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MEASURING THE NEW ECONOMY: AN INTERNATIONAL COMPARATIVE PERSPECTIVE

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1. Introduction

The advances made in the production and use of information and communication technology (ICT) during the past decades may have potentially large effects for long term economic growth. Indeed the substantial acceleration in real GDP growth in many OECD countries, but in particular in the United States, during the second half of the 1990s has led to suggestions that a "new economy" has emerged. In this new economy the old economic rules were supposed to have become invalid. For example, traditional concerns about the limits of maximum production capacity might disappear as the marginal costs of producing ICT goods and services are virtually nil. Moreover, the trade-off between inflation and unemployment could be reduced due to a more efficient inventory management.

The slowdown of economic growth across the OECD area since 2000 shows that most of the old economic rules are still valid, and it has pushed the more extreme versions of the new economy to the background. However, there is still good reason to believe that ICT will have a longer lasting impact on the potential for economic growth. Indeed ICT may be characterized as a typical general purpose technology (Bresnahan and Trajtenberg, 1995; Helpman, 1998). Like earlier technological breakthroughs such as the introduction of steam during the 19th century and electricity at the beginning of the 20th century, ICT has a wide range of applications and a large impact across the economy. ICT also complements new technological and organizational innovations. In fact, not only does it make these other innovations possible, but also the latter are necessary to fully exploit ICT. Finally, ICT is an evolutionary technology as it improves over time and the cost of using it falls continuously.[1]

So far the empirical support for a direct effect of ICT on the acceleration in economic growth mainly comes from the U.S. experience (see Section 2). However, there is some concern that the stronger growth effects in the U.S. are not only due to the greater importance and impact of ICT, but are also associated with different measurement methods concerning ICT output, investment and prices. These concerns are enhanced in the light of recent downward adjustments by the Bureau of Economic Analysis to GDP growth in 1999 and 2000, which at least to some extent are related to revision in estimates of ICT, notably software

[1]For some recent collections of works on the various impacts of ICT, see Brynjolfsson and Kahin (2000) and various papers by Oliner and Sichel, Brynjolfsson and Hitt, and Gordon in *The Journal of Economic Perspectives*, Fall 2000, Vol. 14, No. 4.

(Moulton, Seskin, and Sullivan, 2001). More generally the greater penetration of ICT may have increased measurement problems in some sectors of the economy, in particular in knowledge intensive services. Hence the measurement of ICT is an issue of considerable importance to statisticians and economists.

The papers in this special issue of *The Review of Income and Wealth* deal with various aspects concerning the measurement of ICT and its impact on economic growth. All four papers are strongly empirical and heavily rely on information obtained from statistical agencies in individual countries. All four deal with the impact of ICT on economic performance, in particular on productivity growth and structural change. Together these four papers provide a very good assessment of the state of the art in the research field on ICT and the economy. They also identify the main weaknesses in the statistical system concerning ICT and areas for further improvement. In this introduction I will first briefly review the main economic issues concerning ICT and growth (Section 2), followed by an account of the main measurement issues (Section 3) in an international comparative perspective. In Section 4, I will briefly summarize the main points from the papers that follow this introductory essay.

2. The Contribution of ICT to Economic Growth

During the second half of the 1990s there has been an acceleration of GDP growth in many OECD countries, but in particular in the U.S. Notably productivity growth in the American economy improved very strongly as well. For example, between 1995 and 2000 average labor productivity growth in the U.S. was 0.9 percentage points faster than between 1990 and 1995 (Conference Board, 2002). Some have stressed that this growth acceleration is mainly due to improved productivity growth in the ICT-producing sector (Jorgenson and Stiroh, 2000; Jorgenson, 2001). Others have demonstrated an increasingly productive use of ICT-goods and services elsewhere in the economy (Oliner and Sichel, 2000; Baily and Lawrence, 2001). However, there are also critics who argue that ICT does not have the potential to raise growth by as much as the great innovations earlier in the twentieth century, such as the introduction of electricity, the combustion engine, etc. (Gordon, 2000).[2]

