measuring different things: while the unconditional parameter measures the overall intensity of a process of income convergence which may work in part through changes over time in various structural characteristics, the conditional parameter captures the speed at which the economy would be approaching a *pseudo steady state* whose location is determined by the current values of the conditioning variables.

10.4. Convergence across countries and regions: empirical evidence and theoretical implications

Having reviewed the theoretical and empirical framework used in the convergence literature, we are now in a position to examine the available empirical evidence and discuss its implications. I will begin this section with a review of some of the more significant empirical results in this literature. Although I will pay special attention to the case of Spain, the evolution of regional income distribution follows a similar pattern in most samples. In most industrial countries we observe a significant reduction of the level of regional inequality over the medium and long run, although this process of convergence seems to cease or at least slow down in recent years. There is also clear evidence of β-convergence: the correlation between initial income and subsequent growth is generally negative in regional samples even without conditioning on additional variables. At the national level, the situation is quite different. In broad country samples, the level of inequality increases over time and beta convergence emerges only when we condition on variables like human capital indicators and investment rates. On the other hand, the convergence rate estimated after controlling for these variables is quite similar to the one obtained with regional samples.

In addition to their descriptive interest, these results have interesting theoretical implications. The consensus view in the literature (at least until recently) seems to be that the apparent slowness of the process of convergence can be taken as an indication that the production technology displays almost constant returns to scale in capital—a conclusion that only seems plausible if we extend the traditional concept of capital to incorporate educational investment. Hence, the empirical results seem to point towards an extended version of the neoclassical model built around a richer concept of capital than the one we find in the traditional theory. Some recent studies suggest it is probably premature to conclude that such a simple model provides a satisfactory description of the growth process and of the determinants of income levels.

a. Some classical *results on convergence*

In this section I will review some representative results of a series of studies that follow what Sala i Martin (1996a) has called the *classical approach* to convergence analysis. To summarise the key features of the convergence pattern within a given sample, I will make use of two techniques that have been frequently used in the literature. The first one, designed for the study of sigma convergence, involves plotting the time path of some measure of dispersion of income per

GRAPH 10.1: σ-convergence in the Spanish regions, 1955–91

Note: The original income variable is regional gross value-added per capita in 1990 pts., taken from Banco Bilbao Vizcaya (various years).

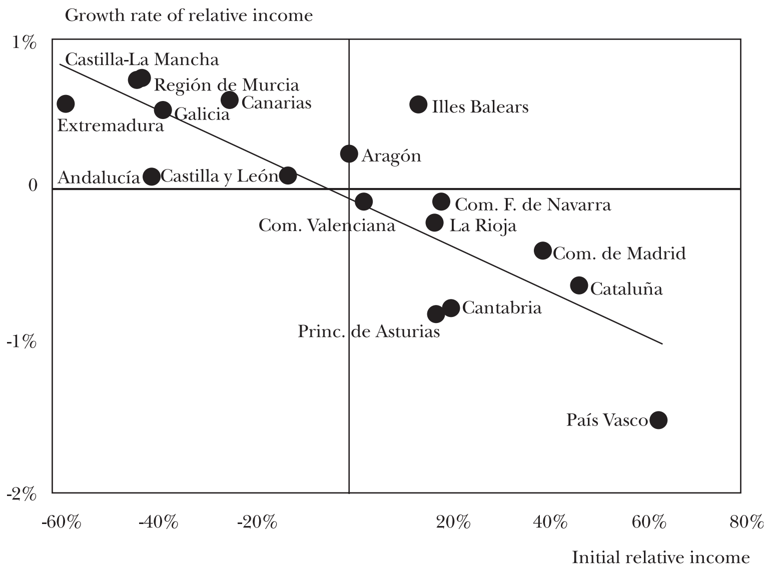
capita, typically the standard deviation of its logarithm. To analyze the pattern of beta convergence, I will estimate an unconditional convergence equation—i.e. a version of equation (10.1) without conditioning variables in which I impose the assumption of a common intercept—and plot the estimated regression line together with the corresponding scatter plot, identifying each of the observations. This procedure allows us to visualize the initial position of each economy and its performance relative to a *typical* region whose behavior is described by the fitted regression line.

The case of Spain provides a representative illustration of what we find in most available regional samples. Graph 10.1 shows the time path of the standard deviation of relative regional income per capita (defined as log income per capita measured in deviations from its interregional average) during the period 1955–91. The pattern of sigma convergence is clear: over the period as a whole, the standard deviation of relative income per capita falls by approximately 40%. The level of inequality, however, stabilizes after the second half of the 1970s. Although this may be an indication that the regional income distribution is close to its steady state, it may still be too soon to rule out the possibility that the interruption of the convergence process may be a transitory phenomenon due to the oil shocks and other macroeconomic turbulences of the last decades.

Graph 10.2 summarises the results of an unconditional convergence regression in which the dependent variable is the average growth rate of relative income during the whole sample period. The negative slope of the fitted regression line indicates that, on average, growth has been faster in the initially poorer regions. The fit of the regression is fairly good but the rate of convergence (i.e. the slope of the regression line) suggests that the process of convergence is very slow. The value of this coefficient (0.015) indicates that, in the case of a *typical region*, only 1.5% of the income differential with respect to the national average is eliminated each year.

Moving on to other countries, the pattern of σ convergence at the regional level is very similar in most industrial economies. The states of the U.S., the Japanese prefectures and the regions of the European Union all display a gradual reduction of the level of inequality, although this process is sometimes interrupted by shocks such as World War II, the Great Depression or the oil shocks. In

GRAPH 10.2: β-convergence in the Spanish regions, 1955–91

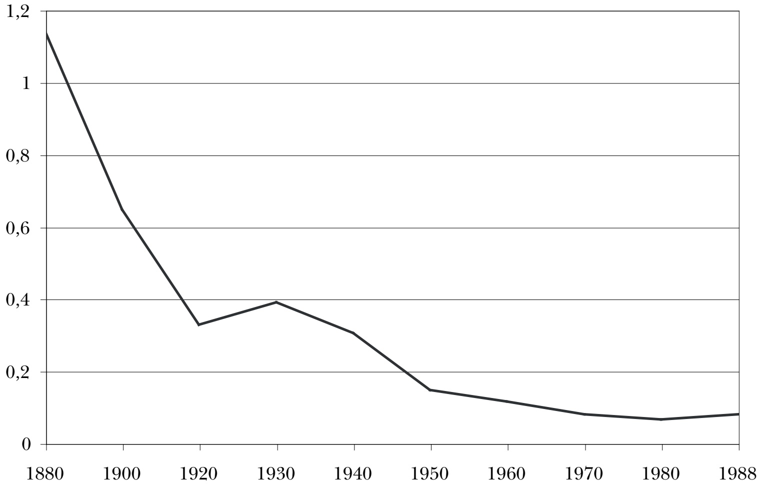


Note: The estimated equation is $\Delta y_i = -0.01506 * y_{io}$ $t = 5.72$ $R^2 = 0.6859$.

the last two decades the pace of convergence slows down. The level of inequality stabilizes and even displays a slight increase insome cases. As an illustration, Graph 10.3 shows the evolution of the dispersion of personal income per capita in the states of the U.S. during the last century.

We also find a similar pattern of β-convergence in most regional samples. Table 10.1 summarises the results of the estimation of a standard convergence equation with regional data for a number of different countries.[4] In the European case, the data for the different countries are pooled and a common value of β is imposed with income measured in deviations from national means. Hence, the results refer to the speed of regional convergence within each country, just as in the individual regressions for the five largest EU members also reported in the table.

GRAPH 10.3: σ-convergence across the U.S. states



Note: Coefficient of variation of the logarithm of personal income per capita.
Source: Barro and Sala i Martin (1991).

