

Lessons for Europe from the U.S. Growth Resurgence

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Abstract: *This paper analyses the sources of U.S. labour productivity growth in the late 1990s and presents projections for both output and labour productivity growth. We show that investment in information technology (IT) played a substantial role in the U.S. productivity revival and that similar trends are evident in data for other leading OECD countries. We then outline a methodology for projecting trend output and productivity growth for the broadly defined U.S. economy. Our base-case projection puts trend productivity growth at 1.78 percent per year over the next decade with a range of 1.14 to 2.38 percent, reflecting fundamental uncertainties about the rate of technical progress in IT-production and investment in IT-equipment and software. Our central projection is below the average growth rate of 2.07 percent during 1995–2000. Similar projections for Europe must await more complete information. (JEL J2)*

1 Introduction

The unusual combination of more rapid growth and lower inflation in the United States from 1995 to 2000 touched off a strenuous debate among economists about whether improvements in U.S. economic performance could be sustained. This debate has now given way to a broad consensus that the role of information technology is the key to understanding the American growth resurgence. Questions persist about whether similar trends have characterised the leading European economies. The answers to these questions are essential for resolving uncertainties about future growth that currently face decision-makers in both public and private sectors in Europe.

In this paper we review the most recent evidence on growth in the United States and the leading OECD countries and quantify the role of information technology (IT). Despite downward revisions to the gross domestic product (GDP) and investment in the annual revisions of the U.S. National Income and Product Accounts (NIPA) by the Bureau of Economic Analysis (BEA) in July

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of 2002, we conclude that the U.S. productivity revival remains largely intact and that IT investment is the predominant source of this revival. The capital deepening contribution from computer hardware, software, and telecommunications equipment greatly exceeded the contribution from all other forms of investment to labour productivity growth after 1995. An increase in total factor productivity (TFP) growth in the IT-producing sectors also contributed to the resurgence of labour productivity, modestly augmented by a smaller increase in TFP growth elsewhere in the economy.

Colecchia and Schreyer (2002) have compiled detailed information on investment in information technology and economic growth in nine OECD countries in the 1990s. This has two important advantages over previous international comparisons. First, the estimates of IT investment are based on national accounting data. Second, prices of information technology equipment and software are comparable among the nine countries. There is clear evidence of a surge of IT investment in all nine countries, even in Germany and Japan, both of which experienced slowdowns in economic growth during the period 1995–2000. More comprehensive comparisons with growth in the United States must await more complete information.

We next turn to the future of U.S. productivity growth for the U.S. economy, defined broadly to include business, households, and the government. Our overall conclusion is that the projections of Jorgenson and Stiroh (2000), prepared more than two years ago, are largely on target. Our base-case projection of trend labour productivity growth for the next decade is 1.78 percent per year, below the average of 2.07 percent per year for the period 1995–2000. Our projection of output growth for the next decade is only 2.78 percent per year, compared with 4.07 percent per year for 1995–2000.¹ The difference is largely due to a projected slowdown in the growth in hours worked due to changing demographics. We conclude that the American growth resurgence of the late 1990s was not sustainable because it depended in large part on a rate of work force expansion that will not be maintained.

We emphasise that projecting growth for periods as long as a decade is fraught with uncertainty. Our pessimistic projection of labour productivity growth is only 1.14 percent per year, while our optimistic projection is 2.38 percent. The range for output growth is from 2.14 percent in the pessimistic case to 3.38 percent in the optimistic case. These ranges result from fundamental uncertainties about future patterns of investment and changes in technology in the

¹ We focus on the period 1995–2000 to avoid the cyclical effects of the 2001 recession. We discuss estimates for the period 1995–2001 later in the paper. Note also that productivity growth for our broad coverage of the U.S. economy is somewhat slower than the nonfarm business sector.

production of IT equipment and software. Jorgenson (2001) has traced these uncertainties to variations in the product cycle for semiconductors, the most important component of computers and telecommunications equipment.

The starting point for projecting U.S. output growth is a projection of future growth of the labour force. The growth of hours worked of 1.99 percent per year from 1995–2000 is not sustainable because labour force growth for the next decade will average only one percent. The slowdown in the growth of hours worked would have reduced output growth by 0.99 percent, even if labour productivity growth had continued unabated. We estimate that labour productivity growth from 1995–2000 also exceeded its sustainable rate, however, due to exceptionally high rates of investment in information technology equipment and software. This implies an additional decline of 0.29 percent in the trend rate of output growth, so that we project output growth at 2.78 percent for the next decade, precisely the same as the rate of growth of output during the period 1973–1995, prior to the growth resurgence of the late 1990s. The decompositions are quite different, however, with stronger productivity growth offset by slower projected hours growth.

Section 2 reviews the historical record, extends the estimates of Jorgenson (2001) to include data for 2000 and 2001 and revises estimates of economic growth for earlier years to incorporate new information. We employ the same methodology and summarise it briefly. We compare IT investment and economic growth for the nine OECD countries analysed by Colecchia and Schreyer (2002). Section 3 presents our projections of the trend growth of output and labour productivity in the U.S. for the next decade. Section 4 concludes the paper.

2 Reviewing the historical record

Our methodology for analysing the sources of growth is based on the production possibility frontier introduced by Jorgenson (1996, pp. 27–28). This framework encompasses substitution between investment and consumption goods on the output side and between capital and labour inputs on the input side. Jorgenson and Stiroh (2000), Jorgenson (2001), and Jorgenson, Ho, and Stiroh (2002b) have used this methodology to measure the contributions of information technology (IT) to U.S. economic growth and the growth of labour productivity.