In the rest of the advanced world the evidence of acceleration in productivity growth due to ICT is weaker though not wholly absent. On average labor productivity growth accelerated at a modest 0.1 percent per year during the second half of the 1990s for the OECD area as a whole, excluding the U.S. But the diversity in growth performance across OECD countries has much increased. For example, within the European Union annual labor productivity growth halved from 2.5 percent between 1990 and 1995 to only 1.3 percent between 1995 and 2000 (Conference Board, 2002). The causes of this diversity in growth performance are multifold: different growth rates in investment, varying paces of structural reforms on labor, product and capital markets, differences in demand effects

[2]In addition, Gordon stresses that part of the growth acceleration in the U.S. is due to the procyclical productivity effect in the upward phase of the business cycle dring the second half of the 1990s. It is only after a complete cycle has passed that we can fully evaluate the growth impact of ICT.

and innovation regimes (OECD, 2001). A smaller effect of ICT on growth is therefore only one of many possible explanations for slower growth in many OECD countries compared to the U.S.

Fortunately there are some studies that have documented the growth contribution of ICT in OECD countries on the basis of a growth accounting framework, using ICT investment as separate factor input. However, as ICT investment series are—as yet—not available on a comprehensive basis for all OECD countries, these studies usually derive information on ICT expenditure from (private) data sources. The latter include consumer expenditure, which needs to be taken out on the basis of crude assumptions to arrive at proxies for ICT investment. More recently, some first attempts were undertaken to obtain genuine investment series for ICT, but the information on ICT investment is still sparse (ECB, 2001; Mulder, Melka, and van Ark, 2001; Colecchia and Schreyer, 2001).

Table 1 summarizes some of the main international comparative studies on contributions of ICT capital and total factor productivity growth to GDP and/ or labor productivity growth. In a study for the G-7, Schreyer (2000) makes use of ICT expenditure data which he reworked to estimates of investment on the basis of various assumptions. The nominal investment figures were converted to real measures by using the difference between the U.S. (hedonic) price index for ICT goods compared to the index for other capital goods, which (after smoothing) is applied to the price index for non-ICT capital for each individual country. Using the perpetual inventory method, Schreyer then cumulated investments which were scrapped on the basis of a hyperbolic age–efficiency pattern that declines slowly in the early years of an ICT capital good's service life and rapidly at the end. The contribution of the ICT capital services to growth is then computed using a growth accounting technique, with user costs as weights. Schreyer's study confirms the U.S. advantage in terms of higher contribution of ICT capital to output growth.

As the original study by Schreyer provided figures up to 1996 only, Goldman Sachs (2000), Daveri (2001) and Colecchia and Schreyer (2001) updated and extended the earlier study. Daveri made substantial changes to Schreyer's method by the reworking ICT-expenditure to ICT-investment data. In his aim to cover more countries than Schreyer he relied more heavily on U.S. evidence to obtain his estimates. A step forward in Daveri's work is that he includes an estimate for software investment. Daveri's estimates of the ICT contribution to growth are therefore substantially higher than those of Schreyer. With software included, the contribution of ICT capital to GDP growth in European countries varies from between 0.31 and 0.64 percentage points during the period 1991–99, compared to 0.94 percentage points in the U.S. In an earlier version of his paper, Daveri (2000) also showed estimates for non-European countries, including Australia and Canada, which showed ICT contributions as large as those for the leading European countries, such as the U.K. and the Netherlands.

At national level similar studies were carried out for Finland, France, the Netherlands, the U.K. and the U.S. (Table 2). These studies largely used actual investment data instead of reworked expenditure data. The overall picture is one which suggests that most countries show somewhat lower contributions of ICT to economic growth than in the U.S., with the exception of Finland. In Finland,

TABLE 1

SUMMARY TABLE OF MAJOR INTERNATIONAL STUDIES ON CONTRIBUTION OF ICT CAPITAL AND TFP IN ICT PRODUCTION TO GROWTH IN GDP AND LABOR PRODUCTIVITY, 1990s

