CHAPTER III THE INFORMATION TECHNOLOGY REVOLUTION

The world is in the midst of an all-purpose technological revolution based on information technology (IT), defined here as computers, computer software, and telecommunications equipment. The macroeconomic benefits of the IT revolution are already apparent in some economies, especially the United States. Historical experience has shown that such revolutions have often been accompanied by financial booms and busts, and the IT revolution has been no exception. But, while spending on IT goods is likely to remain weak in the immediate future, as past overinvestment unwinds, the longer-term benefits for the global economy are likely to continue, or even accelerate, in the years to come.

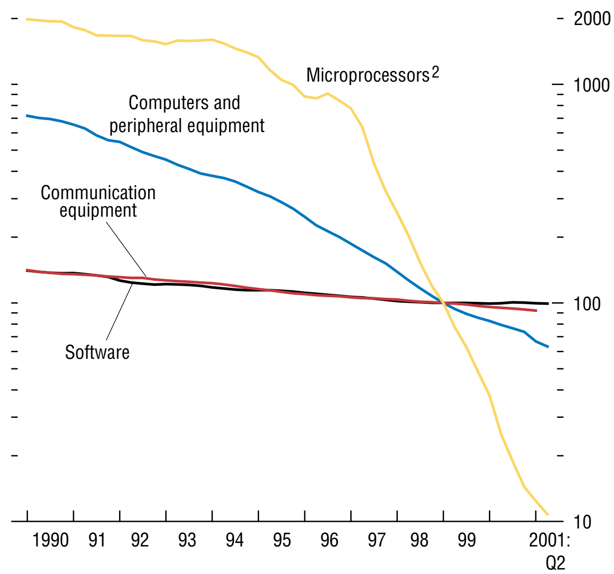
While technological change is an ongoing process, there are periods during which technological progress is especially rapid, resulting in new products and falling prices of existing products that have widespread uses in the rest of the economy. Such periods are generally identified with all-purpose technological revolutions. Earlier examples include textiles production and steam power in the industrial revolution, railroads in the nineteenth century, and electricity in the early twentieth century (the automobile could also be included, but its development was relatively gradual). The effects of such revolutions have generally occurred in three (often overlapping) main stages. First, technological change raises productivity growth in the innovating sector; second, falling prices encourage capital deepening; and, finally, there can be significant reorganization of production around the capital goods that embody the new technology.

At the core of the current IT revolution are advances in materials science, leading to increases in the power of semiconductors, in turn resulting in rapidly declining semiconductor prices (Figure 3.1). Over the past four decades, the capacity of semiconductor chips has doubled

Figure 3.1. United States: Relative Prices of Information Technology Goods[1]

(1999:Q1 = 100; logarithmic scale)

Steep declines in the prices of computer components, such as microprocessors, have led to persistent declines in computer prices.



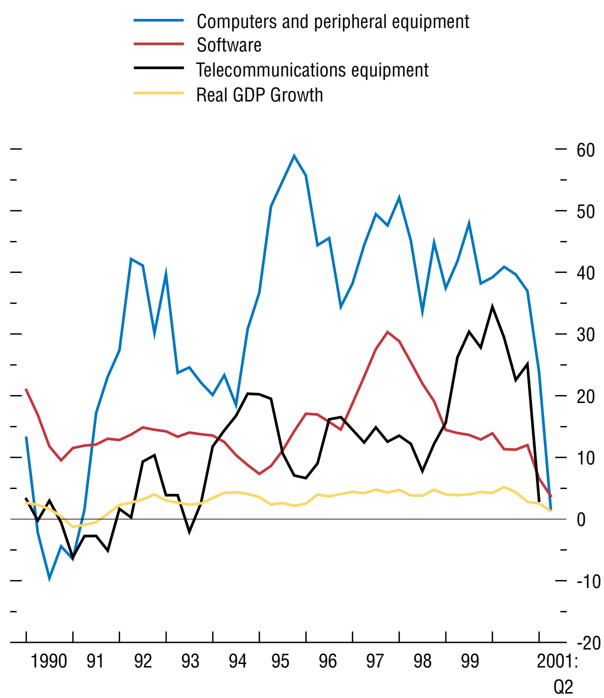
Sources: U.S. Commerce Department, Bureau of Economic Analysis for investment price deflators of computers and peripheral equipment, communication equipment, and software. U.S. Department of Labor, Bureau of Labor Statistics, for producer price index of microprocessors.

[1]Relative to the GDP deflator.

[2]Microprocessor (semiconductor) price indices do not hold quality constant prior to 1997, failing to capture the rapid decline in quality adjusted prices.

Figure 3.2. Information Technology Investment in the United States[1]
(Four-quarter percent change)

Investment in computers, software, and communication equipment grew at extraordinary rates during the 1990s.



Source: U.S. Department of Commerce, Bureau of Economic Analysis.
[1]Real gross fixed investment.

roughly every 18–24 months—a phenomenon known as "Moore's Law," after a prediction made in 1965 by Gordon Moore, then Research Director at Fairchild Semiconductor. Cheaper semiconductors have allowed rapid advances in the production of computers, computer software, and telecommunications equipment, leading to steep price declines in these industries as well. The rapidly falling prices of goods that embody IT have stimulated extraordinary investment in these goods, resulting in significant capital deepening (Figure 3.2). This capital deepening has led, in some countries, to an acceleration in overall productivity growth and may be encouraging changes in the organization of production, which could lead to further improvements in productivity growth.

This chapter focuses on the macroeconomic consequences of the IT revolution, including lessons from past all-purpose technological revolutions, the impact on productivity growth, the distribution of the benefits between producers and users, the consequences for the business cycle and financial markets, and implications for macroeconomic policies.[1] In assessing these consequences, the chapter concentrates on the countries most involved in the IT revolution: the advanced economies and those emerging economies in Asia that are major producers of IT equipment (Figure 3.3).[2]

Past All-Purpose Technological Revolutions

The main all-purpose technological revolutions in the past have been textiles production, steam power, railroads, and electricity.[3] Past revo-

[1]The chapter examines the role of IT goods in investment, as personal consumption of IT goods is just a small fraction of private gross fixed capital spending on IT goods (about 7 percent in the United States in 2000).

[2]For more cross-country comparisons of IT production and use, see OECD (2000).

[3]This section draws extensively on Crafts (2001), which was commissioned for the *World Economic Outlook*. These points are consistent with the work of other economic historians, including David (1990 and 2000), DeLong (2001), and White (1990).

lutions have clearly yielded large benefits, though measurement difficulties associated with new or improved goods abound, and economic historians have had to adjust retrospectively for quality changes (Table 3.1). For example, railroads offered clear benefits in the form of faster and more comfortable travel. Yet the price of rail travel was often higher than the alternative, so it is important to account for the quality of a new service, such as speed and comfort, in calculating the gains from the invention of railroads.

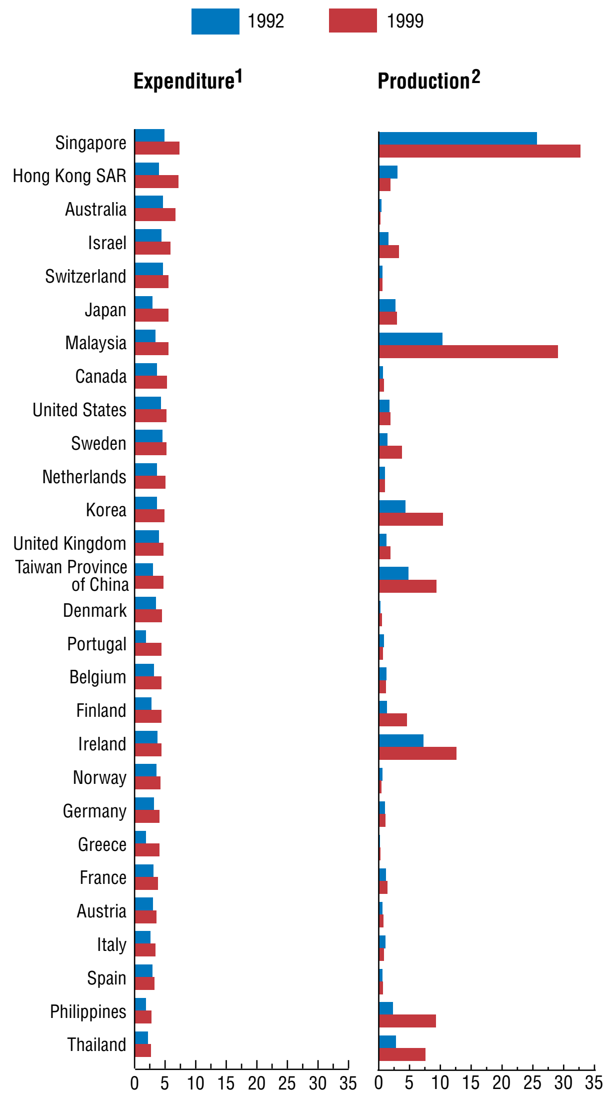
Information technology has a number of striking similarities with past revolutions, but also some notable differences. Of the similarities, four stand out:

- The gains from the new technology initially came through the capital deepening caused by the fall in relative prices, but—when the efficiency gains from the reorganization of production were large—these benefits dominated in the long run. Table 3.1 shows that, in the case of the adoption of electricity in the United States, the contribution to growth was dominated by capital deepening over the initial period (1899–1919) but by gains from reorganization in usage at the end of the period (1919–1929).
- The initial gains were focused on industrial countries.[4] For example, Table 3.2 shows how railroads were initially adopted in the advanced economies of the day. Almost a century passed between the opening of the Liverpool and Manchester Railway in 1830 and the global adoption of railroads by 1920. However, as discussed below, there appears to be a difference in the rate of diffusion of IT to developing countries. In the very long run, the benefits depend on particular circumstances. For example, Table 3.3 shows that for freight transportation the eventual social savings were largest in Mexico, which largely lacked water transport.

[4]However, early users can also end up with significant costs if the technology gets superceded. For example, extensive canal systems were built in the United Kingdom and the United States, only to be made obsolete by the invention of railroads.

Figure 3.3. Information Technology (IT) Expenditure and Production
(Percent of GDP)

Spending on IT (as a share of GDP) is spread relatively evenly across countries, while IT production sectors are large in only a few economies.



Sources: WITSA (2001) for expenditure data; Reed Electronics Research (2001) for production; and IMF staff estimates.
[1]Information technology expenditure comprises hardware, software and telecommunications equipment.
[2]IT production comprises gross output of active components, electronic data processing equipment (adjusted for inputs of active components), and telecommunications equipment (adjusted for inputs of active components).

Table 3.1. Contribution of New Technology to Economic Growth
(Percent per year)

	Time Period	Capital Deepening	Technological Progress in Production	Technological Progress in Usage	Total
Steam—United Kingdom	1780–1860	0.19	. . .	0.32	0.51
Railroads—United Kingdom	1840–1870	0.13	0.10	. . .	0.23
	1870–1890	0.14	0.09	. . .	0.23
Railroads—United States	1839–1870	0.12	0.09	. . .	0.21
	1870–1890	0.32	0.24	. . .	0.56
Electricity—United States	1899–1919	0.34	0.07	—	0.41
	1919–1929	0.23	0.05	0.70	0.98
Information Technology—United States	1974–1990	0.52	0.17	. . .	0.69
	1991–1995	0.55	0.24	. . .	0.79
	1996–2000	1.36	0.50	. . .	1.86

Source: Crafts (2001). The estimates for information technology do not reflect the recent revisions to the U.S. national income and products accounts for 1998–2000.

Table 3.2. Railroad Mileage, 1840–1920
(Percent of world total)

	1840	1880	1920
North America	51.5	45.5	43.3
Europe	46.3	37.9	23.7
Rest of the world	2.2	16.6	33.0
World	100.0	100.0	100.0
Memorandum			
World (Thousands of miles)	5.49	220.76	674.89

Source: Woodruff (1966).

- The gains went largely to users, not producers. The benefits were mostly transferred to users through the fall in the relative price of goods embodying the new technology, while profits and wages in producing industries were rarely exceptional by comparison. The classic case is textiles production in the industrial revolution in Britain, where about half of the benefits from falling prices were exported via worsening terms of trade. Also, the new technology led to a reorganization of production, which marked the beginning of the factory system during the early phase of the industrial revolution. As these technological spillovers were localized, they helped maintain Britain's export competitiveness for many years.
- Technological revolutions have generally led to financial market excesses. The best documented cases are railroads and electricity. Figure 3.4 compares the paths of the stock prices of innovating firms, investment in goods embodying new technology, and real GDP in the "railway mania" in Britain in the 1840s and in the "IT mania" in the United States in recent years. As in other cases, while the collapse of the railroad bubble in the 1840s did not lead to an economy-wide recession, it did lead to significant consolidation in the industry.

There are also two important differences:

- The fall in the relative price of IT goods has been exceptionally sharp—there appears to be no historical equivalent to the sustained, rapid fall in semiconductor prices associated with Moore's Law.[5] As a result, while recognizing the difficulties of comparing data across historical episodes, the benefits of IT seem to be coming faster than those of previous all-purpose technological revolutions.
- Compared to past episodes, the production of goods embodying the new technology is much more globalized. This reflects the high price-to-weight ratio of IT goods, which makes them readily tradable. The

[5]For example, the real price of electricity in the United States fell by 7 percent per year between 1900–1920 (Brookes and Wahhaj, 2000), while the real (quality-adjusted) price of computers fell by 20 percent per year between 1990–2000.

Table 3.3. Social Savings from Railways[1]
(Percent of GNP)

	Year	Passenger	Freight
Brazil	1887	. . .	4.5
	1913	1.6	22.0
England and Wales	1865	. . .	4.1
	1890	. . .	10.2
India	1900	. . .	9.0
Mexico	1895	. . .	14.6
	1910	0.6	31.5
Russia	1907	1.0	4.6
Spain	1878	. . .	6.5
	1912	. . .	18.5
United States	1859	. . .	3.7
	1890	2.6	4.7–10.0

Source: Crafts (2001).
[1]Social savings measure benefits in terms of willingness to pay, that is, the area under the demand curve.

closest historical parallel is cotton textiles in the industrial revolution in Britain, where about half of production was exported.