2.1 Production possibility frontier

In the *production possibility frontier* output (Y) consists of consumption goods (C) and investment goods (I), while inputs consist of capital services (K) and labour input (L). Output can be further decomposed into IT investment goods – computer hardware (I_c), computer software (I_s), communications equipment (I_m) – and non-IT output (Y_n). Capital services can be similarly decomposed into the capital service flows from computer hardware (K_c), software (K_s), communications equipment (K_m), and non-IT capital services (K_n).² The input function (X) is augmented by *total factor productivity* (A). The production possibility frontier can be represented as:

$$(1) \quad Y(Y_n, I_c, I_s, I_m) = A \cdot X(K_n, K_c, K_s, K_m, L)$$

Under the standard assumptions of competitive product and factor markets, and constant returns to scale, Equation (1) can be transformed into an equation that accounts for the sources of economic growth:

$$(2) \quad \begin{aligned} \bar{w}_{Y_n} \Delta \ln Y_n + \bar{w}_{I_c} \Delta \ln I_c + \bar{w}_{I_s} \Delta \ln I_s + \bar{w}_{I_m} \Delta \ln I_m = \\ \bar{v}_{K_n} \Delta \ln K_n + \bar{v}_{K_c} \Delta \ln K_c + \bar{v}_{K_s} \Delta \ln K_s + \\ \bar{v}_{K_m} \Delta \ln K_m + \bar{v}_L \Delta \ln L + \Delta \ln A \end{aligned}$$

where $\Delta x \equiv x_t - x_{t-1}$, \bar{w} denotes the average output shares, \bar{v} the average input shares, and $\bar{w}_{Y_n} + \bar{w}_{I_c} + \bar{w}_{I_s} + \bar{w}_{I_m} = \bar{v}_{K_n} + \bar{v}_{K_c} + \bar{v}_{K_s} + \bar{v}_{K_m} + \bar{v}_L = 1$. The shares are averaged over periods t and $t-1$. We refer to the share-weighted growth rates in Equation (2) as the *contributions* of the inputs and outputs.

Average labour productivity (ALP) is defined as the ratio of output to hours worked, so that $ALP = y = Y / H$, where the lower-case variable (y) denotes output (Y) per hour (H). Equation (2) can be rewritten in per hour terms as:

$$(3) \quad \Delta \ln y = \bar{v}_{K_n} \Delta \ln k_n + \bar{v}_{K_{IT}} \Delta \ln k_{IT} + \bar{v}_L (\Delta \ln L - \Delta \ln H) + \Delta \ln A$$

where $\bar{v}_{K_{IT}} = \bar{v}_{K_c} + \bar{v}_{K_s} + \bar{v}_{K_m}$.

Equation (3) decomposes ALP growth among three components. The first is *capital deepening*, defined as the contribution of capital services per hour and allocated between non-IT and IT components. The interpretation of capital deepening is that increases in capital per worker enhance labour productivity in

² Note that our output and capital service flow concepts include the services of residential structures and consumer durables, as well as government structures and equipment. See Jorgenson (2001) for details.

proportion to the capital share. The second component is *labour quality improvement*, defined as the contribution of increases in labour input per hour worked. This reflects changes in the composition of the work force and raises labour productivity in proportion to the labour share. The third component is *total factor productivity* (TFP) growth, which raises ALP growth point for point.

In an inter-industry production model like that of Jorgenson, Ho, and Stiroh (2002a), the growth of TFP reflects the productivity contributions of individual industries. It is difficult, however, to create the detailed industry data needed to measure industry-level productivity in a timely and accurate manner. The Council of Economic Advisors (CEA, 2001), Jorgenson and Stiroh (2000), Jorgenson (2001), Jorgenson, Ho and Stiroh (2002b), and Oliner and Sichel (2000; 2002) have employed the price dual of industry-level productivity to estimate TFP growth in the production of IT equipment and software.

Intuitively, the idea underlying the dual approach is that declines in relative prices for IT investment goods reflect productivity growth in the IT-producing industries. We weight these relative price declines by the shares in output of each of the components of IT investment in order to estimate the contribution of IT production to economy-wide TFP growth. This enables us to decompose aggregate TFP growth as:

$$(4) \quad \Delta \ln A = \bar{u}_{IT} \Delta \ln A_{IT} + \bar{u}_n \Delta \ln A_n$$

where \bar{u}_{IT} represents IT's average share of output, $\Delta \ln A_{IT}$ is IT-related productivity growth, and $\bar{u}_{IT} \Delta \ln A_{IT}$ is the contribution to aggregate TFP from IT-production. Non-IT productivity growth $\Delta \ln A_n$ includes productivity gains in other industries, as well as reallocations of inputs and outputs among sectors.

We estimate the contribution to aggregate TFP growth from IT production $\bar{u}_{IT} \Delta \ln A_{IT}$ by estimating output shares and growth rates of productivity for computer hardware, software, and communications equipment. Productivity growth for each component of investment is the negative of the rate of price decline, relative to the price change of capital and labour inputs. The output shares are the final expenditures on these investment goods, divided by total output.³ Finally, the contribution of non-IT productivity growth $\bar{u}_n \Delta \ln A_n$ is derived from Equation (4) as a residual.