			Contribution of ICT Capital to		Contribution of TFP in ICT Production to Annual Labor Productivity Growth
Author(s)	Country Coverage	Time Period	Annual GDP Growth	Annual Labor Productivity Growth	
Schreyer (2000)	Canada	1990–96	0.28 out of 1.7		
	France	1990–96	0.17 out of 0.9		
	Germany	1990–96	0.19 out of 1.8		
	Italy	1990–96	0.21 out of 1.2		
	Japan	1990–96	0.19 out of 1.8		
	U.K.	1990–96	0.28 out of 2.1		
	U.S.	1990–96	0.42 out of 3.0		
European Commission (2000)	EU	1991–95		0.2–0.3 out of 2.0	0.1 out of 2.0
	EU	1995–99		0.3–0.5 out of 1.5	0.2 out of 1.5
Daveri (2001)	Ireland	1991–99	0.64 out of 6.9		
	Denmark	1991–99	0.52 out of 2.9		
	Netherlands	1991–99	0.68 out of 2.8		
	U.K.	1991–99	0.76 out of 2.7		
	Portugal	1991–99	0.43 out of 2.5		
	Austria	1991–99	0.45 out of 2.3		
	Spain	1991–99	0.36 out of 2.3		
	Greece	1991–99	0.34 out of 2.3		
	Finland	1991–99	0.45 out of 2.1		
	Belgium	1991–99	0.48 out of 1.9		
	Sweden	1991–99	0.50 out of 1.9		
	Germany	1991–99	0.49 out of 1.7		
	France	1991–99	0.41 out of 1.6		
	Italy	1991–99	0.31 out of 1.4		
Goldman Sachs (2000)	OECD	1990–95		0.38 out of 1.8	0.39 out of 1.8
	OECD	1996–99		0.73 out of 2.1	0.63 out of 2.1
	U.S.	1990–95		0.35 out of 1.7	0.41 out of 1.7
	U.S.	1996–99		0.79 out of 2.7	0.83 out of 2.7
	Japan	1990–95		0.55 out of 1.2	0.48 out of 1.2
	Japan	1996–99		1.14 out of 1.9	0.55 out of 1.9
	U.K.	1990–95		0.37 out of 3.4	0.22 out of 3.4
	U.K.	1996–99		0.84 out of 1.8	0.40 out of 1.8
	Euroland	1990–95		0.28 out of 2.1	0.33 out of 2.1
	Euroland	1996–99		0.38 out of 1.4	0.69 out of 1.4
ECB (2001)	Euroland	1991–95	0.22 out of 1.5	0.26 out of 2.4	
	Euroland	1996–99	0.42 out of 1.9	0.39 out of 1.3	

TABLE 1—continued

Author(s)	Country Coverage	Time Period	Contribution of ICT Capital to: Annual GDP Growth	Contribution of ICT Capital to: Annual Labor Productivity Growth	Contribution of TFP in ICT Production to Annual Labor Productivity Growth
Schreyer and Colecchia	Australia	1990–95	0.48 out of 3.4		
(2001)	Australia	1995–00	0.68 out of 4.6		
	Canada	1990–95	0.30 out of 1.8		
	Canada	1995–00	0.57 out of 4.2		
	Finland	1990–95	0.24 out of 0.7		
	Finland	1995–99	0.62 out of 5.6		
	France	1990–95	0.18 out of 1.0		
	France	1995–00	0.35 out of 2.8		
	Germany	1990–95	0.30 out of 2.2		
	Germany	1995–00	0.38 out of 2.1		
	Italy	1990–95	0.21 out of 1.4		
	Italy	1995–99	0.36 out of 1.9		
	Japan	1990–95	0.31 out of 1.3		
	Japan	1995–99	0.38 out of 1.1		
	U.K.	1990–95	0.27 out of 2.1		
	U.K.	1995–00	0.48 out of 3.6		
	U.S.	1990–95	0.97 out of 2.6		
	U.S.	1995–00	1.71 out of 4.4		

Notes: All estimates refer to total economy GDP, except for Daveri (2001) and Goldman Sachs (2000) which refer to business sector GDP; all estimates on the contribution of ICT capital include software except for Schreyer (2000) and European Commission (2000).

however, the communication equipment industry accounts for a relatively large share of output, explaining the large contribution of that industry to growth.

Most of the studies mentioned above have only looked at the impact of ICT investment on productivity growth without introducing industry detail. One reason is that outside the U.S. reliable and internationally comparable estimates of ICT investment and ICT capital goods at industry level are still largely unavailable.[3] Still an industry decomposition can provide important results on the question of how widespread are the productivity improvements due to ICT. For the U.S. Jorgenson and Stiroh (2000) show that ICT-producing industries contributed as much as 60 percent to TFP growth during the 1990s, while these

[3]The study on the Netherlands by CPB (2000) is a notable exception.