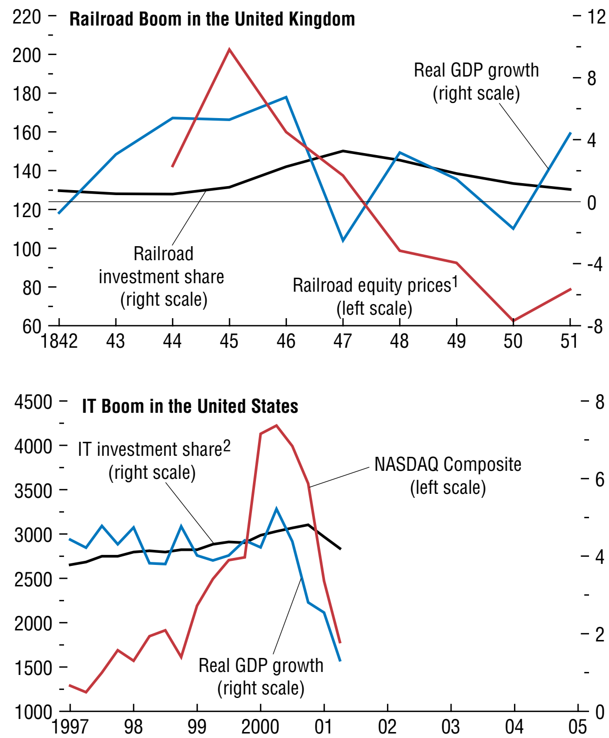
Labor Productivity Growth

The rapidly growing literature on IT and labor productivity growth addresses two main issues: measurement problems and the contribution of IT to labor productivity growth.[6] New goods and rapidly falling relative prices complicate the measurement of output, and different countries use different statistical methodologies to address these issues. In some countries, hedonic methods are used to adjust prices for quality changes, while chain weighting is used to address the substitution bias in fixed-weight aggregation methods (Box 3.1). In addition, the coverage of the IT sector in official statistics is often inadequate: in most countries, national accounts simply do not distinguish IT production, investment, or consumption. Reflecting these problems, cross-country comparisons often use hedonic prices from the U.S. Bureau of Economic Analysis (adjusted for exchange rate changes)

[6]The idea that IT could contribute to labor productivity growth precedes the recently observed acceleration in productivity. See, for example, Kelkar (1982).

Figure 3.4. Initial Phase of Technological Revolutions
(Investment in percent of GDP and real GDP in annual percent change)

Both the railroad and information technology (IT) revolutions led to initial booms in stock prices and investment.



Sources: Hawke (1970) for railroad investment and Mitchell (1988) for GDP data.
[1]Railroad equity price is the average of the closing price in pounds sterling at the end end of July for four British railroad companies: London& North Western, Great Western Railway, London & Lancashire Railway, and the Midland Railway.
[2]Defined as private investment in information processing equipment and software.

Box 3.1. Measurement Issues

There are three important methodological issues in measuring the contribution of information technology (IT) to economic growth.[1] The first issue is how to adjust price indices for new goods and for improvements in the quality of existing goods. In the U.S. national accounts (and increasingly in other countries as well), the price deflators for many IT goods are based on hedonic price indices, which attempt to capture quality changes (see the Table). Hedonic price indices rely on the assumption that the value of a good is an aggregate of individual characteristics. Hence, the price of a new good can be based on the characteristics that it offers. Hedonic price equations for computers, for example, usually contain elements like the clock rate, RAM, and hard disk memory.

While hedonic methods are not a perfect way of adjusting prices for quality changes, they are more systematic than the available alternatives. For example, in Germany, the monetary value of quality changes is estimated on a case-by-case basis according to a set of rules, which may be difficult to apply in cases of extremely large quality changes and thus likely to understate the magnitude of the quality-adjusted price fall.[2] Given the highly tradable nature of IT goods, exchange-rate-adjusted hedonic prices in different countries often track each other closely, and at least two countries have opted to use the U.S. hedonic price index for computers, adjusted for exchange rate movements.

The impact of using hedonic methods on macroeconomic aggregates (in countries that do not already use them) will depend on the structure of production and demand. In IT-producing countries, measured real output of IT goods will tend to increase, boosting measured real GDP

Selected Economies: Features of National Accounts

	Hedonic Price Index for Computers	Chain Weights
Australia	Yes[1]	Yes
Belgium	No	No
Canada	Yes	Yes
China	No	No
Denmark	Yes[1]	No
Finland	No	No
France	Yes[2]	Yes
Germany	No	No
Hong Kong SAR	No	No
India	No	No
Indonesia	No	No
Ireland	No	No
Italy	No	No
Japan	Yes	No
Korea	No	No
Malaysia	No	No
Netherlands	No	Yes
Norway	No	Yes
Philippines	No	No
Singapore	No	No
Spain	No	No
Sweden	Yes	No
Taiwan Province of China	No	No
Thailand	No	No
United Kingdom	No	Yes
United States	Yes	Yes

Source: Gust and Marquez (2000) and national authorities.
[1]Uses U.S. hedonic index, adjusted for exchange rate movements
[2]Hedonic prices used for microcomputers only.

and real exports. As a result, the measured contribution of IT to growth (through TFP growth in the IT sector) will tend to rise. In IT-using countries, real investment in and real imports of IT goods will tend to increase, boosting the contribution of IT to growth through capital deepening and lowering the contribution of TFP growth.[3]

The second issue is how to aggregate the output of goods with large relative price changes. Goods with rapidly declining relative prices tend to be used in new ways with lower marginal product, so any fixed-weight aggregation method—such as the traditional Laspeyres index—will place inappropriately large weights on these rapidly-growing goods (substitution bias) and thus

[1]A fourth issue is that, given the high depreciation rates of many IT capital goods, it would be better to use net output to measure productivity. In the United States, real net domestic product (NDP) grew ¼ percent more slowly than real GDP between 1995–2000. See Landefeld and Fraumeni (2001).

[2]The deflator for IT equipment declined by about four-fifths between 1991–1999 in the United States, but only by about one-fifth in Germany. See Deutsche Bundesbank (2000).

[3]Schreyer (2001) finds that the impact of using hedonic prices (in advanced economies that do not already use them) on real GDP growth is small.

tend to overstate the growth of the aggregate. The further back the base year, the larger is the weight on these fast-growing goods and therefore the greater is the overstatement. This problem is well illustrated by the 1998 growth rate of fixed-weight real GDP in the United States: using 1995 base prices, it was 4.5 percent; using 1990 base prices, it was 6.5 percent; using 1980 base prices, it was 18.8 percent; and using 1970 base prices, it was 37.4 percent (Whelan, 2000).

To address the substitution bias in fixed-weight measures, an increasing number of countries calculate real aggregates using chain weights, based on prices that are updated every year. For example, the United States now aggregates across sectors using the so-called "ideal chain index" popularized by Irving Fisher.[4] The principal benefit of chain weights is that measured real GDP growth does not depend on some arbitrary price structure and is therefore independent of the choice of base year. The main drawback is that, except in the base year, the level of real GDP is not necessarily equal to the sum of its real components, because the weighting scheme takes account of shifting relative prices, and cannot be interpreted as the quantity of output had all prices remained fixed at their base period levels.

The final issue is how to allocate IT spending, especially software spending, between final and intermediate expenditure.[5] In general, business spending on intermediate goods, which are fully incorporated into output, is subtracted from gross output to yield value added (to avoid double counting). Information technology spending is considered investment if, and only if, the corresponding products can be physically isolated, so that IT products embodied in equipment (such as microprocessors) are considered intermediate goods. In practice, the ratio of IT investment to IT intermediate consumption differs substantially across countries, reflecting different statistical practices in different countries (see Colecchia, 2001). For example, France asks buyers to classify their spending, while the United States relies on production data provided by sellers together with input-output tables. In countries that classify a larger proportion of business spending on IT goods as investment, measured GDP growth will be higher when such spending is rising rapidly.

Studies that compare the statistical methodologies used in France, Germany, and the United Kingdom to those used in the United States suggest that differences in the allocation of software spending between intermediate and final expenditure have the largest impact on measured output growth.[6] Differences in the allocation of software spending account for an annual growth differential of about 0.3 percentage points between France and the United States, which both use hedonic prices and chain weighting, while the combined effect of differences in quality adjustment, aggregation, and allocation of software spending accounts for an annual growth differential between both Germany and the United Kingdom, and the United States of about 0.4 percentage points.

[4]The real growth rate is calculated as the geometric average of the growth rates of a Paasche index (which uses current period prices as weights) and a Laspeyres index (which uses previous period prices as weights). See Landefeld and Parker (1998) and Vavares, Prakken, and Guirl (1998) for a description of the methodology and a discussion of related issues.

[5]The 1993 System of National Accounts (SNA93) stipulates that software purchases by firms should be considered investment expenditure.

[6]See Deutsche Bundesbank (2001), Lequiller (2001), and Wadhwani (2000).

and data on IT production and use from private sources, an approach also taken in this chapter.[7]

Information technology can contribute to labor productivity growth through both capital

[7]Expenditure data are from the World Information Technology Services Alliance (2001); production data are from Reed Electronics Research (2001). While the data from private sources cover a broad set of countries, they are not compiled in the same comprehensive manner as national accounts data.

Table 3.4. Contribution of Information Technology (IT) to the Acceleration in Productivity in the United States

	Gordon (2000)	Jorgenson and Stiroh (2000)	Oliner and Sichel (2000)	U.S. Council of Economic Advisers (2001)
Period under study	1995–1999	1995–1998	1995–1999	1995–2000
Acceleration in labor productivity	1.33	0.95	1.16	1.63
Capital deepening	0.33	0.29	0.33	0.38
IT-related	. . .	0.34	0.50	0.62
Other	. . .	–0.05	–0.17	–0.23
Total factor productivity growth	0.31	0.65	0.80	1.19
IT production	0.29	0.24	0.31	0.18
Rest of economy	0.02	0.41	0.49	1.00
Other factors	0.69	0.01	0.04	0.04
Cyclical effect	0.50	. . .	. . .	0.04
Price measurement	0.14	. . .	. . .	. . .
Labor quality	0.05	0.01	0.04	0.00

Source: Stiroh (2001) and U.S. Council of Economic Advisers (2001). See studies for data and methodological differences. The estimates do not reflect the recent revisions to the U.S. national income and products accounts, which were substantial for 2000.

deepening and total factor productivity (TFP) growth.[8] Capital deepening refers to the change in labor productivity attributable to higher levels of capital per worker. TFP growth refers to improvements in the efficiency with which capital and labor are combined to produce output. The existing literature has established that IT is contributing to labor productivity growth through both increases in the levels of IT capital per worker ("IT-related capital deepening") and TFP growth in IT production, though the precise magnitudes of these contributions remain a subject of debate. The main outstanding issue is whether IT has contributed to TFP growth more generally by increasing the efficiency of production, either through usage or knowledge spillovers from the production of IT goods. The literature consists of country-specific and cross-country studies.

Country-specific work broadly follows the pioneering studies on the United States, which generally agree that IT-related capital deepening and TFP growth in IT production made important contributions to the acceleration in labor productivity in the late 1990s.[9] Labor productivity growth in the nonfarm business sector increased from about 1½ percent in 1973–95 to about 2½ percent in 1996–2000. About ¼ to ½ percentage point of the acceleration in labor productivity was attributed to capital deepening, more than accounted for by investment in IT, and about another ¼ percentage point to TFP growth in IT production (Table 3.4).[10] However, there is no consensus on the effect of IT on generalized TFP growth. The debate focuses on whether the remainder of the acceleration reflects cyclical factors or an increase in underlying TFP growth, and—even if it is the latter—the

[8]Under standard assumptions, labor productivity growth (the change in output per unit of labor input) can be expressed as:

$$\left(\frac{\hat{Y}}{L}\right) = \alpha\left(\frac{\hat{K}}{L}\right) + \hat{A}$$

where Y is output, L is labor, K is capital, α is the share of capital in national income, A is the level of total factor productivity, and ^ denotes a percentage change.

[9]See Gordon (2000), Jorgenson and Stiroh (2000), Oliner and Sichel (2000), and U.S. Council of Economic Advisors (2001).

[10]The recent annual revisions to the U.S. national accounts reduced average annual labor productivity growth in the nonfarm business sector during 1996–2000 from 2.8 percent to 2.5 percent, mostly reflecting weaker labor productivity in 2000, and slightly reduced the contribution of IT-related capital deepening to growth, mainly through lower software investment.

extent to which this acceleration in generalized TFP reflects IT. One study attributes the additional ½ percentage point acceleration in labor productivity to cyclical factors, while other studies view this acceleration as structural. More recent studies suggest that little of the acceleration in labor productivity is due to changes in factor utilization, factor accumulation, or returns to scale, and that virtually all of the acceleration is accounted for by IT-using and IT-producing industries (see Box 3.2). Together, these results—if they are borne out by further empirical work—suggest that we may soon see an impact of IT on generalized TFP growth.

Another economy that has seen an acceleration in labor productivity in the 1990s is Australia. Using data released by the Australian Bureau of Statistics, work done by the IMF suggests that IT-related capital deepening and generalized TFP growth played important roles in the acceleration in labor productivity (see Cardarelli, 2001). In particular, IT-related capital deepening increased rapidly during the 1990s, accounting in recent years for about two-thirds of the growth contribution of capital deepening. While the national accounts do not separately identify IT producing sectors, employment and trade data suggest that IT production in Australia is very small, implying that TFP growth in IT production was not important in the acceleration in labor productivity. Conversely, IMF staff does find some evidence across Australian industries of a positive relationship between IT-related capital deepening and TFP growth. This evidence is consistent with the idea that increased IT use has been associated with a reorganization of economic activities, supported by structural reforms.

In most other advanced economies, labor productivity has not accelerated in recent years, implying that any positive contribution of IT must have been offset elsewhere:

- In Japan, labor productivity growth did not increase during the 1990s, despite relatively high levels of overall and IT-related capital deepening. An official study finds that the contribution of IT-related capital deepening to growth increased by about ½ to ¾ percentage points between the early and late 1990s (Japan, Economic Planning Agency, 2000). However, the contribution of non-IT-related capital deepening declined by a corresponding amount. There are no Japan-specific studies on the contribution of IT production or use to TFP growth.
- In France, labor productivity growth fell in the second half of the 1990s. Work by IMF staff attributes this fall to a decline in overall capital deepening, reflecting reduced investment in labor-saving equipment as wage growth remained moderate.[11] Although overall capital deepening fell, the contribution of IT-related capital deepening to growth increased from zero to ¼ percent. While TFP growth rebounded in the second half of the 1990s, this was likely related to the overall economic recovery (and procyclical TFP) and not to IT production, which is relatively small in France. The extent to which this rebound may, or may not, have been related to IT use remains to be established.
- In the United Kingdom, labor productivity has not accelerated, despite a rate of investment in IT capital that is almost as high as in the United States. Work by IMF staff suggests that both IT-related capital deepening and TFP growth in IT production made important contributions to labor productivity growth in the late 1990s (see Kodres, forthcoming, and Oulton, 2001). However, these contributions were offset by decreases in TFP growth outside of the IT sector.
- In most economies in emerging Asia, labor productivity growth fell in the late 1990s, partly reflecting the crisis-related slowdown in output growth. Preliminary work by IMF staff finds that the contributions of IT-re-

[11]See Estevão and Levy (2000). Mairesse, Cette, and Kocoglu (2000) also use aggregate data to assess the impact of IT on labor productivity growth and get similar results. Using micro data, Crépon and Heckel (2000) find a somewhat larger impact of IT on labor productivity growth.