³ Output shares include personal consumption expenditures, gross private domestic investment, government purchases, and net exports for each type of IT equipment and software. Note that the use of the price dual to measure technological change assumes competitive markets in IT production. As pointed out by Aizcorbe (2002), the market for many IT components, notably semiconductors and software, is not perfectly competitive and part of the drop in prices may reflect changes in markups rather than technical progress. However, Aizcorbe (2002), concludes

2.2 Data

We briefly summarise the information required to implement Equations (1) to (4); more detailed descriptions are available in Jorgenson (2001) and Jorgenson, Ho, and Stiroh (2002b). Our output measure is broader than the GDP concept in the U.S. National Income and Product Accounts, the nonfarm business sector that is the focus of many productivity studies (BLS or Oliner and Sichel, 2000; 2002), or the private sector measure used in Jorgenson, Ho, and Stiroh (2002b). In particular, we include imputed capital service flows from residential housing and consumer durables, as well as the rate of return to government capital as in Jorgenson (2001). Our output estimates reflect the most recent revisions to the U.S. National Income and Product Accounts (NIPA), released in July 2002.

Our capital service estimates are based on the Tangible Wealth Study, published by the BEA and described in Lally (2002). This includes data on business, household, and government investment for the U.S. economy through 2001. We construct capital stocks from the investment data by the perpetual inventory method. We assume that the effective capital stock for each asset available for production is an average of current and lagged stocks. The data on tangible assets from BEA are augmented with inventory data to form our measure of the reproducible capital stock. The total capital stock also includes land and inventories.

Finally, we estimate the service flow for each component of capital stock by multiplying the rental price by the effective capital stock, as suggested by Jorgenson and Griliches (1996). Our estimates of rental prices incorporate the asset-specific differences in asset prices, tax rates, tax lifetimes, and depreciation rates presented by Jorgenson and Yun (2001). This is essential for understanding the productive impact of IT investment because IT capital inputs have dramatically higher rates of decline of asset prices and depreciation rates.

We refer to the ratio of capital services to capital stock as *capital quality*, so that:

$$(5) \quad \Delta \ln KQ = \Delta \ln K - \Delta \ln Z$$

where KQ is capital quality, K is capital services, and Z is effective capital stock. The effective capital stock Z is a quantity index of 70 types of structures and equipment, plus land and inventories, using investment goods prices as weights. The flow of capital services K is a quantity index of the same stocks, using rental prices as weights. The difference in growth rates is the growth rate

that the decline in markups accounts for only about one-tenth of the measured decline in the price of microprocessors in the 1990s.

of capital quality. Capital quality increases as firms invest relatively more in assets with higher marginal products like information technology equipment and software.

Labour input is a quantity index of hours worked that takes into account the distribution of the work force by sex, employment class, age, and education. The weights used to construct the index reflect the compensation of the various types of workers. In the same way as for capital, we define *labour quality* as the ratio of labour input to hours worked, so that:

$$(6) \quad \Delta \ln KQ = \Delta \ln K - \Delta \ln Z$$

where LQ is labour quality, L is labour input, and H is hours worked. Labour quality rises as firms hire relatively more highly skilled and highly compensated workers.

Our labour data incorporate individual micro-data on hours worked and compensation per hour from the Censuses of Population for 1970, 1980, and 1990 and the annual Current Population Surveys (CPS) for 1964–2001. We take total hours worked for employees directly from the NIPA (Table 6.9c), self-employed hours worked for the non-farm business sector from the BLS, and self-employed hours worked in the farm sector from the Department of Agriculture.

2.3 Results

Table 1 and Figure 1 report our estimates of the sources of economic growth from Equation (2). For the period 1959–2001, output grew 3.38 percent per year. Capital input contributed 48.9 percent of this growth or 1.62 percent per year. Labour input followed in importance with 34.3 of growth or 1.16 percent per year. Less than 17.5 percent of output growth, 0.59 percentage points, reflects growth in TFP. These results are consistent with the other recent growth accounting estimates, including CEA (2001), Jorgenson and Stiroh (2000), Jorgenson (2001), Jorgenson, Ho, and Stiroh (2002b) and Oliner and Sichel (2000; 2002).

Our data also reveal substantial acceleration in output growth after 1995. The growth rate of output increased from 2.78 percent per year for 1973–1995 to 4.07 percent for 1995–2000, reflecting a substantial acceleration in IT investment and a modest deceleration in non-IT investment. For the period 1995–2001, which includes the U.S. recession that began in March 2001, output growth was 3.55 percent. This is considerably slower, and we focus our attention on the period 1995–2000 to avoid cyclical effects of the 2001 recession.

Table 1

Growth in GDP and the Sources of Growth, 1959-2001

	1959-2001	1959-1973	1973-1995	1995-2000	1995-2001	1995-2000 less 1973-1995	1995-2001 less 1973-1995
Growth in GDP (Y)	3.38	4.18	2.78	4.07	3.55	1.29	0.77
Contribution of Selected Output Components							
Other Output (Y_o)	2.91	3.92	2.30	3.00	2.65	0.70	0.35
Computer Output (Y_c)	0.14	0.06	0.17	0.32	0.28	0.15	0.11
Software Output (Y_s)	0.09	0.03	0.10	0.30	0.24	0.20	0.14
Communications Output (Y_m)	0.11	0.11	0.10	0.19	0.14	0.09	0.04
Information Technology Services (Y_a)	0.11	0.07	0.11	0.25	0.24	0.14	0.13
Contribution of Capital and CD Services (K)	1.62	1.77	1.40	2.08	2.03	0.68	0.63
Other (K_o)	1.20	1.57	0.98	1.10	1.10	0.12	0.12
Computers (K_c)	0.20	0.07	0.20	0.53	0.49	0.33	0.29
Software (K_s)	0.10	0.03	0.10	0.28	0.27	0.18	0.17
Communications (K_m)	0.12	0.10	0.12	0.17	0.17	0.05	0.05
Contribution of Labor (L)	1.16	1.24	1.12	1.37	1.12	0.25	0.00
Aggregate Total Factor Productivity (TFP)	0.59	1.16	0.26	0.62	0.40	0.36	0.14
Contribution of Capital and CD Quality	0.41	0.27	0.36	0.95	0.93	0.59	0.57
Contribution of Capital and CD Stock	1.21	1.51	1.04	1.12	1.11	0.08	0.07
Contribution of Labor Quality	0.28	0.33	0.27	0.21	0.22	-0.06	-0.05
Contribution of Labor Hours	0.88	0.91	0.85	1.16	0.89	0.31	0.04

Note: A contribution of an output or input is defined as the share-weighted, real growth rate.