[4] This table is taken from a recent paper by Sala i Martin (1996b) that summarises the results of various studies on regional convergence (in particular, Barro and Sala i Martin (1990, 1991) for the U.S. and several European countries, Coulombe and Lee (1993) for Canada, and Shioji (1996) for Japan. Similar results are also reported by Dolado, González-Páramo and Roldán (1994) for Spain, and by Persson (1997) for Sweden.

TABLE 10.1: Regional convergence in different samples

	A single long period		Panel
	β	R^2	β
Sample and period	[s.e.]		[s.e.]
48 U.S. states	0.017	0.89	0.022
1880–1990	[0.002]		[0.002]
47 Japanese prefectures	0.019	0.59	0.031
1955–90	[0.004]		[0.004]
90 EU regions	0.015		0.018
1950–90	[0.002]		[0.003]
11 German regions	0.014	0.55	0.016
1950–90	[0.005]		[0.006]
11 UK regions	0.03	0.61	0.029
1950–90	[0.007]		[0.009]
21 French regions	0.016	0.55	0.015
1950–90	[0.004]		[0.003]
20 Italian regions	0.010	0.46	0.016
1950–90	[0.003]		[0.003]
17 Spanish regions	0.023	0.63	0.019
1955–87	[0.007]		[0.005]
10 Canadian provinces	0.024	0.29	
1961–91	[0.008]		

Note: Standard errors in brackets below each coefficient.
Source: Sala i Martin (1996b).

Two alternative estimates of β are reported for most samples. The first one comes from a cross-section regression of the average growth rate of income per capita over the entire sample period on the initial level of income. The second equation is estimated with pooled data for shorter sub-periods, imposing a constant value of β but including fixed time effects. Most of the equations include as regressors indices of the sectoral composition of output (typically the share of agriculture) in order to control for aggregate shocks that may be correlated with initial income. In all cases, the estimated value of the convergence parameter is positive, indicating that poorer regions tend to grow faster than richer ones. A second empirical regularity (to which we will return in the next section) is that the estimated value of β is very small (around 2% per year) and rather stable across samples.

It is interesting to note that results obtained with national data are slightly different. When no additional variables are included to control for possible differences across national steady states, divergence (i.e. a negative value of β) is the norm in large samples. When we control for educational levels and other variables that may be considered reasonable proxies for the steady state, the hypothesis of (conditional) convergence is accepted in all samples and the estimated convergence rate again approaches the ubiquitous 2% figure.

Table 10.2, taken from B&S (1992a) summarises the results of the estimation of a convergence equation with cross-section data for three different samples over roughly the same period: a broad sample of 98 countries, a smaller one formed by the 20 original OECD (Organisation for Economic Co-operation and Development) members, and a third one which comprises the 48 continental states of the U.S. As can be seen in the table, the results are very different in the three cases. When we do not control for other variables, the estimated value of the convergence parameter (β) is negative in the largest sample (equation [10.1]), indicating a tendency for rich countries to grow faster than poor ones. The coefficient is positive in the other two samples (equations [10.3] and [10.5]), but the estimated speed of convergence is twice as large for the U.S. states than for the OECD countries.

Barro and Sala i Martin interpret these results as an indication of the relative importance of the within-sample differences in steady states. As the sample becomes more and more homogeneous, the bias induced in the estimation of β by the omission of the relevant control variables will decrease. The results of equations [10.2], [10.4] and [10.6], where additional control variables are included, are consistent with this interpretation. Regressions [10.2] and [10.4] include as explanatory variables a proxy for the initial level of human capital, two indices of political stability, the share of non-productive public expenditure in GDP and a measure of the distortions that affect the relative price of capital goods. Controlling for these variables, the estimated value of β is positive in both samples and very close

TABLE 10.2: Convergence among countries and regions

Sample and period	β [s.e.]	R^2	Other variables
[1] 98 countries 1960–85	–0.0037 [0.0018]	0.04	no
[2] 98 countries 1960–85	0.0184 [0.0045]	0.52	yes
[3] OECD 1960–85	0.0095 [0.0028]	0.45	no
[4] OECD 1960–85	0.0203 [0.0068]	0.69	yes
[5] 48 U.S. states 1963–86	0.0218 [0.0053]	0.38	no
[6] 48 U.S. states 1963–86	0.0236 [0.0013]	0.61	yes

Source: Barro and Sala i Martin (1992).
The "other variables" included in regressions (10.2) and (10.4) are the primary and secondary enrolment rates in 1960, public consumption (excluding defence and education) as a fraction of GDP, the average annual number of political murders, the average number of revolutions and coups and an index of the relative price of capital goods (constructed by Summers and Heston 1991) in 1967.
In addition to the initial level of income, equation (10.6) includes as regressors a set of regional dummies, a sectoral composition variable and the fraction of the labor force with some university education in 1960.
Standard errors in brackets below each coefficient.

to the value of 2% estimated in equation [10.5] for the continental U.S. states. On the other hand, the inclusion of additional control variables (regional dummies, an index of education and a sectoral composition variable) in the last equation increases only slightly the estimated rate of convergence among the U.S. states.

b. Theoretical implications: A revised neoclassical consensus?

The papers I have just reviewed highlight three interesting empirical regularities. (i) First, evidence of some sort of β-convergence is found in practically all available samples. While convergence is only conditional at the national level, a negative correlation between initial income and subsequent growth emerges without controlling for other variables in regional samples. This second result is consistent with the existence of absolute convergence at the regional level—but most of the studies I have reviewed do not explicitly test this hypothesis.[5] (ii) Second, we have seen that the process of convergence seems to be extremely slow. Many of the existing estimates of the convergence parameter cluster around a value of 2% per year which implies that it takes around 35 years for a typical region to reduce its income gap with the national average by one half. Hence, the expected duration of the convergence process must be measured in decades. (iii) Finally, it is interesting to observe that the estimated convergence coefficient is remarkably stable across samples. This stability suggests that the mechanisms that drive convergence in income per capita across different economies seem to operate in a regular fashion. Hence, we can at least hope to provide a unified structural explanation of the convergence process in terms of a *general* theoretical model.

Perhaps the dominant view in the literature is that a good candidate for this *general* model is a simple extension of the one-sector neoclassical model with exogenous technical progress. Just about the only departure from the traditional assumptions required in order to explain the empirical evidence is a broadening of the relevant concept of capital in order to include investment in intangibles such as human and technological capital. This conclusion is reached essentially by interpreting the results I have reviewed within the framework of the growth model underlying the conditional convergence equation given in (10.2). According to our previous discussion, the finding of (at least conditional) β-convergence in most national or regional samples can be interpreted as evidence in favor of the neoclassical assumption of decreasing returns to capital, as this

[5] Those that do test it by including different sets of conditioning variables generally reject it, as the significance of many of these variables implies important cross-regional differences in steady states. See for instance Dolado, González-Páramo and Roldán (1994) and Mas et al. (1995) for the Spanish provinces, Herz and Röger (1996) for the German *Raumordnungsregionen*, Grahl and Simms (1993), Neven and Gouyette (1995) and Faberberg and Verspagen (1996) for various samples of European regions, Holtz-Eakin (1993) for the states of the U.S. 10.4.b and Paci and Pigliaru (1995), Fabiani and Pellegrini (1996) and Cellini and Scorcu (1996) for the regions of Italy. As we have noted in section 4b, this evidence does not conclusively reject the hypothesis of absolute convergence, as conditioning variables (and hence steady states) may themselves be converging over time.

result would not be consistent with increasing returns models that predict an explosive behavior of income and its distribution. On the other hand, the apparent slowness of the convergence process suggests that we are not that far from having constant returns in reproducible factors—a result that seems considerably more plausible if we think in terms of a broad capital aggregate instead of the rather restrictive concept of capital we find in old-fashioned neoclassical models.