Box 3.2. Has U.S. Total Factor Productivity Growth Accelerated Outside of the Information Technology Sector?

The literature on the contribution of information technology (IT) to labor productivity growth in the United States in the late 1990s has established that it has had benefits through capital deepening in the economy at large and technological progress in the IT sector, though the precise magnitudes of these contributions remain under debate.[1] About ¼ to ½ percent of the acceleration in labor productivity was due to capital deepening, with an IT contribution of ⅓ to ⅔ percent slightly offset by a decline in deepening elsewhere. However, part of the increase in capital deepening may have been temporary, reflecting the investment boom of the late 1990s (see Table 3.4).[2] Finally, about another ¼ percent was due to total factor productivity (TFP) growth in IT production.

Looking forward, an important issue is whether IT has already contributed to underlying TFP growth outside of the IT sector ("generalized" TFP growth). This could occur either through knowledge spillovers from the production of IT goods or business reorganization stemming from the usage of IT goods ("IT spillovers"). These types of benefits provide an incentive for additional investment in IT and have been responsible for a significant portion of the long-term increase in output in most other all-purpose technological revolutions. This box examines what the recent U.S. literature has to say on this issue, a discussion that has generally been subsumed within a more general debate about the sources of the acceleration in labor productivity since 1996.

Those who have been more skeptical of the importance of IT in the observed acceleration of TFP in the late 1990s have argued that it largely reflects cyclical factors associated with the boom over that period, which induced temporary increases in TFP.[3] Indeed, the slowdown in activity and labor productivity since mid-2000 provides some credence to the view that cyclical factors may have played some role, as do recent revisions to the national income accounts that have reduced labor productivity growth in 2000 by 1¼ percent, and for the full 1996–2000 period by over ¼ percent a year.

In addition, these skeptics also used initial evidence that increases in labor productivity growth were concentrated in the computer and semiconductor sectors to question whether the rest of the economy was benefiting from the new technology. Subsequent industry-level analysis, however, indicates that a significant acceleration in labor productivity has also occurred outside of the IT-producing sector, and has been concentrated in IT-using sectors (these results are not adjusted for recent data revisions). In particular, studies have found that the industries outside the IT sector that invested most aggressively in IT in the early 1990s subsequently showed the largest gains in labor productivity growth (and, together with IT-producing industries, accounted for virtually all of the acceleration in labor productivity); that strong labor productivity growth in three IT-intensive sectors (finance, retail trade, and wholesale trade) reflected improvements in the way that businesses were organized and how they used technology; and that, using the income rather than the output side of the national accounts, about half of the acceleration in labor productivity occurred outside of the IT sector.[4] While consistent with the view that part of the increase in U.S. labor productivity growth is structural, the industry-level results do not eliminate the possibility that much of the observed acceleration in TFP could be cyclical. The observed acceleration in labor productivity could reflect capital deepening as well as strong cyclical

[1]See Gordon (2000), Jorgenson and Stiroh (2000), and Oliner and Sichel (2000). For a review of this literature, see De Masi (2000).

[2]Most of these initial studies ended their analysis in 1999, and are hence not significantly affected by recent data revisions that lowered estimated labor productivity growth marginally in 1998 and 1999 but quite substantially in 2000.

[3]These arguments were raised most notably in Gordon (2000).

[4]Stiroh (2001), Baily and Lawrence (2001), and Nordhaus (2001).

effects, as the IT-using sectors expanded particularly rapidly during the late 1990s boom.

Finally, some recent studies have directly addressed the issue of cyclicality in the acceleration in productivity (using the unrevised data). Using proxies for factor utilization, capital accumulation, and returns to scale, one study found that cyclical and other temporary reasons affected year-by-year estimates of TFP growth but did not account for the general acceleration in labor productivity in the second half of the 1990s (Basu, Fernald, and Shapiro, 2001). Another study found that most of the acceleration in labor productivity reflected a structural increase, with the cyclical component contributing almost nothing (U.S. Council of Economic Advisers, 2001). While these results are suggestive of a structural acceleration in TFP, it is notoriously difficult to accurately identify unobservable cyclical components, especially before an entire cycle has been observed.

In summary, while evidence suggests that there has been some increase in underlying labor productivity growth in the United States over the last five years due to IT, there remains considerably more uncertainty about the magnitude and duration of any acceleration in underlying TFP. Evidence of rapid technological innovation in the IT sector is incontrovertible. Evidence of accelerated capital deepening is strong (although investment in IT goods might slow—possibly quite sharply—in the short term). Finally, there is insufficient evidence to come to a firm conclusion on whether there has been a rise in underlying TFP growth outside of the IT sector associated with reorganization of production.

lated capital deepening and TFP growth in the IT sector to labor productivity growth increased during the course of the 1990s, but were more than offset by declining contributions from other sectors (Box 3.3). The increase in IT-related capital deepening reflected the maintenance of high levels of IT investment despite the growth slowdown associated with the Asian crisis.

Cross-country studies also find that IT-related capital deepening and TFP growth in IT production contributed to labor productivity growth in the second half of the 1990s. The cross-country evidence comes in two forms: one set of studies estimates the contribution of IT-related capital deepening using the conventional growth accounting framework, while the others focus on the role played by IT-using (and IT-producing) sectors.[12] Studies following the first approach find that IT-related capital deepening has indeed made an important contribution to growth across a range of countries (Table 3.5). Given the rapid fall in the relative price of IT capital equipment, its contribution to the growth of the capital stock exceeds its nominal share in investment. For example, one study finds that falling prices of capital goods accounted for about one-third of the real growth of the capital stock in the United States between 1995–99 (Colecchia, 2001).

Another way to measure the impact of information technology is to estimate the contributions of the IT-producing sector and of IT-intensive sectors to economic growth through capital deepening. In other words, the contribution of IT is measured as overall capital deepening by IT-related sectors, rather than as the IT-related capital deepening of all sectors. The findings of one such study (Van Ark, 2001) are reported in Table 3.6. This study suggests that industries producing IT equipment or industries using IT equipment intensively contributed between 0.5 and 0.9 percentage points, or between 28 and 57 percent, to economic growth. For most G-7

[12]Studies following the first approach are Colecchia (2001), Daveri (2001), Roeger (2001), and Schreyer (2000). For the second approach, see Lee and Pilat (2001) and Van Ark (2001).

Table 3.5. Contribution of Information Technology Capital Deepening to GDP Growth in the G-7 Economies
(Percentage points)

	Colecchia (2001) 1995–99	Daveri (2001) 1991–1999	Roeger (2001) 1995–1999
Canada[1]	0.4	. . .	. . .
France	0.4	0.4	0.3
Germany[2]	0.3	0.5	0.3
Italy	0.3	0.3	0.3
Japan	0.3	. . .	. . .
United Kingdom	. . .	0.8	0.4
United States	0.9	0.9	0.7

Note: Colecchia (2001) and Daveri (2001) refer to business sector growth, while Roeger (2001) uses GDP growth. In addition to computers and telecommunications equipment, Colecchia (2001) and Daveri (2001) include software, while Roeger (2001) includes semiconductors.
[1]The Colecchia (2001) estimate excludes software.
[2]The Daveri (2001) estimate covers the period 1992–1999.

Table 3.6. Contribution of Information Technology (IT) Activities to GDP Growth, 1990–98
(Percent per year)

	Real GDP Growth	Contribution of IT-Related Industries		
		Total	IT-Using	IT-Producing
Canada	2.1	0.8	0.6	0.2
Denmark	1.8	0.5	0.3	0.2
Finland	1.6	0.7	0.0	0.7
France	1.3	0.5	0.2	0.3
Germany	1.1	0.5	0.4	0.1
Italy	1.4	0.7	0.5	0.2
Japan	1.4	0.8	0.5	0.3
Netherlands	2.5	1.0	0.7	0.3
United Kingdom	2.1	1.0	0.6	0.4
United States	3.2	1.4	0.9	0.5

Source: Van Ark (2001). For Germany, the numbers refer to 1991–97.

economies, the contribution of IT-using sectors is much stronger than the contribution of the IT-producing sector.

The contribution of technological progress in IT production to labor productivity growth is also fairly uncontroversial. Substantial TFP growth in the IT sector, which is the counterpart of the rapid declines in quality-adjusted IT prices, made significant contributions to labor productivity growth in countries with relatively large IT-producing sectors.

The impact of IT on generalized TFP growth can be assessed by examining the cross-country relationship between TFP growth and IT production and use. As in studies of the United States, the cross-country evidence on IT spillovers is ambiguous. There is some evidence of a positive effect of IT spending on the acceleration in TFP growth across 14 advanced economies (see Gramlich, 2001). Work by IMF staff extends this approach to a broader sample of countries and applies a richer specification. It finds that the effect of IT expenditure on TFP growth is ambiguous, with the estimated coefficients and standard errors being sensitive to the specification, time period, and set of countries included in the regression (see Haacker and Morsink, 2001).

In summary, the weight of the evidence suggests that IT is already making an important contribution to labor productivity growth through technological progress in IT production and IT-related capital deepening. Convincing evidence of the impact of IT on the general efficiency of production is not yet available.

Who Benefits—Producers or Users?

While most of the existing literature on the macroeconomic consequences of IT has focused on labor productivity, the allocation of the potential welfare benefits has received less attention. In principle, the benefits of a technological revolution could accrue to owners (in the form of higher profits), labor (through higher wages), or users (through lower prices). In the IT revolution, profits and wages have risen somewhat, but these changes are small relative to the sharp fall in the relative prices of IT goods. This suggests that IT-using countries tend to benefit somewhat more than IT-producing countries, because producing countries lose some of the gains through deteriorating terms of trade.[13] As noted earlier, historical experience suggests that

[13]In some developing countries producing IT goods, the IT industry may also pay wages considerably above those prevailing elsewhere.

Box 3.3. Information Technology and Growth in Emerging Asia

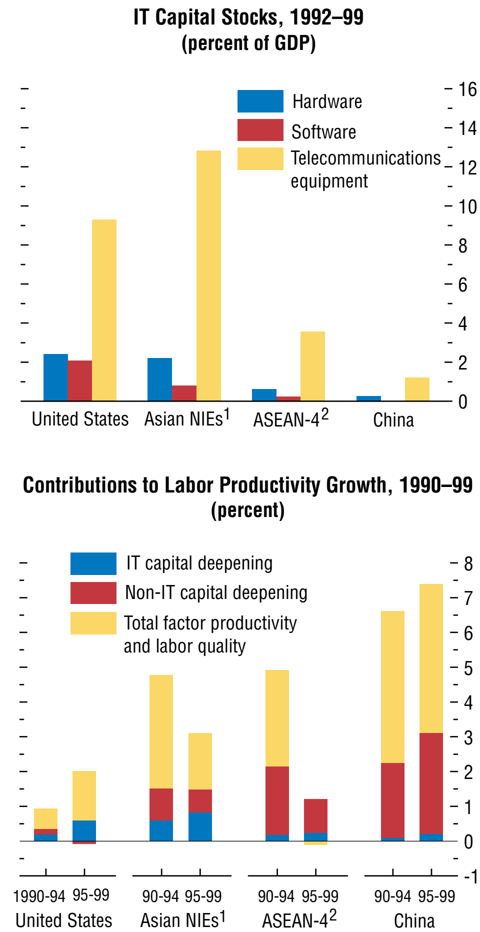
While most of the literature on information technology (IT) and growth covers the advanced economies of North America, Europe, and Japan, many emerging market economies in Asia are important producers and users of IT goods. The IMF has begun a cross-country study of the impact of IT-related capital deepening on labor productivity growth in China, Hong Kong SAR, Indonesia, Korea, Malaysia, Philippines, Singapore, Taiwan Province of China, and Thailand (Lee and Khatri, 2001). As the statistical authorities in these economies do not use hedonic methods to adjust price indices for quality changes or use chain weighting to calculate real growth rates (see Box 3.1), and the national accounts do not distinguish IT production, IT consumption, and IT investment, the IMF study uses consistent cross-country data on IT spending from the World Information Technology Services Alliance (WITSA) and price data from the U.S. Bureau of Economic Analysis, adjusted for exchange rate changes.

Estimates of IT capital stocks (relative to GDP) for emerging Asian economies and the United States are shown in the Figure.[1] IT capital stocks as a ratio of GDP are largest in the United States and the newly industrialized economies (NIEs), followed by the ASEAN-4 countries, and then China, reflecting differences in income per capita. In all economic areas, the stock of telecommunications capital is largest, followed by IT hardware and then IT software. In addition, the proportions differ significantly, with hardware being a much larger part of the IT capital stock in the United States and the Asian NIEs than elsewhere. This is important for calculations of capital deepening, as the relative price declines that drive the additional benefits to IT, as opposed to other capital investment, are much larger in the hardware sector than elsewhere.

Results based on the standard growth accounting decomposition show that the contribution of IT-related capital deepening to labor productivity growth in emerging Asia increased during the 1990s (see the Figure). This contribution was already important in the first half of 1990s in the newly industrialized economies of Asia, and increased even further in the second

[1]These calculations use a perpetual inventory method.

Information Technology (IT) and Labor Productivity



Source: IMF staff estimates.
[1]Simple average of the Asian newly industrialized economies (NIEs): Hong Kong SAR, Korea, Singapore, and Taiwan Province of China.
[2]Simple average of the four members of the ASEAN-4: Indonesia, Malaysia, Philippines, and Thailand.

Box 3.3 ***(concluded)***

half of the 1990s. In the ASEAN-4 and China, the contribution of IT-related capital deepening started from a low base and roughly doubled to around ¼ percent in the ASEAN countries and in China.