Source: Author's calculations based on BEA, BLS, Census Bureau, and other data.

On the input side, more rapid capital accumulation contributed 0.68 percentage points to the post-1995 acceleration through 2000, while faster growth of labour input contributed 0.25 percentage points and accelerated TFP growth the remaining 0.36 percentage points. These estimates are all smaller when 2001 is included. Finally, the contribution of capital input from IT increased from 0.42 percentage points per year for 1973–1995 to 0.98 for 1995–2000, exceeding the increased contributions of all other forms of capital.

The last panel in Table 1 presents an alternative decomposition of the contribution of capital and labour inputs, using Equations (5) and (6). The contributions of capital and labour inputs reflect the contributions of capital quality and capital stock, as well as labour quality and hours worked:

$$(7) \quad \Delta \ln Y = \bar{v}_K \Delta \ln Z + \bar{v}_K \Delta \ln KQ + \bar{v}_L \Delta \ln H + \bar{v}_L \Delta \ln LQ + \Delta \ln A$$

Figure 1

Sources of Economic Growth

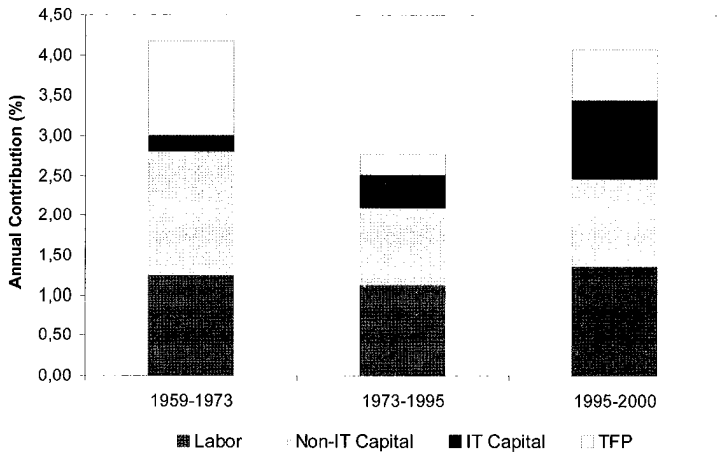


Table 1 shows that the revival of output growth after 1995 can be attributed to two forces. First, the rising contribution of capital quality reflects a massive substitution toward IT capital in response to accelerating IT price declines; the growth of capital stock lagged considerably behind the growth of output. Second, the growth of hours worked surged, while labour quality growth stagnated. A fall in the unemployment rate and an increase in labour force participation drew more workers with relatively low marginal products into the work force.

Table 2

Sources of Growth in Average Labor Productivity 1959-2001

	1959-2001	1959-1973	1973-1995	1995-2000	1995-2001	1995-2000 less 1973-1995	1995-2001 less 1973-1995
Output Growth (Y)	3.38	4.18	2.78	4.07	3.55	1.29	0.77
Hours Growth (H)	1.50	1.56	1.44	1.99	1.53	0.55	0.09
Average Labor Productivity Growth (ALP)	1.88	2.63	1.33	2.07	2.02	0.74	0.69
Capital Deepening	1.00	1.13	0.80	1.24	1.39	0.44	0.59
IT Capital Deepening	0.37	0.19	0.37	0.87	0.85	0.50	0.48
Other Capital Deepening	0.63	0.95	0.43	0.37	0.54	-0.06	0.11
Labor Quality	0.28	0.33	0.27	0.21	0.22	-0.06	-0.05
TFP Growth	0.59	1.16	0.26	0.62	0.40	0.36	0.14
IT-related Contribution	0.19	0.09	0.21	0.45	0.41	0.24	0.20
Other Contribution	0.40	1.07	0.05	0.17	-0.01	0.12	-0.06

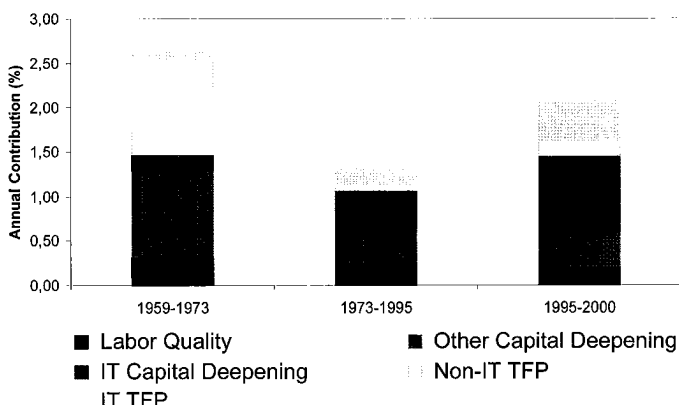
Note: A contribution of an output or input is defined as the share-weighted, real growth rate.

Source: Author's calculations based on BEA, BLS, Census Bureau, and other data.