Since this broader concept of capital is probably one of the most significant contributions of recent literature to our understanding of the mechanics of growth, the issue probably deserves a fairly detailed discussion. The reader will recall that within the framework of the Solow model the convergence coefficient (β) depends on the degree of returns to scale in capital, measured by the coefficient of this factor, α, and on the rates of technical progress *(g)*, population growth *(n)* and depreciation (δ). If we allow for the possibility of externalities, α, can be written as the sum of two terms, $\alpha = a + b$, where a is the coefficient of capital in the *private* production function and b captures the possible externalities. Hence, the relationship among these variables is given by:

$$\beta = (1 - a - b)(\delta + g + n) \tag{10.3'}$$

Using this expression and making reasonable guesses about the values of some of the parameters, we can extract information about key properties of the production technology from empirical estimates of the convergence rate. For a start, let us consider the expected value of β under conventional assumptions about the values of the remaining parameters. Within the framework of a traditional neoclassical model (with constant returns to scale in capital and labor, perfect competition and no externalities) we would have $b = 0$ and a would be equal to capital's share of national income, which is around one third. The average rate of population growth in the industrial countries during the post-World War II period is approximately 1%. Available estimates of the rate of technical progress are around 2% per year. Finally, estimates of the rate of depreciation vary considerably. In the convergence literature it is commonly assumed that $\delta = 0.03$, but a higher value (around 5 or 6% per year) may be more reasonable. Given these assumptions, the expected value of β lies between 0.04 and 0.06.

As we have seen, the empirical results of Barro and Sala i Martin (1990, 1992), Mankiw, Romer and Weil (1992) and other authors point towards a much lower convergence rate. Since the estimated value of the parameter is still positive, the evidence is consistent with decreasing returns to capital (i.e. $a + b < 1$). The low value of β, however, suggests that we are relatively close to having constant returns to capital. Maintaining our previous assumptions about the values of the remaining parameters, a convergence coefficient of 0.02 would imply a value of $a + b$ between 0.67 and 0.78—more than twice the share of capital in national income.

One possible explanation (Romer 1987b) is that this result may reflect the existence of important externalities associated with the accumulation of physical capital (that is, a large positive value of b). While these external effects would not be sufficiently strong to generate increasing returns in capital alone, they might still account for the apparent slowness of convergence. Other authors argue that a more plausible explanation is that the omission of variables that are positively correlated with investment in physical capital may bias upward the coefficient of this variable. Barro and Sala i Martin (1990, 1992) argue that a value of capital's coefficient around 0.7 only makes sense if we count accumulated educational investment as part of the stock of capital.

Mankiw, Romer and Weil (1992) advance the same hypothesis and test it explicitly by estimating a structural convergence equation similar to equation (10.2) above that explicitly incorporates a proxy for the rate of investment in human capital as a regressor. Their results, and those obtained by other authors who estimate similar specifications (Lichtenberg 1993; Holtz-Eakin 1993; Nonneman and Vanhoudt 1996; Murthy and Chien 1997; and De la Fuente 1998a), tend to confirm the hypothesis that investment in human (and technological) capital plays an important role in the growth process (De la Fuente 1997). As Mankiw (1995) points out, once human capital is included as an input in the production function, the resulting model is consistent with some of the key features of the data. Countries that invest more in physical capital and education tend to grow faster and therefore eventually attain high levels of relative income. Cross-country differences in rates of accumulation are sufficiently high to explain the bulk of the observed dispersion of income levels and growth rates.

10.5. Loose ends and recent developments

We have seen in the previous section that the main theoretical conclusion drawn from the earlier studies of convergence is that a modified version of the aggregate neoclassical model provides a satisfactory description of the process of growth and of the evolution of regional (or national) income distribution. The main change relative to the more traditional models is the broadening of the relevant concept of capital in order to include human and possibly technological capital. Other than this, the model is essentially Solow's (1956) with exogenous technological progress and does not incorporate any convergence mechanisms other than the one derived from the existence of decreasing returns to capital.

It is probably fair to say that just a few years ago this extended neoclassical model summarised a consensus view on the mechanics of growth that was shared (possibly with some reservations) by most researchers working in the field. In recent years, this emerging consensus has been challenged by a series of papers that, relying on panel data techniques, obtain results that are difficult to reconcile with the prevailing theoretical framework. In this section I will review some of the key findings of these studies, discuss the theoretical difficulties they raise and summarise some recent research that may provide at least partial answers to some difficult questions. The reader should be warned that the second half of this section draws much more on my own work than the remainder of the paper, and that the views I will present may be controversial.

a. Convergence and panel data

One of the key findings of the *classical* convergence studies is that convergence to the steady state is an extremely slow process. It has recently been argued that this result may be due to a bias arising from the use of econometric specifications that do not adequately allow for unobserved differences across countries or regions. To get around this problem, a number of authors have proposed the use of panel techniques that allow for unobserved fixed effects. As we will see in this section, their results raise some puzzling questions.

Marcet (1994), Raymond and García (1994), Canova and Marcet (1995), De la Fuente (1996), Tondl (1997) and Gorostiaga (1999), among others, estimate fixed-effects convergence models using panel data for a variety of regional samples. Their results suggest a view of the regional convergence process that stands in sharp contrast with the one advanced in earlier studies by B&S and other authors: instead of slow convergence to a common income level, regional economies within a given country seem to be converging extremely fast (at rates of up to 20% per year) but to very different steady states.[6] Cross-national studies provide a roughly similar picture: Knight, Loayza and Villanueva (1992), Canova and Marcet (1995), Islam (1995) and Caselli, Esquivel and Lefort(1996) among others, find evidence of rapid convergence across countries (at rates of up to 12% per annum) toward very different steady states whose dispersion can be explained only in part by observed cross-national differences in rates of population growth and investment ratios. In both cases, many of the standard conditioning variables (and in particular human capital indicators) lose their statistical significance, the estimated coefficient of physical capital adopts rather low values, and the size and significance of the regional or national fixed effects suggests that persistent differences in levels of TFP play a crucial role in explaining the dispersion of income levels.

I will illustrate the sharp contrast between fixed-effects and pooled data or cross-section estimates of the convergence coefficient using data for two samples of (European and Spanish) regions. For each sample I estimate two versions of the following convergence equation:

$$\Delta y_{rt} = \alpha_r - \beta\, y_{rt} + \varepsilon_{rt} \tag{10.5}$$

[6] Similar results are also reported by Evans and Karras (1996) for a sample of U.S. states using time series techniques.

where Δy_{rt} is the average annual growth rate of relative income over the sub-period starting at time t and α_r a region-specific constant that can be used to recover an estimate of the steady state income level ($y_r^* = \alpha_r/\beta$). First, I estimate a restricted or unconditional version of equation (10.5) with the pooled data after imposing the assumption of a common intercept (and therefore a common steady state) for all regions. Next, I estimate an unrestricted or conditional version of the same equation using ordinary LSDV (Least Squares with Dummy Variables) to estimate regional fixed effects. Finally, I will repeat the exercise using Arellano's (1988) OD (Orthogonal Deviations) procedure in order to try to avoid the short sample bias that may affect LSDV estimates.