This capital deepening, however, has occurred against a background in which labor productivity growth in the emerging market economies of Asia dropped from 5 percent in the first half of the 1990s to 2½ percent in the second half of the 1990s. The sharp decline in labor productivity growth in Asia's emerging markets between the early and late 1990s mainly reflected the crisis-related growth slowdown. In particular, the abrupt deceleration in total factor productivity (TFP) and the slowdown in non-IT-related capital deepening in the Asian NIEs and the ASEAN-4 were related to the 1997–98 crisis, as suggested by the contrast with China. It is remarkable, therefore, that the contribution of IT capital to growth increased in all countries, reflecting continued strong IT investment. Indeed, in some crisis-affected countries, strong IT investment helped growth to recover.

the main beneficiaries of technological revolutions have in practice been the users. This is well illustrated by the experience with textiles production in the industrial revolution in the United Kingdom, where about half of the welfare gains were exported through terms of trade losses.

One way of demonstrating the impact of falling technological prices on the international distribution of IT benefits is through an illustrative exercise to calculate the impact of introducing hedonic prices for IT goods and chain-weighting on real GDP and real domestic demand. Intuitively, the results illustrate how rapidly falling relative prices of IT goods increase output, and how trade between countries transfers some of these benefits from countries that produce IT goods to countries that consume them. As shown in the (upper-bound) estimates in Table 3.7, on the production side, the technological improvements incorporated in the fall in relative prices of IT goods raise the annualized growth in output, most notably in Singapore and Malaysia.[14] However, because most of these goods are exported to the rest of the world, and hence exchanged for non-IT goods, which are rapidly becoming relatively more expensive, the benefits to real domestic demand are significantly smaller. Conversely, countries that import IT goods from abroad gain from the continuing improvement in their terms of trade.

Another more theoretically attractive way of looking at the welfare gains from falling IT prices is to calculate the change in consumer surplus, broadly defined. The increase in consumer surplus is represented by the area between the initial price, P_0, and the final price, P_1, under the demand curve for IT products (see Figure 3.5).[15] The entire demand curve is used because, assuming a perfectly competitive environment, all the benefits end up with consumers, even if this includes intermediate or investment goods.[16] Following the methodology used in earlier studies on U.S. data, IMF staff estimated demand curves for IT hardware, software, and telecommunications equipment, using

[14]Specifically, it is assumed that a country switches from deflating the output of the IT sector (for output) or purchases of IT goods (for real domestic demand) by the GDP deflator to using U.S. hedonic prices (adjusted for exchange rate movements) and chain-weighting to take account of substitution effects (see Box 3.1). This is an upper bound calculation because it is extremely unlikely that any country priced IT goods as equal to the GDP deflator, which implies that no relative price benefits from the IT revolution are included in the calculations that do not use hedonic prices.

[15]This concept is known as "social savings" in the economic history literature (see Crafts, 2001).

[16]The highly competitive environment in which most IT companies operate suggests that this assumption may be reasonable, although there are obvious exceptions. Brookes and Wahhaj (2000) suggest that overall profit rates in the IT sector are not exceptional.

Table 3.7. Illustrative Estimates of the Impact of Falling Prices of Information Technology (IT) Goods on GDP, Terms of Trade, and Domestic Demand[1]

(Percent per year, in order of magnitude of impact on domestic demand)

Country	GDP	Terms of Trade (Contribution to GDP Growth)	Domestic Demand (Contribution to GDP Growth)
United States	0.38	0.28	0.67
Sweden	–0.09	0.50	0.41
Canada	0.11	0.26	0.37
Australia	0.03	0.30	0.33
United Kingdom	0.30	0.02	0.32
Korea	0.85	–0.59	0.27
Singapore	6.71	–6.46	0.25
Denmark	–0.01	0.26	0.25
Israel	0.27	–0.04	0.23
Taiwan Province of China	0.58	–0.37	0.21
Norway	0.03	0.18	0.20
Hong Kong SAR	0.20	–0.01	0.20
Finland	–0.09	0.28	0.19
Netherlands	0.13	0.05	0.18
Malaysia	3.31	–3.13	0.18
Ireland	2.10	–1.93	0.18
Switzerland	0.03	0.15	0.17
Japan	0.37	–0.19	0.17
Belgium	0.10	0.03	0.12
Germany	0.04	0.08	0.12
France	0.10	0.02	0.12
Portugal	0.07	0.05	0.12
Austria	0.03	0.09	0.12
Italy	0.09	0.01	0.11
Brazil	0.17	–0.07	0.10
Philippines	1.13	–1.03	0.10
Spain	0.03	0.06	0.09
Thailand	0.96	–0.87	0.09
Greece	0.01	0.04	0.06

Source: Bayoumi and Haacker (2001).

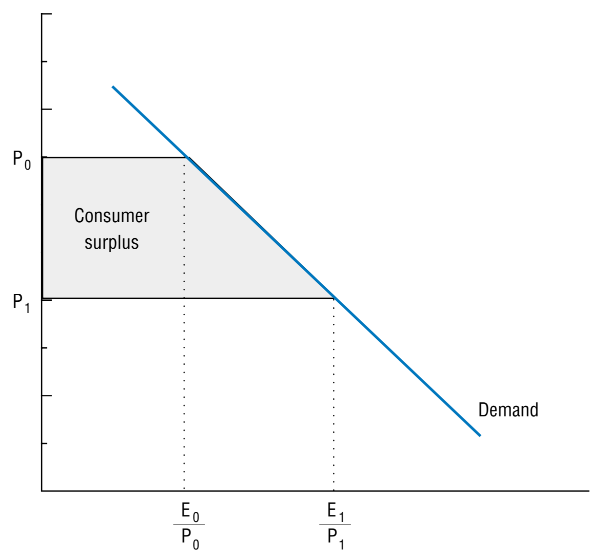
[1]The impact of falling IT prices on real GDP, real domestic demand, and real net exports is calculated by deflating IT final expenditure by exchange-rate-adjusted U.S. hedonic prices (rather than the GDP deflator) and then chain weighting.

panel data on IT-related sales for 41 countries over the years 1992–99 and exchange rate adjusted prices from the U.S. National Income and Products Accounts.[17] Based on the estimated demand curves, the consumer surplus for the year 1999 was then calculated as the gain from the fall in prices between 1992 and 1999.

[17]The IMF staff study is Bayoumi and Haacker (2001). The earlier study of the United States is Brynjolfsson (1996).

Figure 3.5. Demand for Information Technology (IT) Goods and Consumer Surplus[1]

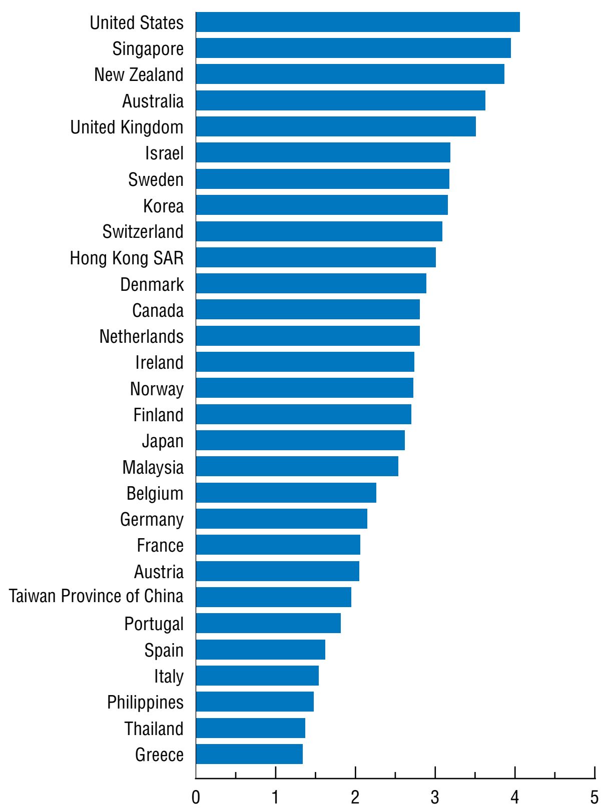
As the price of IT goods falls, consumer surplus increases.



[1]P_0 is the initial price; P_1 is the final price. E_0 is the initial nominal expenditure; E_1 is the final nominal expenditure.

Figure 3.6. Increase in Consumer Surplus, 1992–99
(Percent of GDP)

The increase in consumer surplus due to the fall in relative prices of information technology goods ranged from 1¼–4 percent of GDP in advanced and emerging Asian economies.



Source: Bayoumi and Haacker (2001).

While the results should be interpreted with caution, given the strong underlying assumptions, the estimated increases in consumer surplus are quite large, already amounting to several percentage points of GDP (Figure 3.6). The gain in consumer surplus depends not only on the total amount of IT spending (as a ratio to GDP), but also on the composition of IT spending. Countries with relatively high levels of spending on electronic data processing equipment, the prices of which declined more quickly than for telecommunications equipment and for software, experienced higher increases in the surplus. Cross-country comparisons indicate some interesting variations in consumer surplus gains. The countries with the largest gains in consumer surplus (greater than 3½ percent of GDP) are the United States, Singapore, New Zealand, Australia, and the United Kingdom. Other countries with large gains (2½ to 3½ percent of GDP) are in northern Europe (Sweden, Switzerland, Denmark, Netherlands, Ireland, Norway, and Finland), in Asia (Korea, Hong Kong SAR, Japan, and Malaysia), or have close links to the United States (Israel and Canada). The smallest benefits accrue to most continental European countries, particularly in southern Europe, as well as some important producers of IT goods (the Philippines, Taiwan Province of China, and Thailand). For these Asian countries, however, the consumer surplus gains remain large relative to other countries outside of the sample with similar income per capita, indicating that the IT-producing sector is creating valuable technological spillover.

The IT revolution also affects the distribution of labor income within countries. The development of IT increases the demand for highly skilled workers who can push the technological frontier forward and make the new technology accessible to the rest of the workforce. Even the initial adoption of IT increases the relative demand for skilled labor, as the introduction of computer systems often involves the routinization of simple, repetitive tasks (in service firms) or the automation of production processes (in manufacturing), although the IT-producing sector—which is important in some countries—itself produces many unskilled jobs. Outside of IT, computers can substitute more readily for human labor and judgment in clerical and production jobs, than in managerial and professional jobs.[18] Information technology also increases the returns to the use of marketing and problem solving skills to improve the match between customer-specific needs and existing products and to develop new products. However, over the longer term, as IT becomes more user-friendly and IT equipment becomes more readily available, IT will facilitate the creation of value by less-skilled workers.[19]

In summary, as in past technological revolutions, many of the benefits of the IT revolution accrue to users rather than the producers of IT-related goods. While some countries experienced large increases in real GDP, much of these gains were offset by a deterioration in their terms of trade, although there were also beneficial spillovers through greater IT use. The gains from technological progress, whether measured by an increase in domestic demand or in the consumer surplus, are mainly linked to a country's spending on IT-related goods. Within countries, the IT revolution is raising the wages of more-skilled workers relative to less-skilled workers, though the skill bias may wane in the long run.

Business Cycle Implications

The rapid growth of IT production and use around the world have important implications for the sources and propagation of the business cycle. As IT production becomes a larger share of total output, IT-related shocks are playing a greater role in driving macroeconomic fluctuations, while the increasing use of IT may be speeding up the pace of macroeconomic adjustment. At the same time, the IT revolution has strengthened real and financial linkages across countries, with the result that exports, foreign direct investment, and stock markets in IT-producing countries are vulnerable to shifts in the global demand for IT goods. Also, the heavy reliance of IT firms on equity financing opens up the possibility that swings in investor sentiment (as distinct from changes in fundamentals) may play an independent driving force in global IT cycles.

Domestic Business Cycle

Information technology-related shocks are playing a greater role in driving macroeconomic fluctuations, as IT production becomes a larger share of total output. Some observers have noted the parallels between the current combination of rapid technological progress, more integrated capital markets, and greater macroeconomic discipline, and the economic environment in the late nineteenth and early twentieth centuries (see Bank for International Settlements, 2001). During that period, technology shocks and their impact on investment and on aggregate spending have been acknowledged as a main driving force of business cycles.[20] This contrasts with much of the post-World War II period, during which fiscal and monetary policies played more pivotal roles in stimulating or slowing economic activity.

The diffusion of IT may improve inventory management by reducing time lags in the collection, transmission, and processing of information. Consistent with this idea, inventories-to-sales ratios in Australia, Canada, and the United States declined from the 1980s to the 1990s. Information technology can also help firms ensure that, for a given shock, their inventory

[18]Empirical evidence for advanced economies mostly confirms that IT has thus far increased the demand for and relative wages of more-skilled labor. See Autor, Katz, and Krueger (1998); Autor, Levy, and Murnane (2001); Berman, Bound, and Machin (1998); and Bresnahan, Brynjolfsson, and Hitt (1999). However, Di Nardo and Pischke (1997) suggest that the wage differential may simply reflect the fact that higher-wage workers use computers on their jobs.

[19]Already today, a retail sales clerk not only facilitates sales in the conventional manner, but also automatically engenders a book of accounts, inventory control, and supplier re-orders. See Greenspan (2001b).

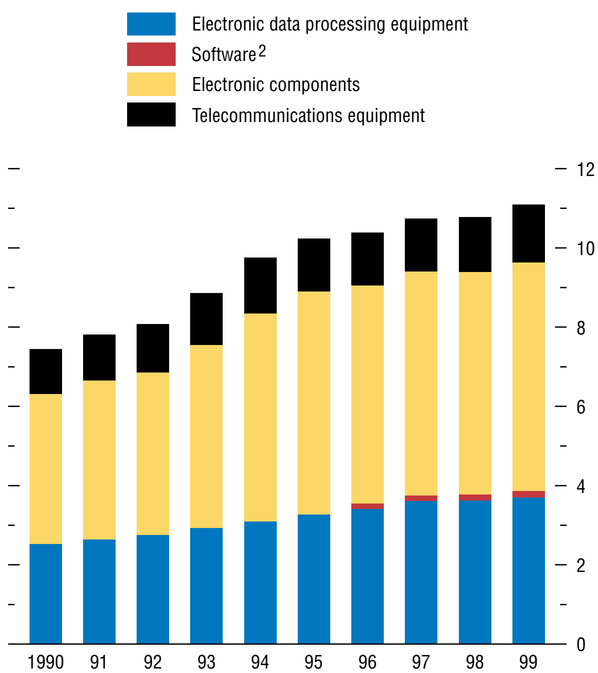
[20]See Hicks (1982) for a concise review of early business cycle models and the relative importance of real versus monetary factors in this connection.

buildup is smaller than it would otherwise have been—though IT by itself cannot mitigate the size or the frequency of the underlying shocks. The international evidence on recent trends in the volatility of inventories and its contribution to the volatility of output is consistent with this view (Box 3.4).