Table 2 and Figure 2 present estimates of the sources of ALP growth from Equations (3) and (4). For the period 1959–2001 as a whole, growth in ALP of 1.88 percentage points per year accounted for 55.6 percent of output growth,

due to capital deepening of 1.00 percentage points per year, improvement of labour quality of 0.28 percentage points, and TFP growth of 0.59 percentage points. Growth in hours worked of 1.50 percentage points per year accounted for the remaining 44.4 percent of output growth.

Figure 2 Sources of Labor Productivity Growth



Looking more closely at the post-1995 period, we see that labour productivity increased by 0.74 percentage points per year from 1.33 percentage points for 1973–1995 to 2.07 percentage points for 1995–2000, while hours worked increased by 0.55 percentage points per year from 1.44 percentage points for 1973–1995 to 1.99 percentage points for 1995–2000. When the recession of 2001 is included, labour productivity falls slightly, while hours growth falls considerably for 1995–2001, which underscores the remarkable strength of U.S. productivity growth during this downturn.

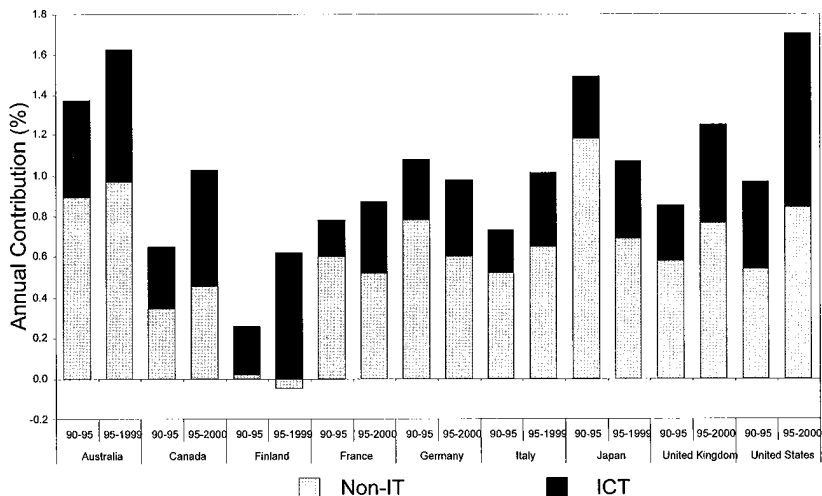
The labour productivity growth revival through 2000 reflects more rapid IT-capital deepening of 0.50 percentage points, partly offset by a decline in non-IT-capital deepening of 0.06 percentage points. It also reflects accelerated productivity growth in IT production of 0.24 percentage points and in non-IT production of 0.12 percentage points. Finally, the contribution of labour quality growth fell by 0.06 percentage points.

Colecchia and Schreyer (2002) have compiled estimates of the contribution of IT investment to the growth of output in nine OECD countries, including the four leading countries of Europe – France, Germany, Italy, and the U.K. – as well as Japan and the United States. An important innovation in that paper was the introduction of “harmonized” price deflators to incorporate comparable quality adjustments for IT assets across countries. While one would ideally

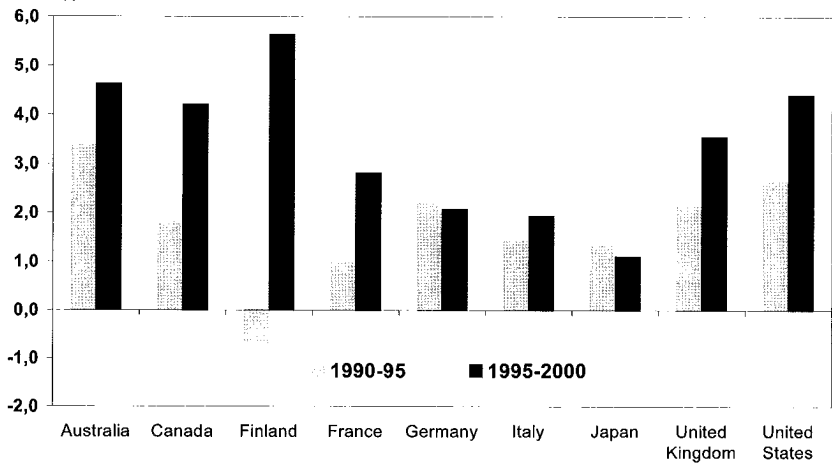
prefer country-specific deflators for each IT asset, the approach of Colecchia and Schreyer is a useful proxy.

Figure 3 presents results for the sub-periods 1990–1995 and 1995–2000. For all nine countries the contribution of IT investment accelerated after 1995, even in Germany and Japan, two countries that experienced a slowdown in growth during the late 1990's. The contribution of IT investment during the late 1990's exceeded that in the United States during the early 1990s in four countries – Australia, Canada, Finland, and the United Kingdom.

Figure 3. Capital Input Contribution of Information Technology by Country



Colecchia and Schreyer (2002) also present growth rates of output for all nine countries before and after 1995 and we give the results in Figure 4. The acceleration in economic growth during the last half of the 1990s was most dramatic for Finland, but both Canada and France also experienced a larger increase in the rate of growth of output than the United States. Unfortunately, a detailed analysis of the sources of economic growth for the nine OECD countries requires information on the impact of non-IT investment, as well as the contributions of labour input and TFP growth. Until these data are available, it is impossible to arrive at an assessment of the role of information technology like what we have presented for the United States.

Figure 4**Output Growth, 1990-1995 versus 1995-2000**

Note: Latest available output growth is 1995-1999 for Finland, Italy, and Japan.