Table 10.3 summarises the results of the exercise. In the Spanish case, the estimated rate of unconditional convergence is 2.2% and the standard deviation of the implied asymptotic distribution of relative income per capita (which reflects only the variance of the shocks ε_{rt}) is 0.10 (column [1] of Table 10.3). With the LSDV specification, the (now conditional) convergence rate increases almost four-fold to 8% per year[7] and more than half of the regional dummies are highly significant. The implied

TABLE 10.3: Estimated regional convergence rates and long-term dispersion of income per capita with various specifications

	[1]	[2]	[3]	[4]	[5]	[6]
β	0.022	0.080	0.076	0.0085	0.2591	0.3912
(t)	(4.76)	(5.63)	(3.91)	(3.24)	(14.64)	(8.83)
std deviation y_r*	[0.000]	0.2057	0.2056	[0.000]	0.2322	0.2328
$\bar{\sigma}_y$	0.0995	0.2120				
σ_y*(1993)*	0.1980	0.1980	0.1980	0.2340	0.2340	0.2340
fixed effects	no	yes	yes	no	yes	yes
Specification	OLS	LSDV	OD	OLS	LSDV	OD
Sample	Spain	Spain	Spain	EU	EU	EU
Period	1955–91	1955–91	1955–91	1980–94	1980–94	1980–94

Note: Data from Eurostat (Statistical Office of European Communities) for 99 regions from the five largest EU countries (Germany, France, UK, Italy and Spain) and from BBV Foundation for the 17 Spanish regions. The Spanish data are available at intervals of generally two (and sometimes three) years and are not corrected for cross-regional price differences, while the Eurostat data are annual figures and corrected for differences in purchasing power. In both cases I work with relative income per capita, that is, income is normalized by its contemporaneous sample average.

[7] This figure is significantly higher when we work with output per employed worker rather than income per capita.

steady states look a lot like the end-of-sample incomes and the standard deviation of the implied stationary distribution (taking into account the estimated variance of the shocks) is $\bar{\sigma}_y = 0.21$, which is quite close to the observed dispersion in the final year of the sample ($\sigma_y(1993) = 0.20$). Finally, the OD procedure yields an estimate of the convergence parameter which is only slightly smaller than the previous one and leaves unaltered the dispersion of the estimated regional steady states (see equation [10.3]).

As in previous studies, the conditional and unconditional versions of equation (10.5) tell very different stories. In the first case, the conclusion is that we have pretty much reached the steady state. Hence, the substantial degree of inequality we observe today is likely to persist indefinitely in the absence of *structural change*. If we believe the restricted equation, we can still hope that regional inequality in Spain will eventually fall to about one half its current level.

The pattern is similar and even more extreme for the sample of European regions (equations [10.4] – [10.6] in Table 10.3). The unconditional specification of equation (10.5) yields an estimate of a convergence rate of less than 1%. The value of this parameter rises to over 25% when we introduce fixed effects and, surprisingly, increases even further when we use the OD procedure. As in the case of Spain, fixed effects specifications predict that the long-term dispersion of relative income per capita will be very close to its observed end-of-sample value.

b. Full circle back to Solow?

The panel results I have just reviewed are rather problematic if we try to interpret them within the standard neoclassical framework. The first difficulty has to do with the interpretation of the convergence rate. Solving for the coefficient of capital, α, in the expression that relates the convergence rate with the parameters of the production function (equation [10.3]), we have:

$$\alpha = 1 - \frac{\beta}{g + n + \delta} \tag{10.6}$$

Maintaining our previous assumptions about the rest of the parameters on the right-hand side of equation (10.6) (and assuming that the regional dummies adequately capture differences in investment shares and rates of population growth), the convergence rate I have estimated for the EU regions (see Table 10.3) implies a negative value of α, while the estimate for the Spanish sample would leave us, under the most *favorable* assumption about the value of δ, with a value of α around 0.20. Hence, these estimates of the convergence rate take us back, in the best of cases, to the old-fashioned Solow model with narrowly defined capital, and often lead to nonsensical results, such as a negative capital share.

A second problem with similar implications is that panel estimates of the neoclassical model tend to attribute most of the observed variation in productivity across economies to the country or regional dummies (i.e. to unknown factors that affect technical efficiency, rather than to differences in factor stocks)—a result that says very little in favor of the model's explanatory power. As I will show below, the estimates of the production function parameters obtained by Islam (1995) and Caselli, Esquivel and Lefort (1996) imply that factor stocks account for only a small fraction (between one tenth and one third) of observed productivity differentials in a sample of OECD countries.

In a very real sense, these results—together with the loss of significance of human capital indicators in panel growth equations—take us back to 1957, right after the discovery of the Solow residual, and negate much of what we thought we had learned since then. While it now arises in a cross-section rather than in a time-series setting, the problem is essentially the same one: we cannot explain why output varies across time or space in terms of the things we think are important and know how to measure.

There have been some attempts in the literature to get us out of this corner, but most of them have not been particularly convincing. Islam (1995) tries to rescue human capital as a determinant of the level of technological development (which is presumably what is being captured by the country dummies) by observing that the fixed effects are highly correlated with standard measures of educational achievement. The argument, however, merely sidesteps the problem: we know that human capital variables work well with cross-section data, but if they really had an effect on the level of technical efficiency they should be significant when entered into the panel equation.

Taking a different approach, Caselli, Esquivel and Lefort (1996) are quite willing to discard human capital and would settle for the old fashioned Solow model, but their estimated convergence rate is too high for even that. To rationalize their results, they turn to some unspecified open-economy version of the standard neoclassical model. The problem is that, although such a model could indeed generate very fast unconditional convergence, this should work largely through factor flows. Once we condition on investment and population growth rates, as Caselli et al. do, the estimated convergence rate should reflect only the characteristics of the technology and would therefore imply an unreasonably low share of capital.

c. Some tentative answers

Growth economists have spent more than forty years slowly chipping away at the Solow residual, largely by attributing increasingly larger chunks of it to investment in human capital and in other intangible assets. A few years ago we were reasonably certain that this was the way to go. But an increasing number of studies seem to be telling us that the effect of these variables on productivity vanishes when we turn to what seem to be the appropriate econometric techniques for the purpose of estimating growth equations.

Should we take these results at face value? Before we do so and abandon the only workable models we have, it seems sensible to search for some way to reconcile recent empirical findings with some kind of plausible theory. In this section, I will argue that this can be done at least to some extent by combining three ingredients: better data on human capital, a further extension of the human capital-augmented neoclassical model that allows for cross-country TFP differentials and for technological diffusion, and a bit more care in the estimation of convergence equations to avoid mixing up short-term and long-term dynamics.

i. Making sense of fast convergence

As we have seen in the previous section, part of the puzzle raised by the panel data studies has to do with the extremely high estimates of the rate of conditional convergence they typically produce. In this section I will argue that a reasonable interpretation of these results is that if we have correctly estimated the relevant parameter (and we may not), then convergence is much too fast to be simply the result of diminishing returns to scale. This observation points to two complementary lines of research. The first one proceeds by identifying plausible mechanisms that may help account for rapid convergence and incorporating them into theoretical and empirical models. The second asks whether panel specifications of growth equations do, in fact, yield estimates of the relevant parameter.

Starting with the second line of research, Shioji (1997a, 1997b) and De la Fuente (1998b) provide some evidence that panel estimates of the convergence rate may tell us very little about the speed at which economies approach their steady states (and therefore about the degree of returns to scale in reproducible factors). The reason is that these estimates are likely to capture short-term adjustments around trend as well as the long-term growth dynamics we are really interested in. Both authors show that correcting for the resulting bias in various ways brings us back to convergence rates that are broadly compatible with a sensible production function.

On the first issue, allowing for technological diffusion can go a long way towards explaining fast conditional convergence without resorting to sharply diminishing returns to scale.[8] In a series of papers, some of them written in collaboration with R. Doménech, I have used a further extension of the neoclassical model that incorporates this convergence mechanism, to analyze the pattern of growth in the OECD and in the Spanish regions with rather encouraging results (De la Fuente 1996, 2002a, 2002b; De la Fuente and Doménech 2000, 2001, 2002).[9] Our specification combines a production function in first differences

[8] There is also some evidence that a significant part of what appears to be TFP convergence at the aggregate level is in fact due to factor reallocation across sectors (Paci and Pigliaru 1995; De la Fuente 1996; Caselli and Coleman 1999; De la Fuente and Freire 2000).

