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Digital Economy 2003

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ECONOMICS AND STATISTICS ADMINISTRATION

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THE SECRETARY OF COMMERCE
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I am pleased to release *Digital Economy 2003* (*DE2003*), the Commerce Department's fifth annual report on the performance of American industries that produce information technology (IT) goods and services, and the effects of IT on U.S. economic strength. This report furthers the Department's mission of providing economic measurement and analysis that supports improved decision-making by policy makers, business people, and the public at large.

America's businesses and workers have a special need today for sound economic information and analysis. With the President's economic policies expanding the public's opportunities for investment, entrepreneurship, and job creation, we need good information to make well-informed business decisions and better economic choices. Moreover, good decisions and a growing economy are particularly important now, when our national security is so closely linked to our continuing economic security and strength.

With the recession well behind us and the recovery gaining strength, we can begin to stand back and assess—more accurately than in the past—IT's role in promoting high performance in the Nation's most dynamic businesses and industries, and rapid and sustained non-inflationary growth in the overall economy. *DE2003* shows that IT-producing industries are once again at the forefront of national economic growth and that, on average, industries and firms that have invested most heavily in IT equipment achieve faster productivity growth than those that do not. In addition, IT seems to be enabling technological advances in other areas—biotechnology, for example—that promise continuing benefits in the years ahead.

DE2003 also shows that along with extraordinary benefits, IT presents an array of new challenges. These include especially the technical and legal challenges of creating conditions for the secure and effective use of IT to expand commerce, enhance business processes, and improve the quality and accessibility of government services. The first step in meeting these challenges, of course, is fully to understand them. *DE2003* is an important step on the way to creating such understanding.

Donald L. Evans

Executive Summary

After two years of retrenchment, IT-producing industries now show signs of resuming the dynamic role they played during 1996–2000.

- Evidence through the third quarter suggests that in 2003 IT-producing industries, which supply about 8 percent of GDP, will contribute about 0.8 percentage points of the estimated 2.9 percent rate of real U.S. economic growth.
- Performance varies by sector. IT service industries, which grew, though at a reduced rate, during 2001–2002, continued to grow at a moderate pace during 2003. Computer and semiconductor manufacturers are rebounding from major losses suffered in 2001–2002, but communications equipment makers show continued weakness.
- IT output is increasingly concentrated in IT services suggesting that future growth in the IT sector may be more modest and less volatile than in the past.

Use of IT continues to be a source of strength in the U.S. economy.

- Investment in and use of IT have played a major role in the recent strong labor productivity growth. From 1989 to 2001, IT-intensive industries experienced average annual labor productivity growth of over 3 percent—much faster than the 1.6 percent pace of the overall non-farm economy.
- Firm- and plant-level research by the Census Bureau's Center for Economic Studies shows that a range of related factors affect IT's role in productivity growth. In addition, the roughly 50 percent of U.S. manufacturing establishments that have computer networks also have higher productivity than manufacturing establishments without networks, even after controlling for many of the plant's economic characteristics in the current and prior periods.
- The use of IT in life sciences R&D exemplifies the dynamic role IT can play in creating new economic opportunities. In bioinformatics (a new field created by the intersection of life sciences R&D with IT-enabled data processing capabilities), IT has expanded R&D horizons by enabling life scientists to acquire, manage, and analyze much larger amounts of and more complicated biological data. This has increased demands on IT producers for more advanced computers and software.

IT employment, which fell sharply during 2001–2002, has been slow to recover.

- Since 2000, the number of workers in IT-producing industries has declined by 11.2 percent (to 4.8 million workers) compared with a decline of less than 2 percent in all private industries. Workers in IT occupations (employed by all industries) totaled 5.9 million in 2002, 8 percent less than in 2000.
- Initially, IT job losses were concentrated in IT manufacturing industries and low-skilled IT occupations. However, the recent job losses have been widespread across almost all IT-goods and services producing industries, and across all IT skill levels.
- In 2002, the average annual wage for workers in IT-producing industries was $67,440, down 1.3 percent from the average of $68,330 for 2001. In contrast, the average annual wage for all private workers increased 1 percent to $36,520. One explanation for this 85 percent wage premium in IT-producing industries is that most IT jobs tend to be high skilled.