Anecdotal evidence that IT may speed up the pace of macroeconomic adjustment comes from the abruptness of the recent global slowdown, especially in the United States. After the growth of spending on consumer durables slowed in the middle of 2000 in the United States, more advanced supply-chain management allowed firms to quickly identify the initial backup in inventories, and more flexible manufacturing processes enabled firms to adjust production levels rapidly. As a result, a round of inventory rebalancing—especially in the auto sector—quickly took hold and the economic slowdown intensified, leading to a sharper-than-expected slowdown. One implication of faster economic adjustment is that monetary policy may need to adjust more quickly than before (Greenspan, 2001a).

Figure 3.7. Exports of Information Technology (IT) Goods[1]
(Percent of global exports)

IT goods have become increasingly important components of world trade.



Source: United Nations Trade Statistics.
[1]IT exports of selected goods for 32 countries. Selected IT goods are electronic data equipment, software, electronic components, and telecommunications equipment. Sample of countries includes Australia, Austria, Belgium-Luxembourg, Brazil, Canada, Denmark, Finland, France, Germany, Greece, Hong Kong SAR, India, Indonesia, Ireland, Israel, Italy, Japan, Korea, Malaysia, Netherlands, Norway, Philippines, Portugal, Singapore, South Africa, Spain, Sweden, Switzerland, Taiwan Province of China, Thailand, United Kingdom, and the United States.
[2]Software data begins in 1996.

International Business Cycle

The IT revolution has strengthened real and financial linkages across countries. One important dimension of these linkages is the rapidly growing share of IT goods in world trade, which has risen from some 7½ percent in 1990 to 11 percent in 1999 (Figure 3.7), reflecting both the growing demand for new technology and the high price to weight ratio of IT goods, which contributes to their greater tradability. The growth of IT-related trade has been particularly impressive among Asian emerging markets, notably Korea, Malaysia, Philippines, Singapore, and Thailand (Figure 3.8). Adding other electronic components, which are mostly associated with the production of IT goods, the total share of electronic goods now exceeds 50 percent of overall exports in a number of East Asian countries. A similar, though weaker, upward trend in the export share of IT goods was also observed for the United States and Europe.

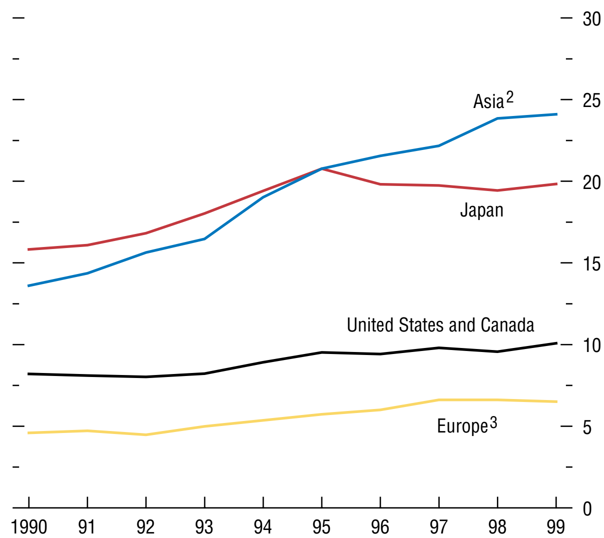
One important implication of these developments is to render those countries' export earnings more vulnerable to shifts in the global demand for IT equipment and components. As noted in the Chapter I Appendix on commodity prices, the prices of IT goods have undergone large swings in recent years. In particular, semiconductor prices have displayed marked cycles with about a four-year periodicity, which partly reflects the typical two-year lead time in building chip factories, as well as the fact that the bulk of such investment is usually made in the later stages of the cyclical upswing when firms are better placed to finance their expansion out of retained earnings. In addition to this cobweb-type mechanism, the sector experienced a succession of favorable shocks in the late 1990s, including the deregulation of local telecommunications in the United States, Y2K concerns, and the commercialization of the Internet. The resulting increase in production capacity is aggravating the oversupply situation in the current retrenchment. The link between the domestic business cycle and the international electronics cycle is particularly noteworthy in several small, open Asian economies, which, as noted earlier, have become highly specialized in the production and exports of semiconductors and IT-related equipment (Box 3.5).

Besides trade linkages, much of the globalization of the IT sector and its increasing role in global business cycle transmission has taken place via foreign direct investment. The rapid overseas expansion of large IT companies such as Intel, Cisco, Compaq, IBM, Motorola, Sony, Ericsson, and Nokia, provides anecdotal evidence in this regard. A more systematic indicator of this trend can be derived from firm-level data on the ratio of sales of foreign subsidiaries to total global sales. This ratio would approach one for companies with extended multinational operations, and zero for companies that operate in only one country.[21] Using firm-level data from a sample of publicly

[21]This definition of international sales is net of exports, so it does not overlap with export data.

Figure 3.8. Trade in Information Technology (IT) Goods[1]
(Percent of total exports for country or group)

The share of IT goods in total exports has risen markedly in Asia.



Sources: United Nations Trade Database; and IMF staff estimates.
[1] Exports of electronic data processing equipment and active components.
[2] Includes Australia, Hong Kong SAR, Korea, Malaysia, Philippines, Singapore, Taiwan Province of China, and Thailand.
[3] Includes Austria, Belgium-Luxembourg, Denmark, France, Germany, Italy, Netherlands, Norway, Finland, Greece, Ireland, Portugal Spain, Sweden, and Switzerland.

Box 3.4. Has the Information Technology Revolution Reduced Output Volatility?

Over the past 20 years output volatility has fallen significantly in most G-7 countries. The standard deviation of quarterly real output growth has almost halved from the 1980s to the 1990s in Canada, Germany, the United Kingdom, and the United States, remained broadly stable in France and Italy, and risen in Japan. This volatility decline partly reflects longer-term structural changes, such as the shift toward services, financial deepening, and improved monetary and fiscal policies. More recently, however, attention has focused on whether information technology (IT) has contributed to the volatility decline.

This box explores whether the adoption of IT by firms has contributed to the volatility decline from the 1980s to the 1990s through improved inventory management. Information technology can affect inventory behavior through at least two channels:

- By increasing the quality of information used by businesses and the speed with which they receive it (for example, through bar coding and real-time transmission of sales information from retailers to distributors).
- Computer aided design (CAD) has made capital equipment easier and faster to produce, reducing set-up times and the incentive to produce in large quantities because of high fixed costs.

Both channels may allow companies to operate with lower inventories and use unsold stocks more efficiently as a buffer against changes in sales. Consistent with this view, inventory-to-sales ratios have declined in recent years, particularly in industries and countries that have adopted IT more quickly. Based on company-level data for G-7 countries, the Figure shows inventories as a share of annual sales from 1988–2000 for three industry classifications: durable consumer goods (electronics, automobiles, and household goods), nondurable consumer goods (beverages, food products, and personal care products) and IT (computer hardware and software).[1] Relative to annual sales, inventories of durable consumer goods have fallen by about one-fifth since 1988 and from a higher level than inventories of nondurable consumer goods, mainly driven by companies in Japan, the United Kingdom, and the United States, rather than Canada or continental Europe. There is a larger and more generalized decline in the inventory-to-sales ratio in the IT sector, which has almost halved since 1988. This suggests that at least some of the decline in inventory levels since the late 1980s is due to IT-related effects, as the adoption of IT is likely most advanced in the IT sector.[2] In 2000, the aggregate inventory-to-sales ratio was lowest in the United States, followed by the United Kingdom, Canada, and Japan, and higher in France, Germany, and Italy.

How has this change in inventories affected output volatility? From the standard breakdown of real output into final sales and inventory investment, it is possible to decompose the change in the volatility of real output growth into that coming from changes in sales growth, changes in the growth of inventory investment, and the change in correlation between these variables.[3] Hence, any decline in output volatility that is not attributable to a reduction in the variance of sales growth is linked either to greater predictability of inventory growth or better use of inventories to smooth irregularities in the path of final sales.

Turning to individual countries, the variance of quarterly real GDP growth in the United

[1]These industry-level ratios represent weighted averages of inventories to annual sales, where company sales as a share of the industry total are used as weights. Fiscal year-end data on inventories and sales are downloaded from Worldscope for up to 2,743 firms (in 1999).

[2]The marked decline in inventory levels in the IT sector, relative to other sectors, may also reflect cyclical factors.

[3]From this decomposition, the variance of real output growth can be written as

$$\mathrm{var}(\Delta y_t) = \mathrm{var}(\Delta s_t) + \mathrm{var}(\Delta I_t) + 2\,\mathrm{cov}(\Delta s_t, \Delta I_t)$$

where Δy_t is real output growth, Δy_t is the growth contribution of final sales, and ΔI_t is the growth contribution of changes in inventory investment. Sales and inventory changes have been broadly stable as components of GDP from the 1980s to the 1990s across G-7 countries, so that changes in their growth contributions derive mainly from changes in the volatility of the growth rates of sales and inventory investment.

States fell by 68 percent between the 1980s to the 1990s, while the variance of sales growth declined by 50 percent (see the Figure). Hence, inventories provided a significant additional reduction in the volatility of output growth, reflecting both a large fall in the volatility of inventories and better "timing" of inventory changes. Inventories also played a significant role in the reduction of output volatility in Canada and the United Kingdom. By contrast, in the continental European countries, there was little sign of a significant contribution from inventories to the decline in output volatility, consistent with lower usage of IT in these countries.

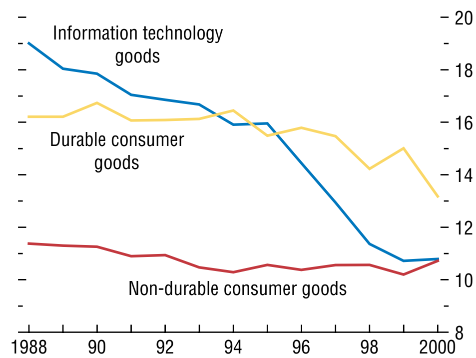
Japan is the one G-7 country where output volatility has increased substantially.[4] As can be seen from the Figure, inventories contributed modestly to this rise in volatility, despite significant usage of IT in the economy. While the variability of changes in inventories has fallen, as expected given the decline in the inventory-to-sales ratio, inventory investment did not offset movements in sales as much as in the past. This suggests that much of the ability of producers to better offset changes in sales in the United States and elsewhere may be in part a cyclical phenomenon that comes with lower output volatility, rather than improved inventory management.

In conclusion, the results are consistent with the idea that IT is helping to reduce output variability through better inventory control. Though some of the decline in output volatility in the G-7 countries probably reflects cyclical factors, it is striking that the volatility of inventory changes has fallen substantially in both Japan (where sales volatility has risen) and the United States. It is more difficult to determine whether inventories are also being used more efficiently, in terms of acting as a better buffer against changes in sales. While anecdotal evidence suggests that this may be occurring, hard evidence at the macroeconomic level is more difficult to identify. Going forward, the current slowdown will be instructive in assessing to what extent the IT revolution has improved inventory management.

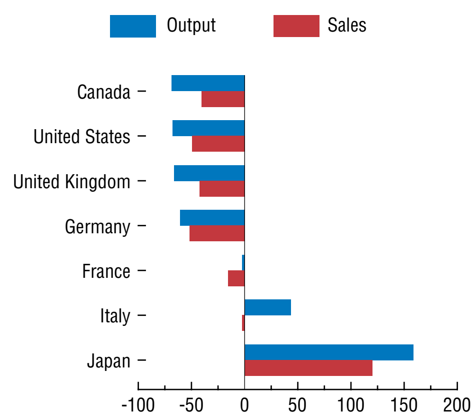
[4]See Box 1.2 in the October 2000 *World Economic Outlook* for a discussion of the reasons for this different evolution of output volatility.

Inventories and Output Volatility

Global Inventories-to-Sales Ratios
(inventories in percent of annual sales)



Change in Volatility of Output and Sales Growth Among the Group of Seven Countries[1]
(percent)



Sources: Thomson Financial, Worldscope database; and IMF staff estimates.
[1]Change in the variance of quarterly real GDP growth, between 1981:Q1–1990:Q4 and 1991:Q1–2000:Q4. The change in variance is then decomposed into inventory and sales components. See text for explanation of calculations.

Box 3.5. The Information Technology Slump and Short-Term Growth Prospects in East Asia

The sensitivity of East Asia's economic performance to cyclical developments in global information technology (IT) markets has increased significantly over the past two decades, with the rapid growth of the IT sector's share of regional production, investment, and exports. By 2000, IT sector exports accounted for 30 percent of total exports of goods from East Asia, equivalent to nearly 10 percent of GDP.[1] This increased sensitivity is clearly reflected in the region's recent growth performance: the slump in global IT markets since mid-2000 is one of the principal factors dampening exports and GDP growth in East Asia in 2001, just as the boom in the IT sector boosted the regional economic recovery in 1999–2000. The increasingly commodity-like characteristics of many IT products—for example, the strong cycles in prices—means that East Asian economies are now experiencing to varying degrees the sort of export and output variability traditionally associated with commodity exporters.

The slump in the IT sector began in the first half of 2000 with a significant reversal of the earlier speculative run-up in IT sector stock prices worldwide, and was followed by a sharp weakening of global sales volumes and prices for IT components and products in late 2000 and into 2001. In the first four months of 2001, global sales of semiconductors were down around 10 percent from the same period in 2000. The impact on Asia of the downturn in the electronics sector is being felt both through trade channels, including weaker trade volumes and prices, and through financial market channels, including the impact of lower regional stock market prices on investment and consumer spending, and weaker foreign direct investment and portfolio investment inflows to the region.

This box examines the impact of the IT sector slump on East Asian growth through the trade channel. More specifically, a simple model is used to estimate the impact on regional economies of a 10 percent decline in the growth of the volume of IT sector exports. The analysis highlights the importance of three factors influencing the effects of the export shock across the region: (1) the magnitude of exports of electronics, *net* of imported intermediate inputs, relative to GDP; (2) the responsiveness of other GDP expenditure components to weaker export earnings; and (3) indirect trade spillovers from weaker growth elsewhere in the region.