[9] Dowrick and Nguyen (1989) also investigate the quantitative importance of technological catch-up as a convergence factor, but their empirical specification makes it difficult to disentangle this effect from the neoclassical convergence mechanism. Helliwell (1992), Coe and Helpman (1995) and Engelbrecht (1997) provide additional evidence on technological diffusion.

with a technical progress function that allows for technological catch-up. The estimated equation is in the form:

$$\Delta q_{it} = \Gamma_o + \gamma_i + \eta_t + \alpha \Delta k_{it} + \gamma \Delta h_{it} + \lambda b_{it} + \varepsilon_{it} \tag{10.7}$$

where Δ denotes annual growth rates, q_{it} is the log of output per employed worker in a country or region i at time t, k the log of the stock of physical capital per employed worker, h a measure of the average stock of human capital and η_t and μ_i are fixed time and country or region effects. The only non-standard term, b_{it}, is a technological gap measure which enters the equation as a determinant of the rate of technical progress in order to allow for a catch-up effect. This term is the Hicks-neutral TFP gap between each country or region and the reference territory, r (the U.S. for the OECD and an artificial average region for the Spanish case) at the beginning of each sub-period, given by:

$$b_{it} = \left(q_{rt} - \alpha k_{rt} - \gamma h_{rt}\right) - \left(q_{it} - \alpha k_{it} - \gamma h_{it}\right) \tag{10.8}$$

To estimate the model we substitute (10.8) into (10.7) and use non-linear least squares on the resulting equation with data on both factor stocks and on their growth rates. In this specification the parameter λ measures the rate of (conditional) technological convergence. Note that if this parameter is positive, relative TFP levels eventually stabilize, signalling a common asymptotic rate of technical progress for all countries, and the territorial fixed effects μ_i capture permanent differences in relative TFP that will presumably reflect differences across countries or regions in R&D (Research and Development) investment and other omitted variables.

The results for both samples suggest that fast conditional convergence is consistent with a sensible production function. The estimated diffusion parameter, λ, (7.4% for the OECD countries and 20% for the Spanish regions) is sufficiently high to generate rapid conditional convergence in output per worker even though the sum of the output elasticity of physical and human capital is around 0.7.

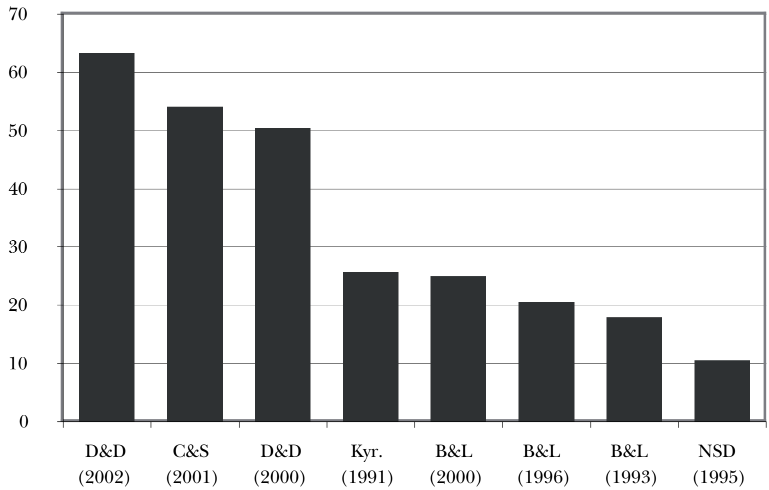
ii. Reassessing the role of human capital

A second troublesome feature of the recent literature is that human capital indicators are often not significant or even display the *wrong* sign in panel analyses and other studies (Knight, Loayza and Villanueva 1992; Benhabib and Spiegel 1994; Islam 1995; Caselli, Esquivel and Lefort 1996; Hamilton and Monteagudo 1998; and Pritchett 1999). There is a widespread feeling in the profession that these results may be due at least in part to the poor quality of the available schooling data. Some recent work by De la Fuente and Doménech (2000, 2001, 2002) helps support this conclusion. We find, in particular, that the amount of measurement error in the educational data sets that have been used in most growth studies is very considerable, and that this induces a large downward bias in the estimated coefficient of human capital in the aggregate production function. When this bias is corrected, the contribution of educational investment to productivity growth turns out to be quite sizeable.

In our latest paper on this issue (De la Fuente and Doménech 2002) we investigate the quality of the schooling data sets that have been used in recent growth literature (including some estimates of our own for the OECD countries). Following Krueger and Lindhal (2001), we construct estimates of reliability ratios that measure the information content of these series, restricting ourselves to a sample of OECD countries for which the available attainment information should presumably be of relatively high quality. The average value of this indicator (computed across different data transformations) for each of these data sets is shown in Graph 10.4. Our mean estimate of the reliability ratio of the schooling data is 0.335. Since this parameter must range between zero and one (with zero indicating that the data contains no information and one corresponding to perfect data without measurement error), our results suggest that the amount of noise in the data is quite high and that as a result, the average estimate of the coefficient of schooling in a growth equation is likely to suffer from a substantial downward bias, as predicted by the classical errors-in-variables model.

Our results also indicate that the importance of measurement error varies significantly across data sets, although their precise ranking depends on the data transformation that is chosen. Two

GRAPH 10.4: **Average reliability ratios for different schooling data sets** (percentage)



Source: De la Fuente and Doménech (2002), Table 8b.
Key: NSD = Nehru, Swanson and Dubey (1995); Kyr. = Kyriacou (1991); B&L = Barro and Lee (various years); C&S = Cohen and Soto (2001); D&D = De la Fuente and Doménech (various years).

of the data sets most widely used in cross-country empirical work, those by Kyriacou (1991) and Barro and Lee (various years), perform relatively well when the data are used in levels but, as Krueger and Lindhal (2001) note, contain very little signal when the data are differenced. Recent efforts to increase the signal content of the schooling data seem to have been at least partially successful. Taking as a reference the average reliability ratio for the 1996 version of the Barro and Lee data set, the latest revision of these series by the same authors has increased their information content by 21%, while the estimates reported in Cohen and Soto (2001) and in De la Fuente and Doménech (2002) raise the estimated reliability ratio by 162% and 207% respectively.

In the last part of the same paper, we systematically compare the performance of the different data sets in a number of growth specifications and find a clear positive correlation between estimated schooling coefficients and data quality measures. We then extrapolate this pattern to construct meta-estimates of the value of the coefficient that would be obtained with the correctly measured stock of human capital. Although there are technical complications that I will not discuss here, the intuition of the exercise is well captured by Graph 10.5, where we plot the estimates of the elasticity of output with respect to the stock of human capital obtained with different data sets and econometric specifications against the relevant reliability ratios. The scatter shows a clear positive correlation between these two variables within each specification and suggests that the true value of the human capital parameter is at least 0.50, which is the prediction of the levels equation for a reliability ratio of one. This figure is significantly larger than Mankiw, Romer and Weil's (1992) estimate of 1/3, which could probably have been considered a consensus value for this parameter a few years ago and had lately come to be regarded as too optimistic in the light of recent negative results in the literature.

iii. How important are factor stocks?