U.S. IT producers remain the most competitive in the world.

- In 2002 (the most recent year for which data are available), estimated sales by U.S. IT companies and their overseas affiliates topped $1 trillion, even as the United States experienced a record foreign trade deficit in IT. The United States remains the world's largest exporter of IT goods and services.
- The side-by-side occurrence of world-class U.S. IT-producing companies and the Nation's chronic deficit in IT goods trade appears to be largely a result of the globalization of production and distribution of IT goods and services—especially the tendency of U.S. IT companies to supply foreign and American markets from off-shore production centers, and the increasing incidence of intra-firm IT trade.

Ongoing challenges to U.S. IT producing companies cannot obscure the immense and still growing importance of IT in economic and other dimensions of social life.

- The digital revolution has altered our relationship with information itself. We now expect that any information we need will be easily and almost instantaneously accessible. IT has enabled new channels for interaction—both for individuals and businesses. Many transactions are now conducted online (e-commerce) and firms are improving business processes through increased use of IT (e-business).
- These remarkable developments also create new challenges—especially challenges to the security of individual identity—that have created a need for new security tools.

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AUTHORS

Introduction .... **Sabrina L. Montes**
Information Technologies in the U.S. Economy — sabrina.montes@esa.doc.gov

Chapter I .... **David Henry**
Information Technology Producing Industries—Hopeful Signs in 2003 — david.henry@esa.doc.gov
Donald Dalton
donald.dalton@esa.doc.gov

Chapter II .... **Sandra Cooke**
Information Technology Workers in the Digital Economy — sandra.cooke@esa.doc.gov

Chapter III .... **Dennis Pastore**
International Sales of Information Technology Goods and Services — dennis.pastore@esa.doc.gov
Donald Dalton
donald.dalton@esa.doc.gov

Chapter IV .... **Jesus Dumagan**
Industry-Level Effects of Information Technology Use on Overall Productivity — jesus.dumagan@esa.doc.gov
Gurmukh Gill
gurmukh.gill@esa.doc.gov
Cassandra Ingram
cassandra.ingram@esa.doc.gov

Chapter V .... **B.K. Atrostic**
IT and Economic Performance: Evidence from Micro Data Studies — barbara.kathryn.atrostic@census.gov
Ron Jarmin
ron.s.jarmin@census.gov

Chapter VI .... **Cassandra Ingram**
Information Technology's Role In Life Sciences Research & Development — cassandra.ingram@esa.doc.gov
Gurmukh Gill
gurmukh.gill@esa.doc.gov

Chapter VII .... **Patricia Buckley**
Digital Transformation: Information, Interaction, and Identity — patricia.buckley@esa.doc

Contributing Editors .... **Sabrina L. Montes**
sabrina.montes@esa.doc.gov
Jeffrey Mayer, Director of Policy Development
jeff.mayer@esa.doc.gov

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Formal Reviewers, U.S. Department of Commerce .... **David Beede**
Economics and Statistics Administration
Carol Ann Meares
Technology Administration

Bureau of Economic Analysis, U.S. Department of Commerce .... **Barbara Fraumeni**
Ana Aizcorbe
Maria Borga
Michael Mann
Brian Moyer
Robert Yuskavage

Bureau of Labor Statistics, U.S. Department of Labor .... **Daniel Hecker**

Technology Administration, U.S. Department of Commerce .... **John Sargent**
Carl Shepherd
Karen Laney-Cummings

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Preface

Kathleen B. Cooper, Under Secretary for Economic Affairs

Digital Economy 2003 (DE2003) is the Department's fifth annual report on conditions in U.S information technology (IT) industries and the effects of IT on national economic performance. Each of these reports has addressed questions that economists have sometimes found difficult to answer. Early nineteenth-century economists earned a reputation as practitioners of the "dismal science" by underestimating the ability of technological innovation to drive faster than expected economic growth. This year, the basic analytic challenge has been complicated by an atypical recovery. Productivity growth has been remarkably strong, output growth has gathered impressive momentum, and prices remain low. But employment has lagged. DE2003 examines IT's role in these unusual developments.