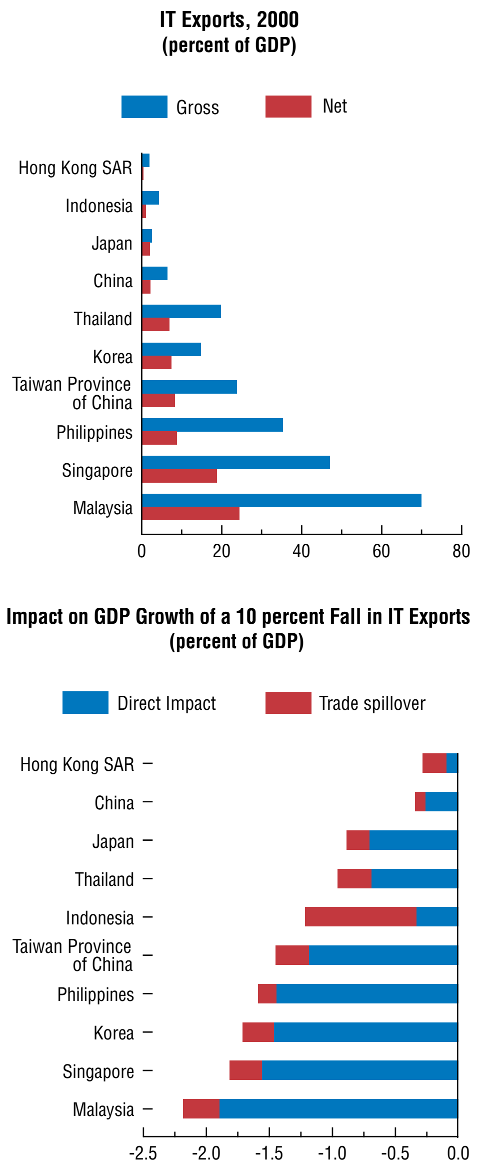
Electronics exports are equivalent to nearly 10 percent of GDP for the Asian region as a whole, and to 20 percent of GDP in the smaller regional economies (see the Figure). For most countries in the region, however, electronics production and exports include a high proportion—between 50 and 75 percent—of imported intermediate inputs, mainly sourced within the region. As a result, a fall in electronics exports leads automatically to a decline in such imports, significantly dampening the spillover into domestic expenditure. The size of IT sector net exports relative to GDP varies substantially across the region—from as much as 25 percent of GDP for Malaysia, to less than 1 percent of GDP for Hong Kong SAR (excluding re-exports)—so the estimated initial impact on the region's economies also varies widely.

An additional consequence of the high import content of electronics exports in most countries in the region is that the fall in electronics prices affects both import and export prices within the region, having an ambiguous effect on terms of trade. The most commodity-like electronics components, such as memory chips, have experienced much larger price falls than many other electronics components. As a result, countries importing such components and exporting other electronics products could even experience terms of trade improvements.

The estimates and assumptions employed in this analysis regarding the responsiveness of different expenditures to lower export growth suggest that, in Malaysia and Singapore in particular, lower multipliers (reflecting higher marginal savings rates) will tend to cushion the

[1]In this analysis, East Asia includes China, Hong Kong SAR, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan Province of China, and Thailand.

Information Technology (IT) Trade



Source: IMF staff estimates.

impact of the IT shock.[2] Conversely, in Indonesia and Japan, higher multipliers (reflecting lower marginal savings rates) tend to accentuate the impact of the external shock. In the Philippines, the effect of a low savings rate is substantially offset by the high responsiveness of nonelectronics imports to weaker domestic demand.

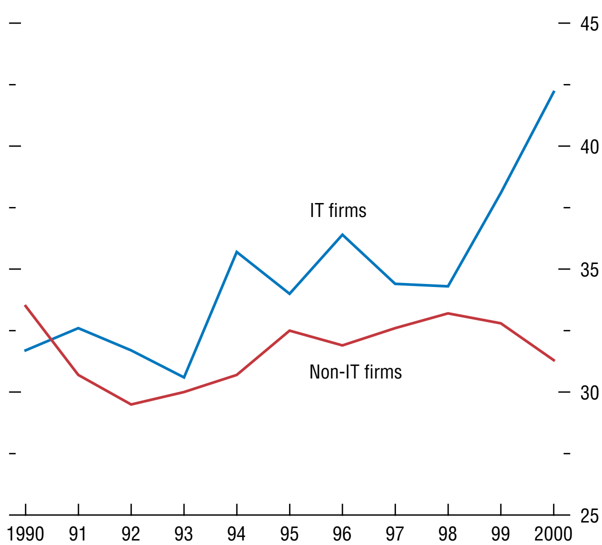
Overall, the direct impact of a 10 percent fall in regional electronics exports is estimated to cut GDP growth in the region by about ½ percentage point. The adverse impact on growth in Malaysia, Singapore, Korea, the Philippines, and Taiwan Province of China is substantially greater (see the Figure), largely reflecting the importance of IT net exports to their economies. In addition to the direct impact of the IT shock to growth in the region, weaker growth will also reduce nonelectronics imports by countries in the region, leading to a further, second-round contraction of other countries' nonelectronics exports and GDP. Analysis using bilateral trade shares to estimate the contraction in nonelectronics trade within the region suggests that these second-round effects would cut growth in the region by an additional ¼ percentage point, bringing the total growth reduction to ¾ of a percentage point, and nearly double that for East Asia excluding China and Japan. Indonesia is likely to be the country most strongly affected by the second-round trade spillover effects, reflecting the unusually high proportion of its exports going to other countries in the region, as well as relative sensitivity of Indonesian consumption to changes in export income.

[2]Private consumption elasticities are based on a recent analysis by J.P. Morgan Chase & Co. (2001), while private investment is assumed to be 2½ times as responsive as private consumption. Public sector expenditure is assumed to be unchanged. The responses of nonelectronics imports are based on elasticities estimated in Senhadji (1998).

traded and mostly very large companies in advanced economies, Figure 3.9 shows that the ratio of international sales (net of exports) to total sales in the IT sector has trended up markedly since the early 1990s relative to the non-IT sector. Much of this increase has been due to the globalization of hardware and software production.

Figure 3.9. Globalization of Information Technology (IT) Firms[1]
(Percent)

The ratio of international sales to total sales is higher for IT firms than for non-IT firms and has risen sharply in the past two years.



Sources: Thomson Financial, Worldscope database; and IMF staff estimates.
[1] Ratio of international sales to total sales, weighted by each firm's total sales.

The strengthening of real linkages—through both merchandise trade and the expansion of overseas subsidiaries of IT firms—has had an important counterpart in financial market linkages. The cross-border correlations of stock prices since the mid-1990s have been higher for the IT sector than for non-IT sectors, reflecting the greater exposure of IT firms to common expectational shocks (regarding the future profitability of IT) and the greater internationalization of IT firms—a shock to the earnings of an IT firm in one country can have a substantial impact on other countries, through its effect on the company's worldwide consolidated balance sheet (Figure 3.10). More rigorous statistical analysis, which decomposes a firm's stock returns into a global business cycle factor, a country-affiliation factor, and an industry-affiliation factor, shows that IT firms have experienced by far the most significant increase in the contribution of the industry affiliation factor to the determination of firms' stock returns (see Brooks and Catão, 2000).

At the same time, the strength of cross-border financial linkages among IT firms opens up the possibility that swings in investor sentiment (as opposed to investors' rational response to changes in fundamentals) may play an independent driving force in global IT cycles. While it is difficult to establish the extent to which the 1995–2000 rise in IT stock prices constituted a bubble, or the extent to which prices now reflect fundamentals, it is clear that those financial market developments can have important business cycle implications. This is because, as discussed in the following paragraphs, the availability of external funds appears to have been a key determinant of investment by IT firms, implying that the higher cost and more limited availability of external funds—relating to the current weakness in stock prices—may be expected to restrain investment in the sector on a global scale, at least in the near term.

Financing Information Technology

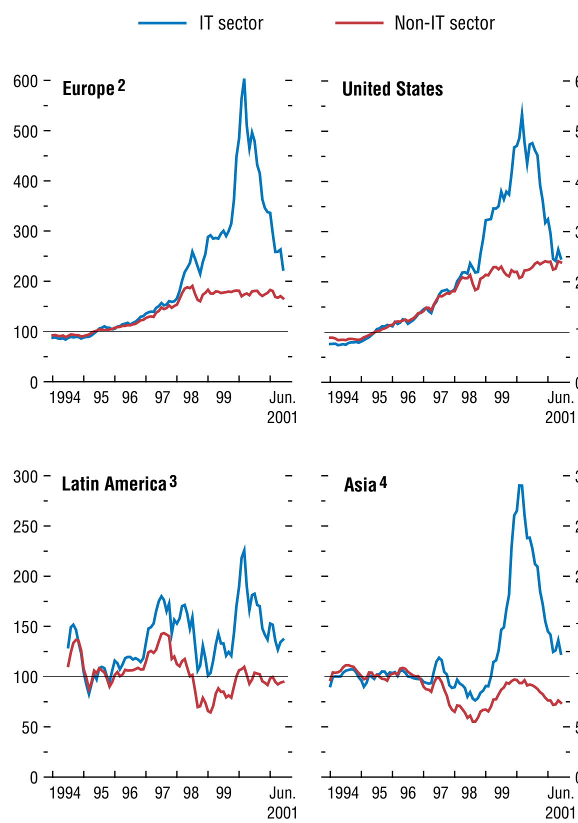
As in past technological revolutions, the initial phase of the IT revolution appears to have been characterized by excessive optimism about the potential earnings of innovating firms. This over-optimism led for several years to soaring stock prices of IT firms, which made equity finance cheaper and more readily available, which in turn boosted investment by IT firms. The association between stock prices and the relative cost of capital for IT producers can be seen in the upper left panel of Figure 3.11, which plots the ratio of the market value of equity to the book value of equity—a widely used measure of the relative cost of investment often known as Tobin's *q*.[22] Partly reflecting soaring optimism about the prospective benefits of IT, the Tobin's *q* of the IT sector rose much more rapidly than that of the rest of the economy in the 1990s and remained higher even in 2000.[23] During the same period, the investment expenditure (scaled by total assets) in the IT sector also rose markedly relative to the rest of the economy (upper right panel of Figure 3.11), similar to the "railway mania" in Britain in the 1840s that was discussed earlier.

These developments echo the findings of a large literature in empirical finance that postulates that capital structure and external financing conditions play a key role in firms' investment decisions.[24] In a world where information is costly and not fully available to investors, a firm's internal funds (retained earnings) tend to be significantly cheaper than external funds (like new debt or equity), as internal funds dispense with costly monitoring of the firm's management decisions. Likewise, the choice between

Figure 3.10. Stock Prices[1]

(1995 average = 100; monthly averages)

The stock prices of information technology (IT) firms have been highly correlated across countries.



Source: Thomson Financial Datastream.
[1]Weighted by market value.
[2]Includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden Switzerland, and the United Kingdom.
[3]Includes Argentina, Brazil, Chile, Colombia, Mexico, and Peru.
[4]Includes China, Hong Kong SAR, India, Indonesia, Japan, Korea, Malaysia, Philippines, Singapore, Taiwan Province of China, and Thailand.

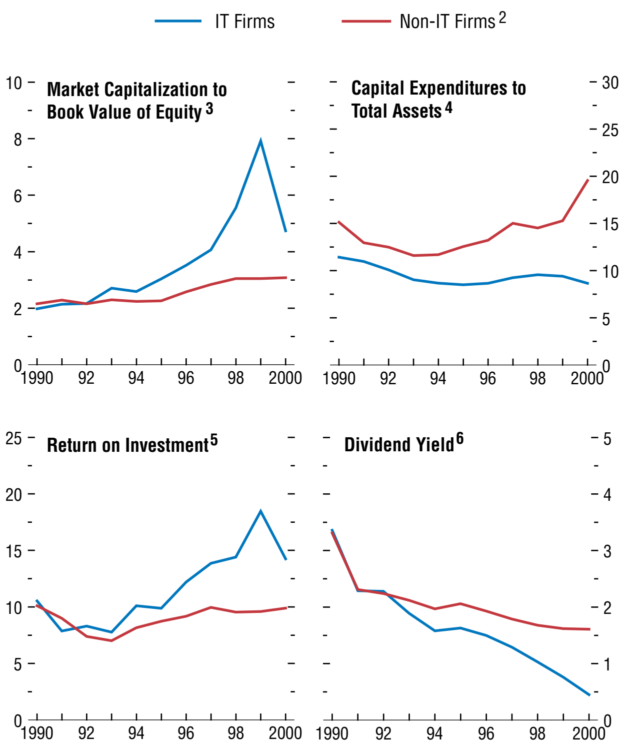
[22]The definition of the non-IT sector excludes banks and financial institutions since, by the nature of their operations, they tend to display very high leverage ratios and large maturity mismatches between assets and liabilities, which would distort the comparison with other sectors. The empirical analysis presented in this section is based on company level information covering 19 advanced economies, obtained from the Worldscope database.

[23]Hall (2001) argues that the higher Tobin's *q* in the IT sector reflects higher human capital, which is not captured by balance-sheet measures of capital. However, this argument implies that the recent sharp swings in IT stock prices primarily reflect rapid changes in human capital.

[24]Fazzari, Hubbard, and Petersen (1988), Gertler and Gilchrist (1994), and Hubbard (1998).

Figure 3.11. Information Technology (IT) Financing in Advanced Economies[1]
(Percent)

There are significant differences in financial structure between IT and non-IT firms.



different instruments of external funds—namely between equity and debt finance as well as between short-term debt and long-term debt—also appears to have an important bearing on the firm's ability to finance new investment projects and hence on how the firm's stocks are valued. In particular, some have argued that firms with high debt to asset ratios, and with high ratios of short-term debt to total debt, are more likely to pass up good investment opportunities for fear of bankruptcy and hence have diminished growth prospects (see Myers, 1977; and Myers and Majluf, 1984).

Looking at the financial performance of IT firms and their capacity to finance new investment with retained earnings, a distinguishing feature of the sector has been its high rates of return on investment and higher earnings relative to the non-IT sector (Figure 3.11). Yet, despite higher earnings, IT firms have remained highly dependent on external finance. Retained earnings (as a share of total earnings) have been increasingly used to finance investment needs, but this has been insufficient to fill the financing gap. This is apparent from the ratios of the dividend yield and retained earnings to investment, both of which trended down during the 1990s, pointing to decreases in liquidity and the sector's capacity for self-financing.[25]

When resorting to external funds, IT firms have been considerably less reliant on debt than the average non-IT firm. Moreover, the ratio of debt to assets of IT firms declined in the second half of the 1990s, during the bull market for IT stocks.[26] At the same time, the share of short-term debt in total debt is higher for IT firms than for non-IT firms. This trend was reinforced in the past two years by heavy short-term borrow-

[25]Within IT, this trend has been more marked for hardware and software producing firms relative to telecoms. Because telecom firms tend to be larger, and financially more established, ratios of net cash flows to assets and retained earnings to investment tend to be higher than in the software and hardware subsectors.