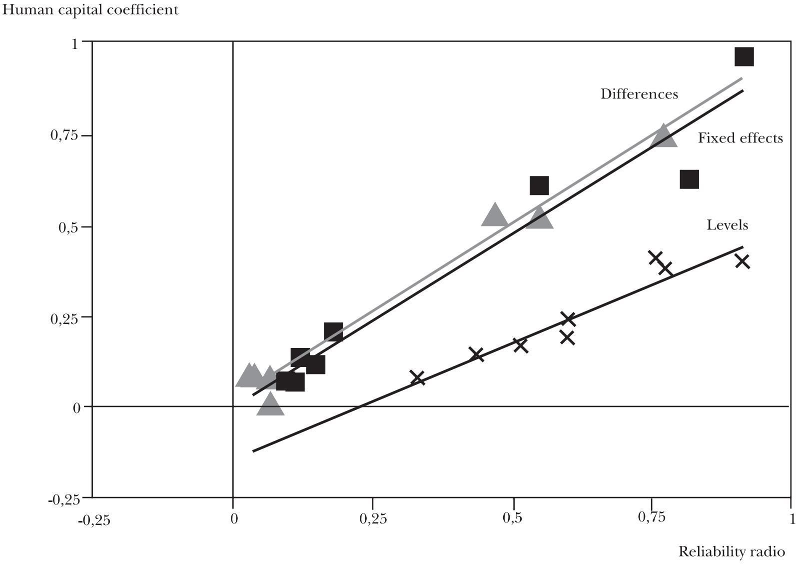
Some of the results I have just discussed can be used to perform a simple accounting exercise that may give us some idea of the explanatory power of the augmented neoclassical model that underlies much of recent research on growth and convergence. The exercise provides a simple way to illustrate the extent to which the results discussed in the previous subsections help overcome the puzzles raised by the panel studies and tie in well with the theme of this conference.

I will, in particular, attempt to gauge the relative importance of factor endowments and of TFP in explaining productivity differentials in a sample of 21 OECD countries.[10] Using the production function given in equation (10.7) above, I will recover the Hicks-neutral technological gap between each country in the sample and a fictional average economy to which I will attribute the observed sample averages of log productivity *(q)* and log factor stocks per employed worker *(k* and *h)*. Thus, I will define relative TFP *(tfprel)* by:

$$tfprel_{it} = (q_{it} - \alpha k_{it} - \beta h_{it}) - (qav_{it} - \alpha kav_{it} - \beta hav_{it}) =$$
$$= qrel_{it} - (\alpha krel_{it} + \beta hrel_{it}) \qquad (10.9)$$

[10] This section updates the exercise in section III of De la Fuente and Doménech (2001) drawing on the results of De la Fuente and Doménech (2002).

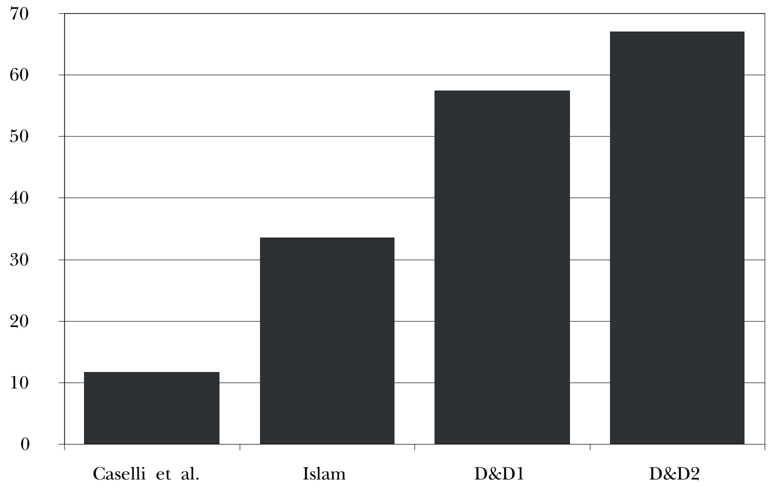
GRAPH 10.5: Estimated human capital coefficient vs. reliability ratio



where *av* denotes sample averages and *rel* deviations from them. To obtain a summary measure of the importance of TFP as a source of productivity differentials, I will regress relative TFP on relative productivity. (Notice that the regression constant will vanish because both variables are measured in deviations from sample means.) The estimated coefficient gives the fraction of the productivity differential with the sample average explained by the TFP gap in a typical OECD country.

Graph 10.6 summarises the results of the exercise for 1990 using four alternative sets of parameter values. The first two are taken from Caselli, Esquivel and Lefort (1996) and from Islam (1995). The other two come from De la Fuente and Doménech (2002). The first of these, labelled D&D1 in the graph, corresponds to uncorrected estimates using the latest version of our data set and the catch-up specification discussed in subsection c, item i; the second one uses our lowest meta-estimate of the coefficient of human capital after correcting for measurement error. As noted above, the results of Caselli, Esquivel and Lefort (1996) and Islam (1995) imply that TFP accounts for the bulk of observed productivity differentials, as factor stocks

GRAPH 10.6: Fraction of the productivity differential with the sample average explained by differences in per worker factor endowments in a typical OECD country in 1990
(percentage)



Notes:
- The data on factor stocks are taken from De la Fuente and Doménech (2002).
- The assumed coefficients of physical capital are 0.305 for Islam (for an OECD sample) and 0.107 for Caselli, Esquivel and Lefort, 1996 (for a sample of 97 countries). Both authors obtain negative coefficients for human capital when this variable is included, so I have taken their estimates for the standard Solow model without human capital and assumed a zero value for the schooling coefficient.
- The estimates labelled D&D1 and D&D2 are based on De la Fuente and Doménech (2002). The first estimate is based on the uncorrected results of our preferred specification, which yields values of 0.345 and 0.394 respectively for the coefficients of physical and human capital. In the second case, we use the same coefficient for physical capital and our lowest meta-estimate of the human capital coefficient after correcting for measurement error (which is 0.587).

only explain between 10% and 30% of them. With our parameter estimates, by contrast, the contribution of factor stocks roughly doubles, leaving only about a 30% unexplained residual that we attribute to TFP.[11] On the other hand, our calculations also suggest that the share of TFP in relative productivity has been rising over time, while the contribution of physical capital has decreased and that of human capital has remained roughly stable.

Hence, our results are more optimistic than those obtained by Klenow and Rodríguez-Clare (1997) in a similar exercise. They fall

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[11] This is considerably lower than our (2001) estimate, where the TFP contribution in 1990 was close to 50%. The difference comes mostly from the upward revision in the coefficient of human capital as a result of improvements in our data (in the estimate labeled D&D1) and the correction for remaining measurement error (D&D2).

approximately half way between the conclusions of Mankiw (1995), who attributes the bulk of observed income differentials to factor endowments, and those of Islam (1996) and some other recent panel studies, where fixed effects that presumably capture TFP differences, account for most of the observed cross-country income disparities. We view these findings as an indication that, while the augmented neoclassical model prevalent in the literature does indeed capture some of the key determinants of productivity, there is a clear need for additional work on the dynamics and determinants of the level of technical efficiency, which seems to be gaining importance over time as a source of productivity disparities.

10.6. Summary and conclusions

In this paper I have reviewed the recent literature on growth and convergence. After discussing the main convergence and divergence mechanisms identified in growth theory, I have developed a framework for the empirical analysis of growth, summarised some of the main results of the relevant literature and discussed their theoretical implications.

In the current state of the literature the conclusions we can draw must necessarily remain rather tentative. Practically all existing studies on the subject find clear evidence of some sort of convergence across countries and regions. These findings allow us to reject with a fair degree of confidence a series of recent models in which the assumption of increasing returns generates an explosive behavior of the distribution of income across economies that cannot be found in the data. Many of the results I have reviewed are consistent with an extended neoclassical model built around an aggregate production function that includes human capital as a productive input. Indeed, such findings seem to have motivated a sort of neoclassical revival that came close to becoming the conventional wisdom in the literature just a few years ago.

Recently, discussion has livened up again as a result of a number of studies that, using panel data techniques, turned up rather discouraging results suggesting in particular that educational investment was not productive and that the bulk of productivity differences across countries or regions has little to do with differences in stocks of productive factors. In my opinion, this has been largely a false alarm, but it has been useful in shaking up what was probably an exaggerated confidence in our ability to explain why some countries or regions are richer than others with an extremely simple model, and in directing researchers' attention to the determinants of technological progress and to some of the difficult econometric and data issues involved in the estimation of growth models.