TABLE 2

SUMMARY TABLE OF MAJOR NATIONAL STUDIES ON CONTRIBUTION OF ICT CAPITAL AND TFP IN ICT PRODUCTION TO GROWTH IN GDP AND LABOR PRODUCTIVITY, 1990S

			Contribution of ICT Capital to		Contribution of TFB in ICT Production to	
Author(s)	Country Coverage	Time Period	Annual GDP Growth	Anual Labor Productivity Growth	Annual GDP Growth	Anual Labor Productivity Growth
Oliner and Sichel (2000)	U.S.	1991–95 1996–99	0.57 out of 2.8 1.10 out of 4.8	0.51 out of 1.5 0.96 out of 2.6		
Jorgenson (2001)	U.S.	1990–95 1995–99		0.43 out of 1.2 0.89 out of 2.1		0.25 out of 1.2 0.50 out of 2.1
CPB (2000)	Netherlands	1991–95 1996–99		0.2 out of 1.5 0.2 out of 1.3		
Mairesse, Cette, and Kocoglu (2000)	France	1989–95 1995–99	0.16 out of 1.3 0.27 out of 2.2			
Oulton (2001)	U.K.	1989–94 1994–98		0.39 out of 2.6 0.62 out of 1.6		
Jalava and Pohjola (2001)	Finland	1990–95 1995–99	0.3 out of −0.3 0.7 out of 5.6	0.5 out of 4.4 0.6 out of 3.2	0.7 out of −0.3 1.2 out of 5.6	0.7 out of 4.4 1.2 out of 3.2

Notes: All estimates refer to total economy GDP, except for Oliner and Sichel (2000) which refers to business sector GDP; all estimates on the contribution of ICT capital include software except for CPB (2000).

industries accounted for only a few percentage points of total output. Computers in the ICT-using industries were primarily used as substitution for other capital goods without significantly contributing to an acceleration in total factor productivity growth. Nevertheless the contribution to TFP growth of industries outside the ICT-producing sector also accelerated during the second half of the 1990s. This might indicate that ICT-using industries generated some TFP growth through possible spillover effects as well, even though this effect cannot be distinguished from other effects on TFP growth. The (lack of) spillovers is the main topic of Kevin Stiroh's contribution to this special issue of the *Review*. His paper, which focuses exclusively on manufacturing industries, suggests little spillover from ICT.

In an international comparative perspective, recent studies by Pilat and Lee (2001), van Ark (2001) and Conference Board (2001b) distinguish between the contributions of ICT-producing industries, ICT-intensive using industries and other industries to labor productivity growth, thereby circumventing the problem of having to estimate the contribution of ICT capital at industry level. These studies show that even though ICT-producing industries contribute to labor productivity growth to a different degree across countries, the largest contributions to labor productivity growth mostly come from industries that make intensive use of ICT. These studies show that in particular major services industries, such as financial and business services and trade, are intensive users of ICT and have contributed significantly to productivity growth over the past decade, even though the effects differ between individual industries and countries.

In conclusion, there are three important channels by which ICT affects growth. The first channel is the ICT-production channel. Industries that produce IT hardware and software as well as those that make communication equipment have experienced enormous technological progress which has been translated into substantial TFP growth. However, this "production effect" from ICT differs across countries depending on the relative importance of these industries in the economy. The second channel is the ICT-investment channel. In almost all countries there are large industries in manufacturing and in particular in services that have substantially raised investment in ICT. This has often led to a positive "use" effect on labor productivity growth. However, for a TFP growth effect from ICT beyond that created by the ICT-producing industries one needs to exploit the spillover effects from ICT, which represents the third channel. These spillover effects are created through the inventions and innovations that emerge in the slipstream of ICT as a general purpose technology. The evidence on spillovers at the macro level, however, is still quite sparse.