Important developments that we anticipated (or hoped for) in our 2002 report have come to pass. Renewed IT investment and strong if selective growth in IT-producing industries have helped the sector reassert its role as an engine of economic growth. In addition, strong productivity growth during and after the 2001 recession has answered the challenge posed four years ago by Robert Solow when he suggested that IT's enduring effects on productivity would be clear only when the economy had weathered its first IT-era recession.

DE2003 shows that: (i) recovery in IT-producing industries and increased use of IT throughout the economy are once again helping to drive very rapid productivity and output growth; (ii) employment growth in IT industries and IT occupations has yet to recover; (iii) highly competitive U.S. IT-producing industries are globally integrated; and (iv) even as we begin to take its presence for granted, IT continues to alter our lives, expanding our choices, and presenting us with new opportunities and challenges. In short, our continuing study shows that the digital era is living up to many of our expectations and hopes. But there is much more to understand about IT's role in our growing and changing economy.

INTRODUCTION:

INFORMATION TECHNOLOGIES IN THE U.S. ECONOMY

By Sabrina L. Montes*

In the late 1990s, the U.S. economy achieved performance levels unseen for a generation. Strong output and productivity growth accompanied low inflation and healthy employment growth. Then and now, economic research has suggested that investment in and use of information technologies (IT) played a role in bringing about that happy macroeconomic situation. Some observers, however, were skeptical of whether the observed changes would endure—and especially whether long-term trends in measures like labor productivity growth have indeed improved. They wanted, for instance, to see how the economy would fare as it moved through a business cycle.

The economy has passed through that test with a shallow, 8-month recession beginning in March 2001. However, the recession and post-recession period have been atypical. During the recession, real gross domestic product (GDP)—buoyed by consumer spending and a strong housing market—did not decline as much as during a typical recession. However, real business investment declined faster and more deeply and the job losses stayed higher longer than during an average recession. The job market has remained stubbornly weak in the post-recession period, and the U.S. economy has endured an extended period of modest output growth that only recently has begun to improve. On the other hand, throughout the recession and the post-recession period, inflation has remained low and labor productivity growth has been strong.

In addition, questions persist about the impact of IT on the U.S. economy. Do the economic forces that were at work during the latter half of the 1990s still resonate in our current economic situation? Three questions, in particular, stand out: What are the prospects for IT producers? How are IT workers faring in the current slack job market? And, do investment in and use of IT

* Ms. Montes (sabrina.montes@esa.doc.gov) is an economic policy analyst in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

still play a commanding role in U.S. economic activity? The desire to illuminate these questions underlies this report.

IT Producers

Since the mid-1990s, the IT-producing sector has been vital to U.S. output growth. On average, between 1996 and 2000, IT producing industries, which represented between 8 and 9 percent of the economy, supplied an average annual 1.4 percentage points to the nation's 4–5 percent real annual output growth. We estimate IT producers' contribution to economic growth dropped to 0.1 percentage point of the estimated 2.3 percent growth rate in 2002. However, IT producers' contribution to economic growth revived in 2003, as growth in both the overall economy and in parts of the IT producing sector, improved. In 2003, IT producers contributed 0.8 percentage point to the estimated 2.9 percent growth rate. (Chapter 1.)

Since 2000, however, some IT producers have been struggling. IT manufacturing nominal output reached a peak in 2000. It began declining prior to the recession and has continued to decline through most of the post-recession period. Growth slowed dramatically in IT services industries—but did not actually decline.

The situation for IT-producing industries also differed by market segment. The consumer market did not slow significantly, reflecting strong consumer spending throughout the recession and post-recession period. Indeed, while many firms in today's IT sector continue to struggle, corporate sales and profit reports suggest that companies selling consumer-oriented technologies are seeing strong sales and earnings growth.[1]