References

ABRAMOVITZ, Moses. "Rapid Growth Potential and its Realization." In Moses Abramovitz. *Thinking About Growth and Other Essays on Economic Growth and Welfare*. Cambridge, MA: Cambridge University Press, 1989a, 187–219.

—. "Catching Up, Forging Ahead and Falling Behind." In Moses Abramovitz. *Thinking About Growth and Other Essays on Economic Growth and Welfare*. Cambridge, MA: Cambridge University Press, 1989b, 220–44.

ARELLANO, Manuel. *An alternative transformation for fixed effects models with predetermined variables*. Applied Economics Discussion Paper no. 57. Oxford: Institute of Economics and Statistics, University of Oxford, 1988.

BARRO, Robert J. "Economic Growth in a Cross Section of Countries." *Quarterly Journal of Economics* 106, no. 2 (1991): 407–43.

BARRO, Robert J., and Jong-Wha LEE. "International Comparisons of Educational Attainment." *Journal of Monetary Economics* 32, no. 3 (1993): 363–94.

—. "Data set for a panel of 138 countries." Mimeo, Harvard University, Cambdrige, MA, 1994.

—. "International Measures of Schooling Years and Schooling Quality." *American Economic Review* 86, no. 2 (1996): 218–23.

—. *International data on educational attainment, updates and implications*. NBER Working Paper no. 7911. Cambridge, MA: National Bureau of Economic Research, 2000. Available online at http://www.nber.org/papers/w7911.

BARRO, Robert J., and Xavier SALA I MARTIN. *Economic Growth and Convergence Across the United States*. NBER Working Paper no. 3419. Cambridge, MA: National Bureau of Economic Research, 1990.

—. "Convergence across States and Regions." *Brookings Papers on Economic Activity* 1 (1991): 107–82.

—. "Convergence." *Journal of Political Economy* 100, no. 2 (1992): 223–51.

BAUMOL, William J. "Productivity Growth, Convergence and Welfare: What the Long-Run Data Show." *American Economic Review* 76, no. 5 (1986): 1072–85.

BBV FOUNDATION. *Renta nacional de España y su distribución provincial*. Bilbao: BBV Foundation (various years).

BENHABIB, Jess, and Mark M. SPIEGEL. "The Role of Human Capital in Economic Development: Evidence from Aggregate Cross-Country Data." *Journal of Monetary Economics* 34, no. 2 (1994): 143–73.

CANOVA, Fabio, and Albert MARCET. *The Poor Stay Poor: Non-Convergence across Countries and Regions*. CEPR Discussion Paper no. 1265. London: Center for Economic Policy Research, 1995.

CASELLI, Francesco, and Wilbur J. COLEMAN. *How regions converge.* CEPR Discussion Paper no. 2191. London: Center for Economic Policy Research, 1999.

CASELLI, Francesco, Gerardo ESQUIVEL, and Fernando LEFORT. "Reopening the convergence debate: a new look at cross-country growth empirics." *Journal of Economic Growth* 1, no. 3 (1996): 363–89.

CASS, David. "Optimum Growth in an Aggregative Model of Capital Accumulation." *Review of Economic Studies* 32 (July 1965): 223–40.

CELLINI, Roberto, and Antonello SCORCU. "How many Italies? What data show about growth of convergence across Italian regions, 1970–91." Mimeo, University of Bologna, 1996.

COE, David, and Elhanan HELPMAN. "International R&D spillovers." *European Economic Review* 39, no. 5 (1995): 859–87.

COHEN, Daniel. *Tests of the "convergence hypothesis": a critical note.* CEPR Discussion Paper no. 691. London: Center for Economic Policy Research, 1992.

COHEN, Daniel, and Marcelo SOTO. *Growth and human capital: good data, good results.* CEPR Discussion Paper no. 3025. London: Center for Economic Policy Research, 2001.

COULOMBE, Serge, and Frank C. LEE. *Regional Economic Disparities in Canada.* Paper no. 9317e. Ottawa: University of Ottawa, Departement des Sciences Economiques, 1993.

DE LA FUENTE, Ángel. "Convergencia y otras historias: economía regional desde una perspectiva neoclásica." *Revista de Economía Aplicada* 4, no. 10 (1996): 5–64.

—. "The empirics of growth and convergence: a selective review." *Journal of Economic Dynamics and Control* 21, no. 1 (1997): 23–74.

—. *Convergence equations and income dynamics: The sources of OECD Convergence, 1970–95.* CEPR Discussion Paper no. 1794. London: Center for Economic Policy Research, 1998a. (Later published in *Economica* 70, no. 280 [November 2003]: 655–71.)

—. *What kind of regional convergence?* CEPR Discussion Paper no. 1924. London: Center for Economic Policy Research, 1998b.

—. "On the sources of convergence: A close look at the Spanish regions." *European Economic Review* 46, no. 3 (2002a): 569–99.

—. *The effect of Structural Fund Spending on the Spanish regions: an assessment of the 1994–99 Objective 1 CSF.* CEPR Discussion Paper no. 3673. London: Center for Economic Policy Research, 2002b.

DE LA FUENTE, Ángel, and Rafael DOMÉNECH. *Human capital in growth regressions: how much difference does data quality make?* CEPR Discussion Paper no. 2466. London: Center for Economic Policy Research, 2000. (Also published as Economics Department Working Paper no. 262. Paris: Organisation for Economic Co-operation and Development, 2000.)

—. "Schooling data, technological diffusion and the neoclassical model." *American Economic Review* 91, no. 2 (2001): 323–27.

—. *Human capital in growth regressions: how much difference does data quality make? An update and further results.* CEPR Discussion Paper no. 3587. London: Center for Economic Policy Research, 2002.

DE LA FUENTE, Ángel, and María Jesús FREIRE "Estructura sectorial y convergencia regional." *Revista de Economía Aplicada* 23 (2000): 189–205.

DOLADO, Juan J., José Manuel GONZÁLEZ-PÁRAMO, and José María ROLDÁN. "Convergencia Económica entre las Provincias Españolas: Evidencia Empírica (1955–1989)." *Moneda y Crédito* 198, no. 8 (1994): 1–131.

DOWRICK, Steve, and Duc-Tho NGUYEN. "OECD Comparative Economic Growth 1950–85: Catch-up and Convergence." *American Economic Review* 79, no. 5 (1989): 1010–30.

ENGELBRECHT, Hans Jürgen. "International R&D spillovers, human capital and productivity in the OECD economies: an empirical investigation." *European Economic Review* 41 (1997): 1479–88.

EVANS, Paul, and Georgios KARRAS. "Do economies converge? Evidence from a panel of US states." *Review of Economics and Statistics* 78, no. 3 (August 1996): 384–88.

FABERBERG, Jan, and Bart VERSPAGEN. "Heading for divergence? Regional growth in Europe reconsidered." *Journal of Common Market Studies* 34, no. 3 (1996): 431–48.

FABIANI, Silvia, and Guido PELLEGRINI. "Education, infrastructure, geography and growth: an empirical analysis of the development of Italian provinces." Paper no. 323, Bank of Italy, Servizio di Studi, 1996.

GERSCHENKRON, Alexander. "Economic Backwardness in Historical Perspective." In Bert Hoselitz, ed. *The Progress of Underdeveloped Areas.* Chicago: Chicago University Press, 1952.

GOROSTIAGA, Arantzazu. "¿Cómo afectan el capital público y el capital humano al crecimiento? Un análisis para las regiones españolas en el marco neoclásico." *Investigaciones Económicas* 23, no. 1 (January 1999): 95–114.

GRAHL, John, and Jonathan SIMMS. "Endogenous Growth in the European Regions." Mimeo, University of Manchester, Institute of Science and Technology, 1993.