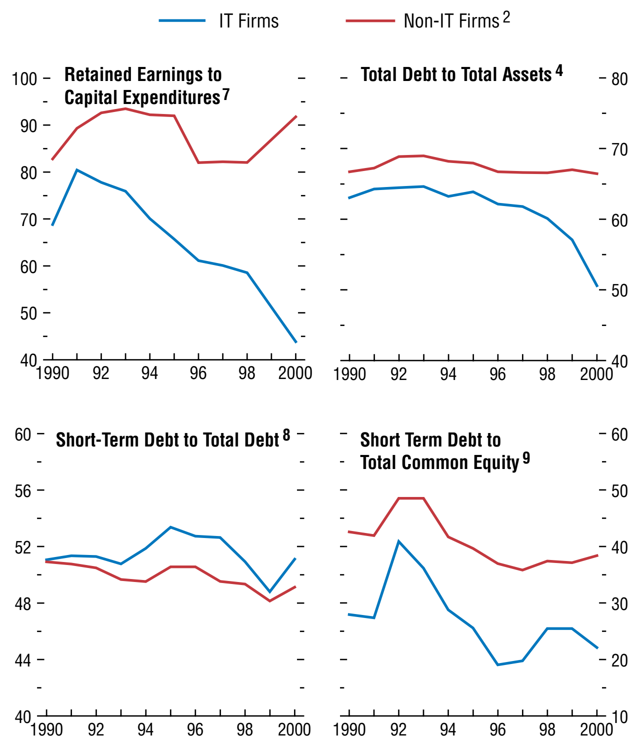
[26]Again, this is particularly the case among hardware and software producers than among telecom companies.

ing by telecommunications firms in Europe (Figure 3.12).

The greater reliance of the IT sector on equity relative to debt and on short-term relative to long-term debt is explained by several factors. First, firms specializing in the development of new technology tend to be younger, have a less established credit reputation, and are riskier from a bondholder's perspective. Under these circumstances, equity financing tends to be cheaper, especially during periods of euphoria about the economic prospects for the adoption of new technologies. Second, one of the main distinguishing characteristics of the IT revolution compared to past technological revolutions is that the optimal firm size is much smaller.[27] This implies that IT firms have a limited stock of fixed assets to pledge as a collateral against loans, which tends to increase borrowing costs. Third, to the extent that new IT ventures tend to be riskier, subject to greater earnings volatility, but also have projects with higher expected returns, theory suggests that equity tends to be superior to debt financing (see Myers, 1977). Greater reliance on short-term debt relative to long-term debt also reflects a combination of demand and supply factors. On supply side, greater long-term risks imply that the yield curve faced by younger and smaller IT firms will tend to be steeper. On the demand side, higher depreciation rates in IT imply that tangible assets will tend to have a relatively short life span, so that maturity matching considerations will point toward a more intensive use of short-term debt.

These capital structure characteristics of the IT sector have significant economywide implications. Higher intensity in the use of external funds tends to foster the development of domestic financial systems. In particular, greater reliance on the use of equity financing tends to favor the development of domestic stock markets—a desirable feature, especially for developing countries. Interestingly, these characteristics of IT firms have

Figure 3.11 ***(concluded)***

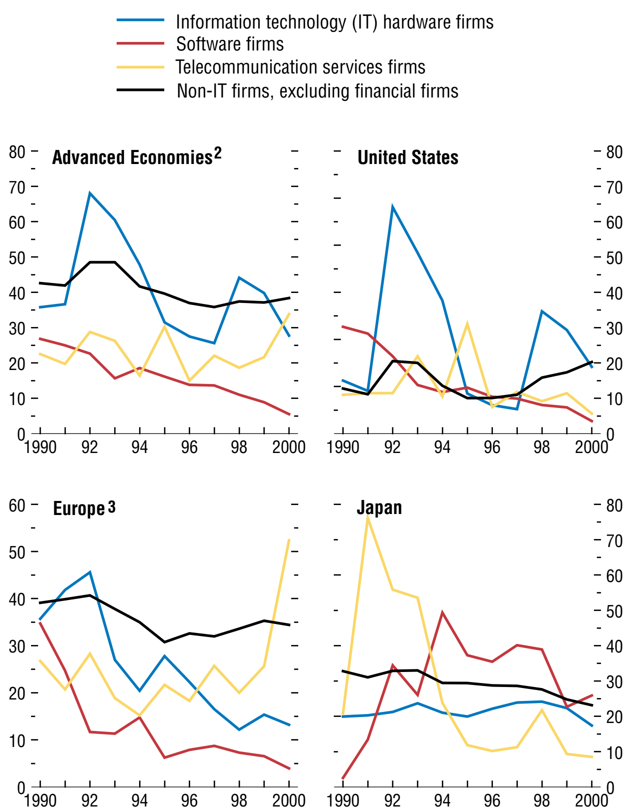


Source: Thomson Financial, Worldscope database.
[1]Advanced economies include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, and the United States.
[2]Excludes financial firms.
[3]Ratio for each firm weighted by its book value of equity.
[4]Ratio for each firm weighted by its total total assets.
[5]Ratio for each firm weighted by its total sales.
[6]Ratio for each firm weighted by its market capitalization.
[7]Ratio for each firm weighted by its capital expenditures.
[8]Ratio for each firm weighted by its total liabilities.
[9]Ratio for each firm weighted by its total common equity.

[27]Digital technology and the Internet tend to reduce the optimal firm size to the extent that they increase opportunities for outsourcing and lower fixed costs.

Figure 3.12. Short-Term Debt to Book Value of Equity[1]
(Percent)

The reliance of telecommunications firms in Europe on short-term debt increases sharply in 2000.



Source: Thomson Financial, Worldscope database.
[1]Weighted by the firm's book value of equity.
[2]Countries include Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Ireland, Italy, Japan, Luxembourg, Netherlands, New Zealand, Norway, Spain, Sweden, Switzerland, United Kingdom, and the United States.
[3]Countries include Austria, Belgium, Denmark, France, Germany, Italy, Luxembourg, Netherlands, Norway, Finland, Ireland, Spain, Sweden, and Switzerland.

been observed across a variety of economies, including both those where bank loans have been the main source of business financing (as in Germany and Japan) and those where the stock market has played a more central role (as in Canada, the United Kingdom, and the United States). At the same time, however, greater reliance on external finance, the stock market, and on short-term debt also makes the IT sector more vulnerable to changes in macroeconomic conditions and shifts in investor confidence. As in previous technological revolutions, this could pave the way for substantial industry consolidation and for a relatively protracted period of lower investment and slowdown in the diffusion of the new technology.

Prospects for the Information Technology Revolution

While global demand for IT goods is falling sharply at present, reflecting in part a retreat from the unsustainably high level of a year ago, IT adoption will likely continue to expand in the medium term. As users bring their IT spending back into line with their medium-term needs, short-term prospects for IT-producing countries and for the contribution of IT-related capital deepening to labor productivity growth may be limited. However, in the medium term, the diffusion of IT is likely to make substantial contributions to productivity growth, as the increasing use of computers and telecommunications equipment streamlines business processes and organization, boosting the efficiency with which other factors of production are used.

Advanced Economies

Further innovation in the production of IT equipment, leading to TFP growth in the IT sector, and additional purchases of IT equipment, resulting in IT-related capital deepening, are highly likely in the medium term. As Moore's Law is likely to continue to hold for some time, advances in semiconductor technology will continue to drive declines in computer prices

(Jorgenson, 2001). Imminent innovations in semiconductors include larger chips, which will reduce costs by 30 percent, and thinner circuit lines, which will allow manufacturers to etch more transistors on a single chip. As a result, the relative price of computer power is likely to continue to fall sharply at least for several years.

In conjunction with the continued fall in computer prices, two characteristics of IT equipment suggest that in the medium term IT investment and adoption will likely remain strong. Given that computers depreciate rapidly, firms will probably invest in computers at a faster rate than they do in other forms of capital in order to maintain a given level of the capital stock. The rapid replacement of IT equipment means that new technology becomes "embodied" in the capital stock at a faster rate than is the case for longer-lived assets (Ferguson, 2001). Second, empirical research has shown that the demand for computers—unlike that for other classes of capital—is quite sensitive to movements in the cost of capital (Tevlin and Whelan, 2000). The combination of this higher price elasticity and rapid decline in relative computer prices is likely to sustain investment in IT equipment, though investment may slow from the frenetic pace of the late 1990s, implying slower capital deepening and therefore slower labor productivity growth. This is consistent with the idea that firms and individuals are still finding new uses for IT, implying a price elasticity of demand for IT goods and services greater than unity, so that technological progress (and hence falling prices) results in a growing sector over time.[28]

Beyond TFP growth in IT production and IT-related capital deepening, the reorganization of production around IT may have a positive impact on productivity growth over the medium term. There is already microeconomic evidence of productivity gains associated with the invention of new processes, procedures, and organizational structures that leverage IT (see Brynjolfsson and Hitt, 2000, and Litan and Rivlin, 2000). Specifically, IT can sharply reduce transaction costs in the production and distribution of goods and services, especially in data-intensive industries, such as medical care and financial services, and reduce communication costs, enabling firms to improve supply chain management, assess customers' needs more effectively, and enhance internal efficiency. Microeconomic evidence suggests that IT is already having a disproportionately large impact on business performance by enabling complementary organizational innovations (new processes and structures). Together, IT and reorganization are leading to cost reductions and product-quality improvements.

Information technology is likely to affect not only the organization of workplaces but also firms' sourcing and location decisions. By reducing information and communication costs, which are important barriers to cross-border transactions, IT has the potential to raise international trade, reduce home-market bias, boost cross-border financial flows, and facilitate technology transfer. Recent work suggests that standard measures of distance in empirical models of international trade may partly capture information costs—adding measures of information flows to these models sharply diminishes the role of distance (Portes and Rey, 1999).

The overall impact of IT on the location of production in central versus peripheral areas is less clear. On the one hand, lower transaction and communication costs, combined with goods production that is increasingly characterized by flexible specialization rather than economies of scale, will tend to favor the dispersion of economic activity. Indeed, cities based on large-scale concentrated manufacturing are already past history in some countries (Glaeser, 1998). On the other hand, the combination of increasingly up-to-date information about shifting consumer preferences, the rising importance of intermediates in production, and easier outsourcing, will tend to favor locating production near to markets. If

[28]By contrast, the price elasticity of demand for agricultural goods is considerably less than unity, so that technological progress (and falling prices) results in a shrinking sector over time.

Table 3.8. Selected Economies: Indicators of Information Technology (IT) Use

Country	IT/GDP *(In percent)* Change 1992–99	IT/GDP 1999	IT per Capita *(Nominal U.S. dollars)* Growth 1992–99 (percent)	IT per Capita 1999	Personal Computers *(per 100 people)* Change 1990–2000	Personal Computers 2000	Telephone Lines *(per 100 people)* Change 1990–2000	Telephone Lines 2000
Developing								
Argentina	1.0	3.4	78.0	294.3	4.4	5.1	12.0	21.3
Brazil	2.3	5.8	199.4	267.4	4.1	4.4	8.4	14.9
Chile	1.1	5.7	121.8	321.0	7.5	8.6	15.5	22.1
China	3.0	4.9	465.7	37.9	1.6	1.6	8.0	8.6
India	1.8	3.5	220.8	15.4	0.5	0.5	2.6	3.2
Indonesia	–0.3	1.4	7.0	13.7	0.9	1.0	2.5	3.1
Korea	–0.5	4.4	53.8	521.5	15.3	19.0	15.4	46.4
Malaysia	2.1	5.5	61.8	168.4	9.7	10.5	12.2	21.1
Mexico	5.2	1.0	30.6	231.8	4.3	5.1	6.0	12.5
Philippines	0.9	2.7	82.6	33.6	1.6	1.9	2.9	3.9
South Africa	1.8	7.2	49.5	240.6	5.5	6.2	3.2	12.5
Advanced								
Canada	1.6	5.3	31.6	1,808.7	28.3	39.0	11.1	67.6
Denmark	1.0	4.5	45.3	2,540.3	31.6	43.1	13.8	70.5
France	0.8	3.8	27.5	1,706.6	23.4	30.5	8.5	58.0
Germany	0.9	4.1	29.4	1,699.9	23.4	33.6	16.0	60.1
United Kingdom	0.7	4.7	52.0	1,979.5	23.0	33.8	12.6	56.7
United States	0.9	5.2	57.9	2,792.1	36.8	58.5	12.8	67.3

Sources: ITU Statistical Yearbook, 1999; World Information Technology Services Alliances, *Digital Planet*, 2001.

outsourcing involves the proliferation of new intermediaries supplying various services (such as accounting, marketing, purchasing), which still rely in part on people providing the services in person, then close proximity is also valuable because it economizes on the cost of time.

Developing Countries

Looking ahead, it appears likely that usage of information technology products will continue to expand rapidly in developing countries, but productivity benefits will accrue only slowly. As in advanced economies, expanded usage is driven by the rapid decline in prices of information technology products. Enhanced productivity through that use, however, is a development task that may require complementary human capital, efficient (de)regulation of the telecommunications infrastructure and of information flows, and, more generally, overcoming organizational rigidities that limit the benefits from new ideas and technologies. As such, even though information technology will contribute to raising the absolute levels of productivity in developing countries, it may increase the productivity gap between advanced economies and developing countries.

The rate of diffusion of IT to developing countries has been rapid compared to earlier all purpose technologies. Just 10 years after the "start" of the IT revolution, developing countries (with about 85 percent of the world's population) already had about a 10 percent share of Internet subscribers in 2000. By contrast, it took more than 80 years from the opening of the first rail line in 1830 for developing countries to account for 30 percent of the world's rail track in 1913. Though from a low base, IT expenditure rose throughout the 1990s for most developing countries and for many of them at a rate significantly greater than in advanced economies (Table 3.8). Investment spending slowed when economic conditions were unfavorable, as in Indonesia in the late-1990s, but the expenditures typically grew substantially, with the result that much larger numbers of personal computers and telephone lines per capita were in use at the end of the 1990s than at the start, which, in turn, enabled a more widespread use of the

Internet. This trend toward more widespread use is likely to continue.

What explains the patterns of diffusion of these new technologies? A recent analysis points to several important factors (Dasgupta, Lall, and Wheeler, 2001). Countries with relatively high growth rates, greater urbanization, and a superior economic policy environment have expanded their use of cell phones and Internet connections at a faster pace than others. Once these factors are controlled for, those with low usage have caught up. Other studies, such as those by Caselli and Coleman (2001) and Lee (2000), reinforce these findings. High levels of human capital are strongly correlated with the rate of adoption of information technology. Since the new technology is typically embodied in new equipment, high investment rates speed up adoption (Chile, for example, has one of the highest investment rates in Latin America and Malaysia and Korea achieved historically high investment rates in the 1990s). Finally, a policy regime that is open to imports and foreign direct investment creates a window to the world and hence raises the likelihood of adopting new technologies in general, and computers in particular.