3. Measurement Problems

In the past few years there have been increasing concerns about whether the macroeconomic statistics correctly trace the changes in the information society. Griliches (1994) showed a striking difference between the acceleration of labor productivity growth in "measurable" sectors of the U.S. economy (agriculture, mining, manufacturing, transport and communication, and public utililities) and the slowdown in "unmeasurable" sectors (like construction, trade, the financial sector, "other" market services and government) over past decades. Apart from this rise in measurement error at the aggregate level due to shift toward the unmeasurable sectors of the economy, one may also observe an increase in measurement problems in the "unmeasurable" sector itself. This component of the rise in measurement problems may—at least in part—be related to the increased use of ICT.

For a comprehesive view of the role of ICT in increasing the measurement problems concerning output, value added and productivity, one needs to make a distinction between the various sources of measurement problems. These can be divided into four categories, namely measurement problems with regard to output in manufacturing (which is the major industry of the "measurable" sector of the economy) and output in services (which dominate the "unmeasurable" sector) *vis-à-vis* measurement problems concerning the inputs (production factors and intermediate inputs) in manufacturing and services. Figure 1 presents a summary of the major issues in each quadrant as well as the most desirable and feasible solutions.

For manufacturing output the problems are relatively straightforward. Nominal output and prices of industrial products are relatively easy to measure. The measurement problems in the northwest quadrant of the diagram are therefore largely confined to measuring ICT output in constant prices. For the construction of price indices, statistical offices mostly use a method that compares prices of identical products in subsequent periods. This "matched model" approach is difficult to apply for products such as computers (and other ICT goods) because the technical characteristics of these products change very

	Manufacturing	Services
Output	Primarily computers and other ICT Solution primarily through use of hedonic price indices Feasible provided data availability	Most services with "customized" production, and non-market services (education, health, etc.) Solutions through detailed surveys on multiple dimensions of output for each industry Difficult in methodological terms as well as in terms of data availability
Input	Primarily semiconductors and software Solution primarily through use of hedonic price indices Feasible given availability of data and use of input–output matrices	Primarily ICT input including software Solution through use of real input series adjusted with hedonic price deflators Feasible provided availability of capital-flow matrices

Figure 1. The Four Categories of Measurement Problem

rapidly.[4] Hence, it is difficult to adjust for quality changes in the price series of these products. The alternative approach is to develop hedonic price indices, which relates the prices of each good to changes in selected characteristics of the product rather than the product itself. In the case of a personal computer such characteristics involve, for example, the type of processor, memory capacity, disk drives, CD-ROM stations, etc. (Triplett, 1989, 1990). Since 1986 this method has been used in the U.S. National Income and Product Accounts (NIPA).

Wyckoff (1995) was among the first to show that the large differences in computer deflators between countries were at least partly due to methodological differences. He applied the U.S. deflator for office and computing equipment to nominal output series in other OECD countries, which led to an upward adjustment of productivity growth of between 5 and 20 percent relative to the U.S. during the 1980s. More recently hedonic methods were developed for computers in Australia, Canada and France and applied in their national accounts. Sweden and the U.K. have also developed hedonic measures for personal computers. The Danish national accounts directly apply the U.S. hedonic deflators after a correction for exchange rate fluctuations. The latter methodology was applied to all countries by Goldman Sachs (2000) and by Daveri (2001).[5] Such a method may, however, lead to biases for several reasons. Firstly, as computer hardware production in the U.S. mainly consists of PCs and semiconductors, which show the fastest price declines, an adjustment of nominal ICT output in Europe, which is more strongly dominated by the production of peripheral equipment, with the U.S. deflator may lead to an exaggeration of the price decline. Secondly, the application of hedonic price indices needs to be combined with the use of chain weights in the price index, as is done in the U.S. and France. When fixed weights are used the price decline for computers will be overstated because of the relatively large weight in the base year compared to successive years (Landefeld and

[4]Except for ICT these deflation problems also apply to some other industrial products, such as pharmaceutical products, large equipment and some durable consumer goods.

[5]European Commission (2000) applied a full as well as a 50 percent adjustment of European prices for U.S. deflators.

Grimm, 2000). Thirdly, it is questionable whether one can assume that the computer hardware producing industry in Europe is as competitive as in the U.S., which implies again that the price decline in Europe might be overstated when using the U.S. index. Schreyer (2000) constructed a 'harmonized'' hedonic computer deflator for the G-7 countries assuming that the difference between price changes for ICT capital goods and non-ICT capital goods in the U.S. was applicable to the deflator for non-ICT capital goods of other countries.