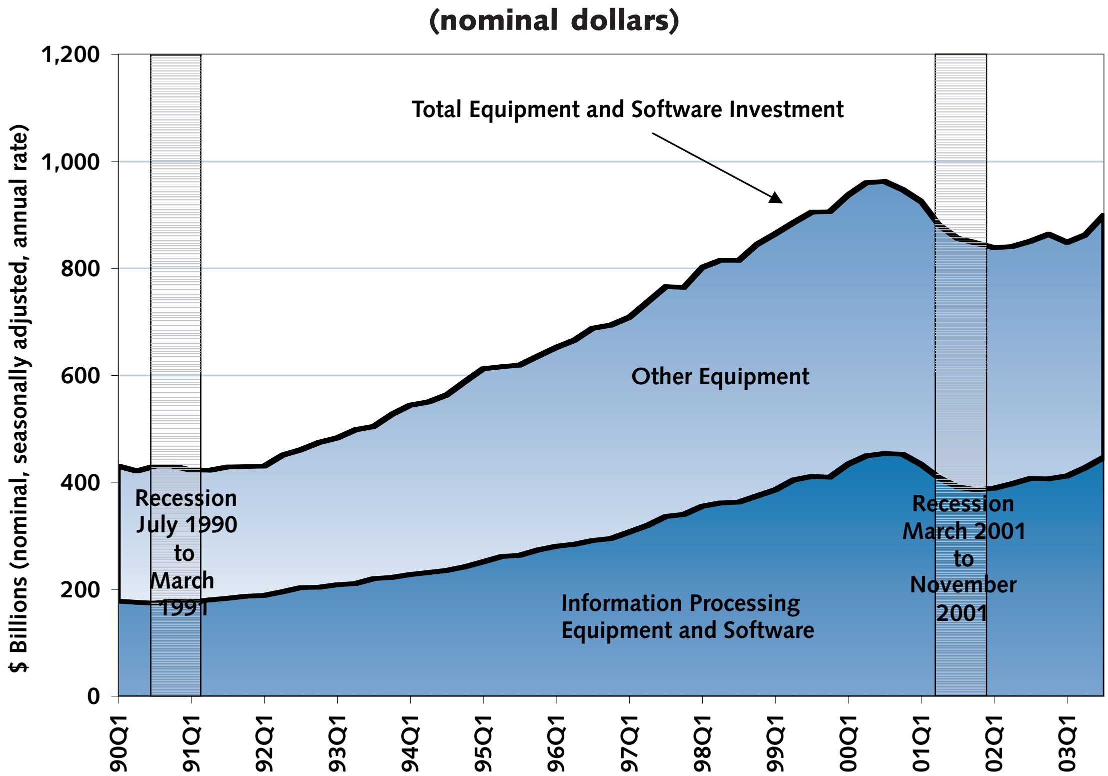
The business market segment fared much worse. Products produced by IT firms make up a large and growing share of total business investment in equipment and software. While overall investment spending is still high relative to historic levels, spending has dropped off since 2000 and has only recently begun to recover. (Figure 1.)

Although current growth rates of business investment rival those that occurred during the latter half of the 1990s, it may take a while to see the levels reached during that period. Arguably, there were a number of one-time only factors driving investment during those years. For example, the investment associated with the year 2000 conversion, the initial build out of the Internet, and a post-deregulation surge in telecommunications spending will not occur again. On the other hand, it is impossible to foresee future events that might have the same positive effect on business IT spending.

Some observers have suggested that the high levels of overall business investment at the end of the 1990s and into 2000 reflect some over-investment in IT, or even an IT investment bubble. This resulted from the stock market bubble, which reduced the cost of capital to firms, and the initial exuberance associated with the Internet and dot.com companies, which encouraged

[1] Ken Belson, "Consumer Electronics Surge Ahead of Office Computers," *New York Times*, 1 Aug. 2003.

Figure 1. Private Fixed Investment in Equipment and Software



Source: Bureau of Economic Analysis, National Income and Product Accounts, Table 5.4.

IT (Information processing equipment and software) represents a large (40–45 percent) and stable share (in nominal dollars) of business spending on equipment and software. Since IT equipment has seen rapid price declines relative to other equipment, IT's contribution to real business investment has grown. Overall investment spending—and consequently IT spending—peaked in 2000 and has only recently begun to recover.