3 Projecting productivity growth

While there is no disagreement about the resurgence of ALP growth in the United States after 1995, there has been considerable debate about whether this is permanent or transitory. This distinction is crucial for understanding the sources of the recent productivity revival and projecting future productivity growth. Changes in the underlying trend growth rates of productivity and the work force are permanent, while cyclical factors such as strong output growth due to extraordinarily high rates of investment are transitory.

This section presents our projections of trend rates of growth for output and labour productivity over the next decade, abstracting from business cycle fluctuations. Our key assumptions are that output and the reproducible capital stock will grow at the same rate and that labour hours and the labour force will also grow at the same rate.⁴ These are characteristic features of the U.S. and most industrialised economies over periods longer than a typical business cycle. For example, U.S. output growth averaged 3.38 percent per year for 1959–2001, while our measure of the reproducible capital stock grew 3.55 percent.⁵

⁴ The assumption that output and the capital stock grow at the same rate is a property of balanced growth equilibrium in the standard neo-classical growth model.

⁵ Reproducible assets exclude land.

We begin by decomposing the aggregate capital stock between reproducible capital stock and land, which we assume to be fixed. This implies:

$$(8) \quad \Delta \ln Z = \bar{\mu}_R \Delta \ln Z_R + (1 - \bar{\mu}_R) \Delta \ln LAND = \bar{\mu}_R \Delta \ln Z_R$$

where $\bar{\mu}_R$ is the value share of reproducible capital stock in total capital stock.

We construct estimates of trend output and labour productivity growth, conditional on the projected growth of the remaining sources of economic growth. More formally, if $\Delta \ln Y = \Delta \ln Z_R$, then Equations (3), (4), (7), and (8) imply that trend labour productivity and output growth are given by:

$$(9) \quad \Delta \ln y = \frac{\bar{v}_K \Delta \ln KQ - \bar{v}_K (1 - \bar{\mu}_R) \Delta \ln H + \bar{v}_L \Delta \ln LQ + \bar{u}_{IT} \Delta \ln A_{IT} + \ln A_n}{1 - \bar{v}_K \bar{\mu}_R}$$

$$\Delta \ln Y = \Delta \ln y + \Delta \ln H$$

Equation (9) is a long-run relationship that averages over cyclical and stochastic elements and removes the transitional dynamics due to capital accumulation. The second part of the definition of trend growth is that the unemployment rate remains constant and hours growth matches labour force growth. Growth in hours worked was exceptionally rapid in the 1995–2000 period, as the unemployment rate fell from 5.6 percent in 1995 to 4.0 in 2000, so output growth was considerably above its trend rate.⁶ We estimate hours growth over the next decade by means of detailed demographic projections, based on Census Bureau data.

In order to complete intermediate-term growth projections based on Equation (9), we require estimates of capital and labour shares, the IT output share, the share of reproducible capital stock, capital quality growth, labour quality growth, and TFP growth. Labour quality growth and the various shares are relatively easy to project, while extrapolations of the other variables are subject to considerable uncertainty. Accordingly, we present three sets of projections – a base-case scenario, a pessimistic scenario, and an optimistic scenario.

We hold labour quality growth, hours growth, the capital share, the reproducible capital stock share, and the IT output share constant across the three scenarios. We refer to these as the “common assumptions”. We vary IT-related TFP growth, the contribution to TFP growth from non-IT sources, and capital quality growth across these scenarios and label them “alternative assumptions”. Generally speaking for these variables, the base-case scenario incorporates data from the long expansion of 1990–2000, the optimistic scenario as-

⁶ These unemployment rates are annual averages for the civilian labor force, 16 years and older from BLS.

sumes the patterns of 1995–2000 will persist, and the pessimistic case assumes that the economy reverts to 1973–1995 averages.

3.1 Common assumptions

Hours growth ($\Delta \ln H$) and labour quality growth ($\Delta \ln LQ$) are relatively easy to project. The Congressional Budget Office (2002) projects growth in the potential labour force of 1.0 percent per year, a slight decrease from earlier projections. We project hours growth at 1.0 percent per year for 2002–2012. CBO (2002) does not employ the labour quality concept.

We construct our own projections of demographic trends. Ho and Jorgenson (1999) have shown that the dominant trends in labour quality growth are due to rapid improvements in educational attainment in the 1960s and 1970s, and the rise in female participation rates in the 1970s. The improvement in educational attainment of new entrants into the labour force largely ceased in the 1990s, although the average educational level continued to rise as younger and better educated workers entered the labour force and older workers retired.

We project growth in the population from the demographic model of the Bureau of Census, which breaks the population down by individual year of age, race and sex.⁷ For each group the population in period t is equal to the population in period $t-1$, less deaths plus net immigration. Death rates are group-specific and are projected by assuming a steady rate of improvement in health. The population of newborns in each period reflects the number of females in each age group and the age- and race-specific fertility rates. These fertility rates are projected to fall steadily.

We observe labour force participation rates in the last year of our sample period. We then project the work force by assuming constant participation rates for each sex-age group. The educational attainment of workers aged a in period t is projected by assuming that it is equal to the attainment of the workers of age $a-1$ in period $t-1$ for all those who are over 35 years of age in the last year of the sample. For those who are younger than 35 we assume that the educational attainment of workers aged a in forecast period t is equal to the attainment of workers aged a in the base year.

Our index of labour quality is constructed from hours worked and compensation rates. We project hours worked by multiplying the projected population in each sex-age-education group by the annual hours per person in the last year of

⁷ The details of the population model are given in Census (2000).

the sample. The relative compensation rates for each group are assumed to be equal to the observed compensation in this sample period. We project labour quality growth from our projections of hours worked and compensation per hour.