A comprehensive implementation of hedonics deflators, however, requires some further considerations. Except for adjusting the deflator for computer output, it is also necessary to make an adjustment for the most important ICT inputs in industry (the southwest quadrant of Figure 1). Triplett (1996) showed that between 1974 and 1994 the prices of semiconductors declined almost 3000 times compared to only 20 times for computers over the same period.[6] As semiconductors account for between 15 and 45 percent of input costs in the computer industry, much to almost all of the productivity increase in the computer industry can be traced to productivity gains in the semiconductor industry. In addition, in many OECD countries semiconductors (or even computers) are hardly domestically produced but imported. It is therefore necessary to make comprehensive adjustments of output, input and imports of ICT products. In addition to ICT hardware, the issue of deflation of software (which up till now is only done in the U.S. for prepackaged software) and its use as an input in other industries needs to be considered as well.[7] The paper by Schreyer in this volume considers some of these issues in greater detail, and carefully assesses the sensitivity of the various estimates and assumptions in hedonic price measurement when applied for international comparisons.

In contrast to manufacturing, measurement problems in the service sector are perhaps easier to deal with for inputs than for output. The most important technological inputs in the service sector are ICT products, which give rise to the same measurement issues as for ICT output. The share of computers and other high tech equipment in market services has strongly increased in most OECD countries. However, among different industries in market services the distribution of ICT capital is still highly unequal.

The largest measurement problems, however, relate to the measurement of output in the service sector. The current methodology of splitting the change in output value into a quantity component and a price component is difficult to apply to many service activities, as often no clear quantity component can be distinguished. Moreover possible changes in the quality of services are also difficult to measure. These problems are not new, and improvement in measurement of service output has been a topic on the agenda of statisticians and academics for a long time.[8] In many service industries information on inputs (such as labor

[6]See also Jorgenson (2001) for updated series.

[7]A comprehensive handbook on price indices for ICT products will be published by the OECD in the fall of 2001. Aizcorbe *et al.* (2000) have argued that the use of the matched model method at a higher frequency than only once a year (e.g. every quarter or every month) mimics the hedonic price index reasonably well. Still high-frequency matched models place a very heavy demand on the intensity of data collection compared to hedonic models.

[8]See, for example, Griliches (1992) and the statistical work of the Voorburg Group on Service Statistics (http://www4.statcan.ca/english/voorburg/).

income) was and still is used as a proxy for output. As long as the price or cost developments are not affected too much by changes in the quality of the services, the traditional method suffices at least to measure the change in real output as the statistical bias remains relatively constant (Hulten, 2000). However, the increased importance of ICT may have accelerated quality changes in services. Multiple dimensions of a service should be taken into account, including the service concept, the client interface and the service delivery system (den Hertog, 2000). This implies that the real output of a particular service cannot be so easily measured on the basis of one exclusive quantity indicator. For example, improved inventory management in the trade sector makes it possible to differentiate supply of goods in terms of time, place and type of product. The application of ICT has supported the customization of financial products or combinations of those products (like an insurance, an investment fund and a mortgage). Services in the public sector, such as health care, are also increasingly characterized by diversity and differentiation in time, place and type of treatment. Even though such changes have not exclusively led to upward adjustments of real output, on balance the bias is probably towards an understatement of the growth in real service output (Triplett and Bosworth, 2000).

It should be emphasized that statistical offices are doing much to improve measurement methods. In the U.S., the U.S. Bureau of Labor Statistics (which is responsible for the development of price indices) and the Bureau of Economic Analysis (which produces the National Income and Product Accounts) have introduced various improvements in measurement methods (Dean, 1999; Gullickson and Harper, 1999; Landefeld and Fraumeni, 2001). In particular, the introduction of hedonic price indices and, more recently, chain indices had a strong upward effect on the U.S. measures of real output growth. These continuous adjustments of U.S. series also raises a point of criticism concerning *ad hoc* changes in measurement methods in the U.S. and suggest that a greater use of comprehensive methodologies, such as input–output tables and capital flow matrices, might be a preferable strategy. The use of input–output tables in combination with chain price and quantity indices has been an established practice in several countries, including France and the Netherlands, for some time.