GRIER, Kevin, and Gordon TULLOCK. "An Empirical Analysis of Cross-National Economic Growth, 1951–80." *Journal of Monetary Economics* 24 (1989): 259–76.

GROSSMAN, Gene M., and Elhanan HELPMAN. *Innovation and Growth in the Global Economy.* Cambridge, MA: The MIT Press, 1991.

HAMILTON, James, and Josefa MONTEAGUDO PUJALTE. "The augmented Solow model and the productivity slowdown." *Journal of Monetary Economics* 42, no. 3 (1998): 495–509.

HELLIWELL, John F. *Trade and Technical Progress.* NBER Working Paper no. 4226. Cambridge, MA: National Bureau of Economic Research, 1992.

HERZ, Bernhard, and Werner RÖGER. "Economic growth and convergence in Germany." *Weltwirtschaftliches Archiv* 1/1996, (1996): 133–43.

HOLTZ-EAKIN, Douglas. "Solow and the states: Capital accumulation, productivity, and economic growth." *National Tax Journal* 46 (December 1993): 425–39.

ISLAM, Nazrul. "Growth Empirics: A Panel Data Approach." *Quarterly Journal of Economics* 110, no. 4 (1995): 1127–70.

KLENOW, Peter J., and Andrés RODRÍGUEZ-CLARE. "The neoclassical revival in growth economics: has it gone too far?" In B. Bernanke and J. Rotenberg, eds. *NBER Macroeconomics Annual 1997.* Cambridge, MA: MIT Press, 1997, 73–102.

KNIGHT, Malcolm, Norman LOAYZA, and Delano VILLANUEVA. *Testing the neoclassical theory of economic growth: a panel data approach.* IMF WorkingPapers no. 92/106. Washington, DC: International Monetary Fund, 1992.

KOOPMANS, Tjalling C. "On the Concept of Optimal Economic Growth." In *The Econometric Approach to Development Planning.* Amsterdam: North-Holland, 1965.

KORMENDI, Roger, and Phillip G. MEGUIRE. "Macroeconomic Determinants of Growth: Cross-Country Evidence." *Journal of Monetary Economics* 16, no. 2. (September 1985): 141–63.

KRUEGER, Alan B., and Mikael LINDAHL. "Education for growth: why and for whom?" *Journal of Economic Literature* 39, no. 4 (2001): 1101–36.

KYRIACOU, George. "Level and Growth Effects of Human Capital, A Cross-Country Study of the Convergence Hypothesis." Mimeo, New York University, 1991.

LICHTENBERG, Frank R. *R&D Investment and International Productivity Differences.* NBER Working Paper no. 4161. Cambridge, MA: National Bureau of Economic Research, 1993.

LUCAS, Robert E. *Models of Business Cycles.* Oxford: Basil Blackwell, 1987.

—. "On the Mechanics of Economic Development." *Journal of Monetary Economics* 22, no. 1 (1988): 3–42.

—. "Why Doesn't Capital Flow from Rich to Poor Nations?" *American Economic Review* 80 (1990): 92–96.

MANKIW, N. Gregory. "The Growth of Nations." *Brookings Papers on Economic Activity* 1 (1995): 275–326.

MANKIW, N. Gregory, David ROMER, and David N. WEIL. "A Contribution to the Empirics of Economic Growth." *Quartely Journal of Economics* 107, no. 2 (May 1992): 407–37.

MARCET, Albert. "Los pobres siguen siendo pobres: Convergencia entre regiones y países, un análisis bayesiano de datos de panel." In Instituto de Análisis Económico, ed. *Crecimiento y convergencia regional en España y Europa*. Vol. 2. Barcelona: Instituto de Análisis Económico, 1994.

MAS, Matilde, Joaquín MAUDOS, Francisco PÉREZ, and Ezequiel URIEL. "Growth and convergence in the Spanish provinces." In H. Amstrong and R. Vickerman, eds. *Convergence and divergence among European Regions*. London: Pion, 1995.

—. "Disparidades regionales y convergencia en las comunidades autónomas." *Revista de Economía Aplicada* 4 (1994): 129–48.

MURTHY, N. R. Vasudeva, and I. S. CHIEN. "The empirics of economic growth for OECD countries: some new findings." *Economics Letters* 55, no. 3 (1997): 425–29.

NEHRU, Vikram, Eric SWANSON, and Ashutosh DUBEY. "A New Database on Human Capital Stock in Developing and Industrial Countries: Sources, Methodology, and Results." *Journal of Development Economics* 46, no. 2 (1995): 379–401.

NELSON, Richard R., and Gavin WRIGHT. "The Rise and Fall of American Technological Leadership: the Postwar Era in Historical Perspective." *Journal of Economic Literature* 30, no. 4 (1992): 1931–64.

NEVEN, Damien J., and Claudine GOUYETTE. "Regional convergence in the European Community." *Journal of Common Market Studies* 33 (1995): 47–65.

NONNEMAN, Walter, and Patrick VANHOUDT. "A further augmentation of the Solow model and the empirics of economic growth for OECD countries." *Quarterly Journal of Economics* 111, no. 3 (1996): 943–53.

PACI, Raffaelle, and Francesco PIGLIARU. "β convergence and/or structural change? Evidence from the Italian regions." Nota di Lavoro 72.95, Eni Enrico Mattei Foundation, 1995.

PERSSON, Joakim. "Convergence across the Swedish counties, 1911–1993." *European Economic Review* 41 (1997): 1835–52.

PRESCOTT, Edward C. "Needed: A theory of total factor productivity." *International Economic Review* 39, no. 3 (1998): 525–51.

PRITCHETT, Lant. "Where has all the education gone?" Mimeo, World Bank, Washington, DC, 1999.

RAYMOND, José Luis, and Begoña GARCÍA. "Las disparidades en el PIB per cápita entre comunidades autónomas y la hipótesis de convergencia." *Papeles de Economía Española* 59 (1994): 37–58.

ROMER, Paul M. "Increasing Returns and Long-Run Growth." *Journal of Political Economy* 94, no. 5 (1986): 1002–37.

—. "Growth Based on Increasing Returns due to Specialization." *American Economic Review* 77, no. 2 (1987a): 56–62.

—. "Crazy Explanations for the Productivity Slowdown." *NBER Macroeconomics Annual* 2 (1987b): 163–210.

—. "Endogenous Technical Change." *Journal of Political Economy* 98 (1990): S71–S102.

SALA I MARTIN, Xavier. "The classical approach to convergence analysis." *Economic Journal* 106 (1996a): 1019–36.

—. "Regional cohesion: evidence and theories of regional growth and convergence." *European Economic Review* 40 (1996b): 1325–52.

SHIOJI, Etsuro. *Regional Growth in Japan*. CEPR Discussion Paper no. 1425. London: Center for Economic Policy Research, 1996.

—. "Convergence in panel data: evidence from the skipping estimation." Mimeo, Pompeu Fabra University, Barcelona, 1997a.

—. "It's still 2%. Evidence of convergence from 116 years of the US states panel data." Mimeo, Pompeu Fabra University, Barcelona, 1997b.

SOLOW, Robert. "A Contribution to the Theory of Economic Growth." *Quarterly Journal of Economics* 70, no. 1 (1956): 65–94.

—. "Technical Change and the Aggregate Production Function." *Review of Economics and Statistics* 39, no. 3 (1957): 312–20.

SUMMERS, Robert, and Alan HESTON. "The Penn World Table (Mark 5): An Expanded Set of International Comparisons, 1950–88." *Quarterly Journal of Economics* 106, no. 2 (1991): 327–68.

TONDL, Gabriele. "The changing pattern of regional convergence in Europe." Mimeo, European University Institute, Florence, 1997.

WOLFF, Edward N. "Capital Formation and Productivity Convergence Over the Long Term." *American Economic Review* 81, no. 3 (1991): 565–79.

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