Our estimates suggest that hours growth ($\Delta \ln H$) will be about 1.0 percent per year over the next ten years, essentially the same as the CBO (2002) estimate. We estimate that growth in labour quality ($\Delta \ln LQ$) will be 0.16 percent per year over the next decade. This is considerably lower than the 0.28 percent growth rate for the period 1959–2000, driven by rising average educational attainment and stabilising female participation.

The capital share (\bar{v}_K) has not shown any obvious trend over the past 40 years. We assume it holds constant at 40.9 percent, the average for 1959–2000. Similarly, the fixed reproducible capital share ($\bar{\mu}_R$) has shown little change and we assume that it remains constant at 83.7 percent, the average for 1959–2000. We assume the IT output share (\bar{u}_{IT}) remains at 4.5 percent, the average for 1995–2000. This is likely to prove a conservative estimate, since IT has steadily increased in relative importance in the U.S. economy, rising from 1.7 percent of output in 1970 to 2.3 percent in 1980, 3.3 percent in 1990, and 4.7 percent in 2000.

3.2 Alternative assumptions

Productivity growth in IT production ($\Delta \ln A_{IT}$) has been extremely rapid in recent years with a substantial acceleration after 1995. For 1990–1995 productivity growth for IT production averaged 7.35 percent per year, while for 1995–2000 growth averaged 9.31 percent. While these growth rates are high, they are consistent with industry-level productivity estimates for high-tech sectors. For example, Jorgenson, Ho, and Stiroh (2002a) report productivity growth of 18.00 percent per year for 1995–2000 in electronic components, including semiconductors, and 16.75 in computers and office equipment.

Jorgenson (2001) argues the large increase in IT productivity growth was triggered by a much sharper acceleration in the decline of semiconductor prices. This can be traced to a shift in the product cycle for semiconductors in 1995 from three years to two years, a consequence of intensifying competition in the semiconductor market. It would be premature to extrapolate the recent acceleration in productivity growth into the indefinite future, however, because this depends on the persistence of a two-year product cycle for semiconductors.

To better gauge the future prospects of technical progress in the semiconductor industry, we turn to *The International Technology Roadmap for Semiconductors*.⁸ This *Roadmap*, constructed every two years by a consortium of industry associations and updated annually, projects a two-year product cycle through 2005 and a three-year product cycle thereafter. This is a reasonable basis for projecting the productivity growth related to IT for the U.S. economy. Moreover, continuation of a two-year cycle provides an upper bound for growth projections, while an immediate reversion to a three-year cycle gives a lower bound.

Our base-case scenario projects IT-related growth of 8.33 percent per year, the average for 1990–2000, giving equal weight to the two-year product cycle for 1995–2000 and the three-year product cycle for 1990–1995.⁹ The optimistic scenario assumes that the two-year product cycle for semiconductors remains in place so that productivity growth in IT production averages 9.31 percent per year, as it did for 1995–2000. Our pessimistic projection assumes a reversion to the three-year semiconductor product cycle of 1973–1995, when IT-related productivity growth was 6.93 percent per year. In all cases, the contribution of IT to TFP growth reflects the 1995–2000 IT share of GDP of 4.5 percent.

The non-IT TFP contribution is more difficult to project, so we present a range of alternative estimates that are consistent with the historical record. Our base-case projection uses the average contribution from the 1990s and assumes a contribution 0.11 percentage points. This assumes that the myriad factors that drove TFP growth in the 1990s – technical progress, resource reallocations, and increased competitive pressures – will continue into the future. Our optimistic case assumes that the contribution for 1995–2000 of 0.17 percentage points per year will continue, while our pessimistic case assumes that the U.S. economy will revert back to the slow-growth period from 1973–1995 when this contribution averaged only 0.06 percent per year.

The final step in our projections is to estimate the growth in capital quality ($\Delta \ln KQ$). The one-sector neo-classical growth model has capital stock and output growing at the same rate in balanced growth equilibrium. We distinguish between IT and non-IT capital and the historical record shows that substitution between these two types of capital is an important source of output and productivity growth. For the period 1959–2001 as a whole capital quality growth contributed 0.41 percentage points to output growth as firms substituted toward IT capital inputs with higher marginal products.

⁸ See *International Technology Roadmap for Semiconductors* (2001), <http://public.itrs.net>.

⁹ Note that we explicitly exclude 2001 because the cyclical declines associated with the 2001 recession obscure the underlying trends.

An important difficulty in projecting capital quality growth from recent data, however, is that investment patterns in the 1990s may partially reflect an unsustainable investment boom in response to temporary factors like Y2K investment and the NASDAQ stock market bubble, which may have skewed investment toward IT assets. Capital quality for 1995–2000 grew at 2.30 percent per year as firms invested heavily in IT, but there has been a sizeable slowdown in IT investment in the second half of 2000 and 2001. Therefore, we must be cautious about relying too heavily on the most recent investment experience.

Our base-case projection uses the average rate of capital quality growth for 1990–2000, which was 1.63 percentage points; this averages the high rates of substitution of IT for non-IT capital inputs in the late 1990s with the more moderate rates of the early 1990s. Our optimistic projection ignores the possibility that capital substitution was unsustainably high in the late 1990s and assumes that capital quality growth will continue at the annual rate of 2.30 percent for the period 1995–2000. Our pessimistic scenario assumes that the growth of capital quality will revert to the 0.88 annual growth rate for 1973–1995.