In a series of reports, Eurostat recently evaluated measurement practices in various service activities, such as financial services and public services, and "difficult to measure" production of goods, such as computers and large equipment (Eurostat, 1998a, 1998b, 1999a, 1999b, 2000). These reports suggest that many of the desired adjustments put a large demand on data and therefore on the burden for companies to report and on financial resources of statistical office to process the data. An important priority therefore is to develop statistical techniques that make improvements possible on the basis of relatively small databases. For example, a recent Eurostat initiative to develop harmonized hedonic deflators for computers across European countries can substantially reduce the cost of such indicators.

In conclusion, measurement error at macroeconomic level has partly increased because of the greater share of "difficult to measure" industries in the economy. In addition, there are indications that within these industries, in particular in services, measurement errors get bigger because of the increased use of

ICT. It also appears that the use of hedonic price indices, which is applied or experimented with by many statistical offices, is a promising avenue to improve the measurement of real output and input of computers. The biggest problem area, however, remains the measurement of real output in many service industries. How much of this explains the observed differences in output and productivity growth between countries remains an unanswered question for the time being, and an important topic on the future research agenda.

4. The Contribution of the Papers in this Volume

The following four papers in this volume reflect the state of the art in measuring the contribution of ICT to economic growth in an international comparative perspective. The first paper by Paul Schreyer deals with the implications of changes in measurement of computer prices. For this purpose Schreyer disentangles the effects of improved measurement of computer prices on real measures of final output, intermediate inputs and imports of ICT equipment. By simulating the impact of these various components of price change in a national accounts/input–output framework, he shows that there are substantial offsetting effects which reduce the impact of better measurement methods on the measurement of real GDP. Obviously this does not mean that improved price measurement of ICT goods and services should not have the highest priority. Schreyer shows the effects of different price measures can be substantial for disaggregated output measures. Measures of productivity also appear affected in particular for countries which heavily invest in ICT equipment.

The second paper by Kevin Stiroh provides substantive evidence of a widespread acceleration in labor productivity growth and total factor productivity (TFP) growth across U.S. manufacturing industries. However, Stiroh moderates the enthusiasm about the "new economy," as he shows that little of the TFP acceleration can be related to spillovers, network effects, etc. Once an allowance is made for differences in productivity growth across industries, TFP growth shows no correlation with ICT capital. Naturally spillover effects may take more time to materialize than the time period covered by Stiroh. Moreover, the effects of ICT on productivity growth in service industries, which are among the largest investors in ICT, have not been investigated in this paper and await, among other things, better measurement of service output.

The third paper by Crépon and Heckel looks at the contribution of ICT investment on output and productivity growth in France. In contrast to studies that use information at industry level, such as Stiroh's paper on the U.S. as well as earlier papers on this issue for France (e.g. Mairesse, Cette, and Kocoglu, 2000), the present study makes use of a large sample of firm-level data. It shows substantially stronger effects of ICT capital on output and productivity growth than the macro studies; something that was also observed in earlier studies for the U.S. (see, for example, Yang and Brynjolfsson, 2000). The difference seems due to the larger share of IT equipment in the capital stock according to the firm data, but the authors also raise the issue of other factors that may influence the stronger impact at firm level which may be hidden at macro-level, due to possible aggregation problems and the role of complementary intangible capital (see van

Ark, 2000, for an overview). A particular strength of the study by Crépon and Heckel is that it applies a dual accounting approach, i.e., it not only measures the contribution of ICT capital to real output growth but also the contribution of price changes in ICT capital to the change in overall prices.

The final paper by Edward Wolff shifts the emphasis from productivity to other measures of structural change. He finds that computer investment in particular affects occupation composition and changes in the input structure of industries. Productivity effects are unlikely to emerge before such major structural changes have been materialized. According to Wolff these results point at the high adjustment costs that are associated with the new technology, the possible larger impact of ICT on product differentiation rather than productivity enhancement, and the complementary role of intangible capital, including occupation skills.

Together these papers help to determine the statistical and research agendas for the future in this area. Apart from better measurement of ICT output and inputs, there should be considerable attention for appropriate adjustments for quality change in the price indices for ICT and for services output. Another area of importance concerns the measurement of intangible assets, including human capital, research and development and other types of intellectual capital. It is hoped that the contributions in this volume will help to shape those agendas.

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