The implications are, therefore, mixed. Strong growth and good policies raise the rate of IT adoption, which, in turn, has long-term beneficial growth effects; this implies the likelihood of a "virtuous" circle—with growth, policies, urbanization, education, and information technology reinforcing each other. However, those with the least developed infrastructures are also closing the IT usage gap. An important finding is that in some of the poorest countries, the ratio of Internet users to telephones is no lower, and often higher, than in advanced economies. The suggestion, therefore, is the latent demand for access to IT (and to the international knowledge networks) is strong even in poor countries. The critical question in the case of such countries is whether the new technologies could be productively used to accelerate the pace of development.

Information technology presents the attractive possibility of bypassing older technologies ("leapfrogging"). For example, countries with old-fashioned mechanical telephone systems can skip the analog electronic era and go straight to advanced digital technologies, and that certainly is happening. Leapfrogging is also made possible in a more radical developmental sense. Education can potentially be delivered at much lower expense to a much wider group of people. People on the margins of domestic and international markets can be brought into the mainstream through the provision of better information and the reduction of transactions costs. Again, some are realizing this potential. Bangladesh's Grameen Bank, a pioneer in the area of microfinance, has launched an effort to build cell phone and Internet access in rural areas. The range of IT applications and their creative deployment for raising productivity is large and includes factories, banks, ports, and, more recently, the business of governments themselves. Continued innovation and the relentless decline in costs is likely to further bolster these trends.

Despite the many specific examples of IT benefits in developing countries, the aggregate impact has thus far been limited.[29] This reflects in part some fundamental constraints, including the lack of complementary human capital, telecommunications sectors that are not yet sufficiently responsive, and organizational rigidities. With regard to human capital, IT may in some instances reduce the demand for human capital by embodying "intelligence" in information products and services, thus facilitating development. For example, electronic course content may sometimes substitute partially for trained teachers. Such substitutability between human capital in the old-fashioned sense and IT is likely to increase with the maturation of the technologies and the delivery systems. By contrast, the

[29]In a cross-country analysis, Pohjola (2000) shows that IT helps raise growth in advanced economies but not in developing countries.

complementary human capital requirements of IT are often significant, especially in business and government applications. For example, factory floor microelectronics-based technologies were expected to improve efficiency even in low wage environments by reducing waste and increasing throughput. However, as a series of engineering-economic studies showed, the achievement of those efficiencies required strong quality control ability, which was more a function of industrial literacy than sophisticated machinery (Mody, Suri, and Sanders, 1992).

Telecommunications infrastructure is paramount. The ratio of Internet users to telephone lines varies across countries in a much smaller range than does the number of telephone lines per capita. Thus, the latent demand for connections to the web—despite the high costs of doing so in most developing countries—is being constrained by the availability of telephone line connections. Privatization has brought significant gains but the process of awarding privatization contracts and the extent of subsequent market competition have remained controversial. In particular, regulatory oversight has proved complex and demanding, with considerable scope for regulatory overreach. New challenges lie ahead in setting standards and regulations, taxing and regulating electronic transactions, undertaking antitrust actions, and protecting privacy.

Finally, the widespread adoption and effective use of new technologies requires organizational flexibility and the willingness to take risks.[30] For example, though the potential exists for considerable efficiency improvements in the running of governments, rigid bureaucratic structures have often prevented a more aggressive adoption. While this concept is linked to the quality of human capital, it refers further to the organizational capacity to engineer change.

In summary, the unprecedented decline in IT prices has implied a faster rate of diffusion than in previous technological revolutions. The present constraints on more productive uses of the technology are real, but a continued vigorous effort to harness the potential of IT is likely to pay dividends, as these become available over the next two or three decades.

Policy Implications

The IT revolution raises at least three important questions for policymakers. First, how can countries promote the use of IT and maximize its impact on growth? Second, how should macroeconomic policies take into account the uncertainty over any acceleration in productivity? And, finally, what are the implications of IT for fiscal, monetary, and financial policies in the long run?

Structural Policies

Differences in recent and prospective productivity performance across advanced economies reinforces the case for aggressive structural reform. Among the G-7 countries, the United States has seen large IT investment translate into an increase in underlying labor productivity growth, while in Japan and Europe it is more difficult to discern any positive impact on growth. This difference likely reflects, at least in part, less flexible labor markets and less efficient services sectors—especially telecommunications, finance, and distribution—in Japan and Europe. Such rigidities limit firms' abilities to exploit new opportunities, including those afforded by information technology. For example, employment practices—as reflected in official regulations, union rules, or simply employee culture—can restrict firms from offering appropriate incentive compensation, changing the tasks of existing employees, or dismissing workers. Indeed, theoretical work has emphasized the importance of workers (and managers) continually taking on new tasks to on-the-job learning in human capital accumulation (Lucas, 1993). Equally, an inefficient distribution sector not only raises the price of IT goods,

[30]Abramowitz and David (1996) discuss the limitations that arise from weak "social capability."

thus stifling adoption, but also may prevent its effective use—for example, by sharply increasing delivery times (Mann, Eckert, and Knight, 2000).

The implications of the IT revolution for structural policies may run even deeper, to the very foundations underpinning market-based economic systems. The use of IT, and the related reorganization of economic activity, almost inevitably creates new challenges for educational systems as well as legal and institutional arrangements, as illustrated by past technological revolutions. In the United States in the nineteenth century, innovative activity was stimulated by the development of the patent system, especially the growth of intermediaries (agents and lawyers) who specialized in trading patent rights, well before the rise of large-scale businesses and their founding of in-house research and development laboratories (Lamoreaux and Sokoloff, 1999). Similarly, the advent of mass production, the large corporation, and the continent-wide market in the United States in the late nineteenth and early twentieth centuries required not only improvements in production technology, but also legal and institutional changes, including limited liability, investment banking, a common market, and antitrust policy (DeLong, 2001).

Macroeconomic Policies Under Productivity Uncertainty

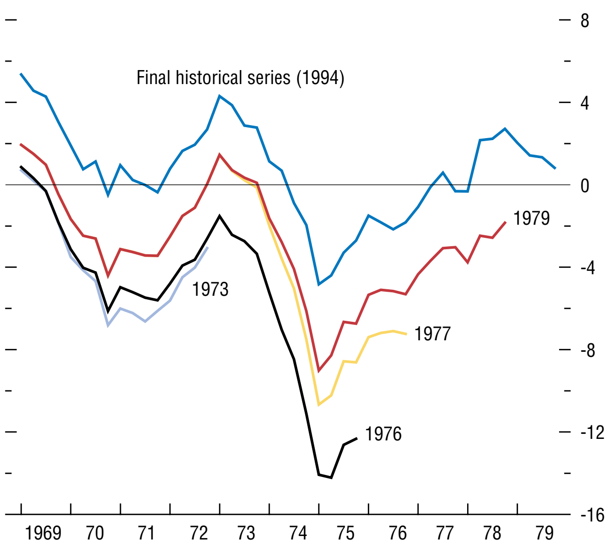
The considerable uncertainty about the precise magnitude and likely duration of the acceleration in underlying productivity has important implications for macroeconomic policies. Specifically, uncertainty about the acceleration complicates the assessment of the sustainability of the external current account position and potential output. With regard to the external current account, economic theory tells us that a country-specific positive productivity shock tends to increase the external current account deficit, by causing investment to rise (reflecting the increased marginal product of capital) and saving to fall (as households anticipate greater future income). While recent empirical work finds some support for this effect in the United States in the late 1990s, the results for other major advanced economies are mixed (Marquez, 2001; see also Glick and Rogoff, 1995). More generally, uncertainty about the current and prospective impact of IT on productivity growth across countries makes it difficult to assess the extent to which global current account imbalances reflect structural or cyclical factors.

The difficulty of correctly assessing potential output at a time of changing productivity growth is well illustrated by the experience of the 1970s. In the United States, real-time official estimates of potential output, which were used by the U.S. Federal Reserve, failed to capture the slowdown in productivity growth that occurred in the early 1970s (see Figure 3.13 and Orphanides, 2000). Partly as a result, monetary policy may have tried to "stabilize" output at too high a level, contributing to rising inflation. More generally, in a situation where productivity growth is uncertain, the costs of maintaining an inappropriate policy stance rise rapidly over time, as discussed in Chapter II of the October 2000 *World Economic Outlook* and also mentioned in Appendix II of Chapter I.

How should macroeconomic policies be formulated with a "broken speedometer?" If the structure of the economy is changing, policymakers should place more weight on recent observations, which reflect these changes, and less weight on the distant past, which does not. Equally, policymakers should focus on observable variables, such as current inflation, rather than on unobservable concepts, such as the output gap, which depend on historical data (see Orphanides, 1998; and Swanson, 2000). In other words, policymakers should "attenuate" their response to less reliable indicators. There is evidence that the U.S. Federal Reserve in the ate 1990s placed less weight on the output gap and the unemployment rate, and more weight on inflation and a wide array of early warning indicators of emerging inflation, including credit conditions, wages, salaries, and other employment costs, profit

Figure 3.13. United States: Evolving Official Estimates of the Output Gap[1]
(Percent of potential GDP)

In the 1970s, policymakers severely underestimated the output gap, resulting in a monetary policy stance that was—in retrospect—too expansionary.



Source: Orphanides (2000).
[1]Except for the final historical series, each line shows the historical series for the output gap based on data available in the first quarter of the year shown. The final historical series is estimated with data available at the end of 1994.

margins, the stock market, and the monetary aggregates.[31]

As with monetary policy, the implication of increased uncertainty about productivity growth for countercyclical fiscal policy is to place more weight on recent observed indicators rather than on historical patterns. With regard to medium-term fiscal objectives, increased uncertainty about productivity growth calls for greater prudence in budget projections, because the political economy of the budget process means that it is easier to spend unexpected windfalls than to make up for unexpected deficits.

Long-Term Effects on Macroeconomic Policies

In the long run, IT may affect fiscal, monetary, and financial policies in fundamental ways. First, IT has the potential to transform the way that governments do their work. Governments can use IT to improve the procurement of goods and services; the quality and delivery of the government services; especially information; and the efficiency with which applications are filed and taxes are paid. However, IT may undermine a government's ability to collect certain taxes, such as sales taxes in the United States, though the associated revenue loss is estimated to be small.[32] In addition, IT may make it more difficult to define a "permanent establishment" for taxing the sale of digital products, like music, photographs, medical and financial advice, and educational services (Tanzi, 2000).

Information technology also has the potential to reduce the demand for bank reserves held at the central bank, which would affect the central

[31]See Meyer (2000) and the minutes of the June 2000 and August 2000 Federal Open Market Committee meetings.

[32]Sales taxes are collected by states. The U.S. Supreme Court has ruled that a state has no jurisdiction to require an out-of-state merchant with no employees or other physical presence in a state to collect the tax. For a more detailed discussion of the law, see U.S. General Accounting Office (2000). Goolsbee (2001) puts the revenue loss at about $612 million (less than 0.01 percent of GDP) in 1999, rising to $6.88 billion (0.06 percent of GDP) in 2004.

bank's ability to conduct monetary policy. At present, central banks have enormous leverage, even though the size of their balance sheet is small in relation to that of the private sector, because base money—especially bank reserves at the central bank—is the medium of final settlement. IT could allow final settlements to be carried out by the private sector without the need for clearing through the central bank. For example, private parties could settle a transaction by transferring wealth from one electronic account to another, with pre-agreed algorithms determining which financial assets were sold by the purchaser and bought by the seller (King, 1999). The key to any such development is the ability of information and communication systems to allow instantaneous verification of creditworthiness, thereby enabling private sector real time gross settlement to occur with finality. While there would be a new need to ensure the integrity of the systems used for settlement purposes, base money would no longer have a unique role and central banks would lose their ability to implement monetary policy. However, the demand for bank reserves at the central bank is likely to remain strong for many years, given their current key role in final settlement (Cecchetti, 2001).

Finally, as the financial services industry adopts IT, the regulation and supervision of financial systems will need to respond. The IT revolution is transforming financial services by changing the speed, scope, and nature of information, computation, and communication. Financial institutions are offering new products, developing new processes, and facing stiffer competition from nonfinancial institutions. Banks' risk management will have to adapt to greater risks in operations (the use of increasingly complex technology by employees who do not fully understand it), counterparty location (the physical or legal location of a financial institution will become more difficult to identify), and systemic risk (from accidents to or sabotage of common software or the Internet) (Turner, forthcoming). In identifying and addressing new challenges, prudential oversight will need to be flexible, stress guidance rather than detailed rules, rely more on improved disclosure requirements, and extend to new providers of financial services.

Conclusion

To date, the IT revolution has largely followed the pattern of past technological revolutions, including an initial phase characterized by a boom and bust in the stock prices of innovating firms, as well as in spending on goods embodying the new technology. The IT revolution is different from past technological revolutions in the globalization of production, which has strengthened real and financial linkages across countries. The rapid growth in the production of IT goods implies that changes in global demand conditions, driven mainly by IT-using advanced economies, have a significant impact on the exports of IT-producing countries. While positive demand shocks helped to boost IT production in 1999 and 2000, the current slump in global IT spending is a heavy drag on these IT-producing countries.

Notwithstanding the adverse impact of the current IT slump on some countries, the economic benefits of the IT revolution are already significant and will likely continue. Thus far, the benefits arise mainly from the fall in the relative prices of semiconductors and computers, and accrue primarily to the users of these products. There is evidence that TFP growth in IT production and IT-related capital deepening have boosted labor productivity growth in some countries, and it is likely that—in the coming years—economic activities in a variety of countries will be increasingly reorganized to take advantage of IT, yielding further benefits. The fall in relative prices of IT goods has also led to significant increases in consumer surplus in IT-using countries. Over the near term, despite the relatively rapid diffusion of the technology around the globe, the IT revolution is likely to benefit advanced economies more than developing countries. In the long run, however, the distribution of the benefits will depend on specific country characteristics rather than relative incomes.

The IT revolution has important policy implications. Structural policies should encourage the widespread adoption and effective use of IT, including by promoting flexible labor markets and efficient service sectors. Uncertainty about the precise magnitude and likely duration of the acceleration in productivity imply that policymakers should place less weight on variables about which uncertainty has increased, such as the output gap, and more weight on observable variables, like actual inflation and a wide array of indicators of future inflation.

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