3.3 Output and productivity projections

Table 3 assembles the components of our projections and presents the three scenarios. The top panel of Table 3 shows the projected growth of output, labor productivity, and the effective capital stock. The second panel reports the five factors that are held constant across scenarios – hours growth, labor quality growth, the capital share, the IT output share, and the reproducible capital stock share. The bottom panel includes the three components that vary across scenarios – TFP growth in IT, the TFP contribution from other sources, and capital quality growth.

Our base-case scenario puts trend labour productivity growth at 1.78 percent per year, and trend output growth at 2.78 percent per year. Figure 5 presents our projection of labour productivity growth and its decomposition, while Figure 6 gives the corresponding projection of output growth. Projected productivity growth falls short of our estimate of 2.07 percent for 1995–2000 and even the 2.02 percent for 1995–2001. Output growth is considerably slower due to the projected slowdown in hours growth. Hours grew at 1.99 percent per year for 1995–2000 and 1.53 percent per year for 1995–2001, compared to our projection of 1.0 percent for the next decade. Capital stock growth is projected to fall in the base-case to 2.32 percent per year.

Our optimistic scenario projects labour productivity growth at 2.30 percent per year, reflecting our assumption of continuing rapid technical progress in IT production. In particular, the two-year product cycle in semiconductors is assumed to persist for the intermediate future, driving rapid TFP growth in IT production, as well as continued substitution toward IT capital input and rapid growth in capital quality. In addition, non-IT TFP growth continues at the pace for 1995–2000.

Table 3

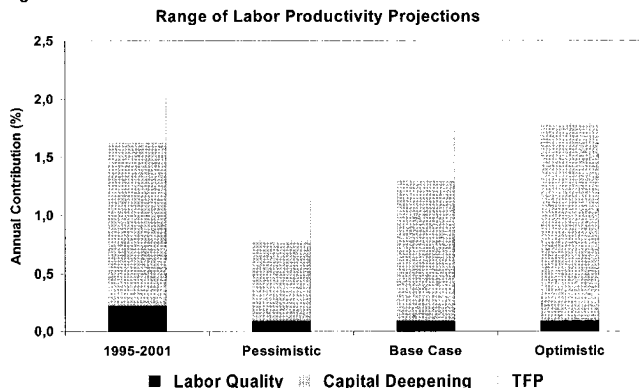
**Output and Labor Productivity Projections
Total Economy**

	Projections		
	Pessimistic	Base-case	Optimistic
	Projections		
Output Growth	2,14	2,78	3,38
ALP Growth	1,14	1,78	2,38
Effective Capital Stock	1,79	2,32	2,83
	Common Assumptions		
Hours Growth	1,00	1,00	1,00
Labor Quality Growth	0,157	0,157	0,157
Capital Share	0,409	0,409	0,409
IT Output Share	0,045	0,045	0,045
Reproducible Capital Stock Share	0,837	0,837	0,837
	Alternative Assumptions		
TFP Growth in IT	6,93	8,33	9,31
Implied IT-related TFP Contribution	0,31	0,37	0,43
Other TFP Contribution	0,06	0,11	0,17
Capital Quality Growth	0,88	1,63	2,30
Implied Capital Deepening Contribution	0,68	1,21	1,69
Notes: In all projections, hours growth and labor quality growth are from internal projections, capital share and reproducible capital stock shares are 1959-2000 averages, and IT output shares are for 1995-2000. Pessimistic case uses 1973-1995 average growth of capital quality, IT-related TFP growth, and non-IT TFP contribution. Base case uses 1990-2000 averages and optimistic cases uses 1995-2000 averages.			

Finally, the pessimistic projection of 1.14 percent per year growth in labour productivity assumes that underlying trends in TFP growth and growth in capital quality revert back to the sluggish growth rates of the 1973–1995 period and that the three-year product cycle for semiconductors begins immedi-

ately. Even with the larger share of IT, labour productivity growth in this scenario will fall short of the rates seen in the 1970's and 1980's.

Figure 5



4 Conclusions

Our primary conclusion is that a consensus has emerged about trend rates of growth for output and labour productivity. Our methodology assumes that trend growth rates in output and reproducible capital are the same, and that hours growth is constrained by the growth of the labour force along a balanced growth path. While productivity is projected below the pace seen in late 1990's, we conclude the U.S. productivity revival is likely to remain intact for the intermediate future. Similar projections for the leading countries of Europe will have to await the availability of detailed information on productivity similar to that we have employed for the United States.

Our second conclusion is that trend growth rates are subject to considerable uncertainty. For the U.S. economy this can be identified with the future product cycle for semiconductors and its impact on the production of other high-tech gear. The switch from a three-year to a two-year product cycle in 1995 produced a dramatic increase in the rate of decline of IT prices. This is reflected in the investment boom of 1995–2000 and the massive substitution of IT capital for other types of capital that took place in response to price changes. The issue that must be confronted by policy-makers is whether this two-year product cycle can continue, and whether firms will continue to re-

spond to the dramatic improvements in the performance/price ratio of IT investment goods.

The lessons for Europe from the American growth resurgence are, first, that investment in information technology equipment and software has increased in relative importance in all the major OECD countries. This lesson has not been fully absorbed by analysts who focus on trends in the growth of output or labour productivity alone. Second, future trends in economic growth depend on future labour force growth, as well as future changes in technology. While trends in labour force growth are relatively easy to project, considerable uncertainty will continue to characterise projections of new developments in technology.

A complete understanding of the role of information technology in Europe requires a full accounting for recent economic growth like that we have presented for the United States. A key part of this is the successful measurement of quality-adjusted prices for IT assets. The U.S. National Accounts currently employ such deflators for computer hardware, and portions of software and telecomm equipment. This is critical as failure to capture these important quality improvements leads both capital input and output to be severely understated.

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