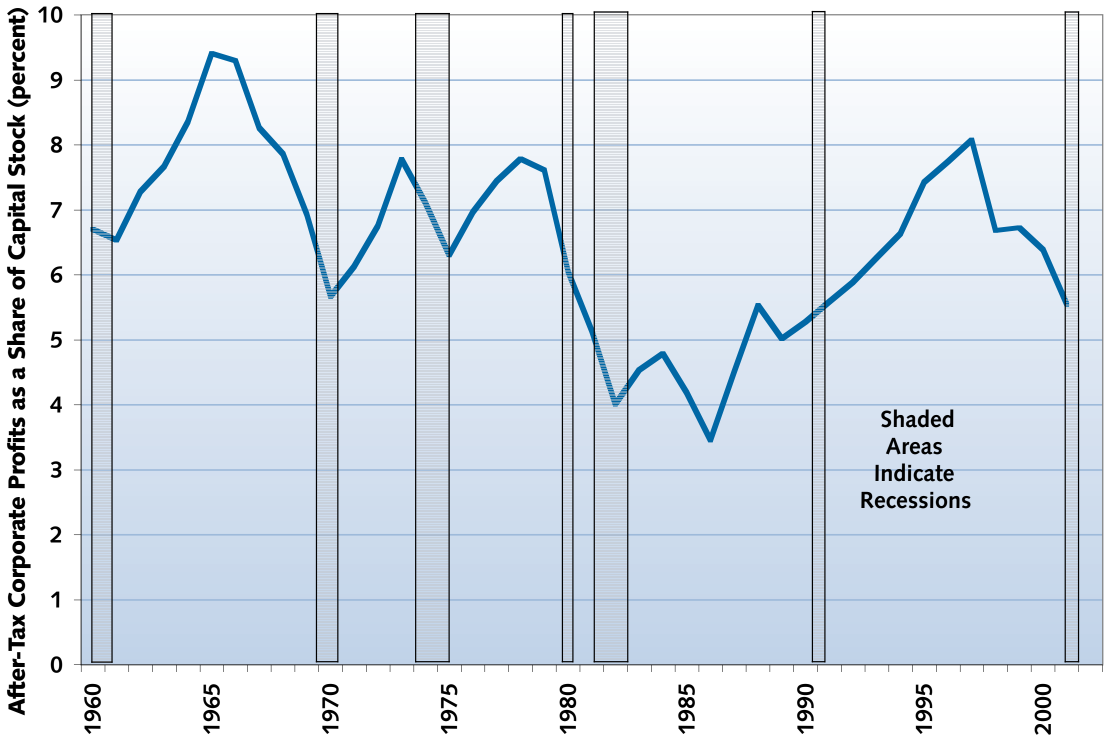
investment in IT.[2] Such over-investment, if it indeed occurred, would foreshadow a longer recovery period for IT producers because businesses would need to work off the IT investment overhang before renewing IT investments.

Evidence of over-investment is mixed. For example, one would expect falling profits to accompany over-investment or an investment bubble because such retrospectively unwise investments would not earn returns at the same rate as more rational investments.

In fact, the profit data are ambiguous. After-tax returns to capital—a basic measure of profits peaked in 1997 at 8.1 percent and fell to 5.5 percent in 2001, which is consistent with some over-investment. However, the levels of after-tax return to profits are still higher than the level that prevailed during the mid-1980s. (Figure 2.) This overall increase is consistent with capital

[2] Kevin J. Lansing, "Growth in the Post-Bubble Economy," *Federal Reserve of San Francisco Economic Letter* 2003-17 (2003) (http://www.frbsf.org/publications/economics/letter/index.html).

Figure 2. After-Tax Return to Capital



Source: Bureau of Economic Analysis

After-tax return to capital—the ratio of after-tax corporate profits to the value of the corporate capital stock (current cost)—achieved a local peak of 8.1 percent in 1997. The measure has since declined. Levels remain higher than during the mid-1980s.

becoming more efficient (for example via technological change), and more profitable—i.e., consistent with the conclusion that IT investments in the 1997–2001 period were not excessive.

Declining IT investment and retrenchment among IT-producers were among the reasons for IT-related job losses throughout the economy. (Chapter 2.) In the IT producing sector itself, the number of jobs fell by 10.7 percent during 2002. Preliminary 2003 data suggest no improvement.

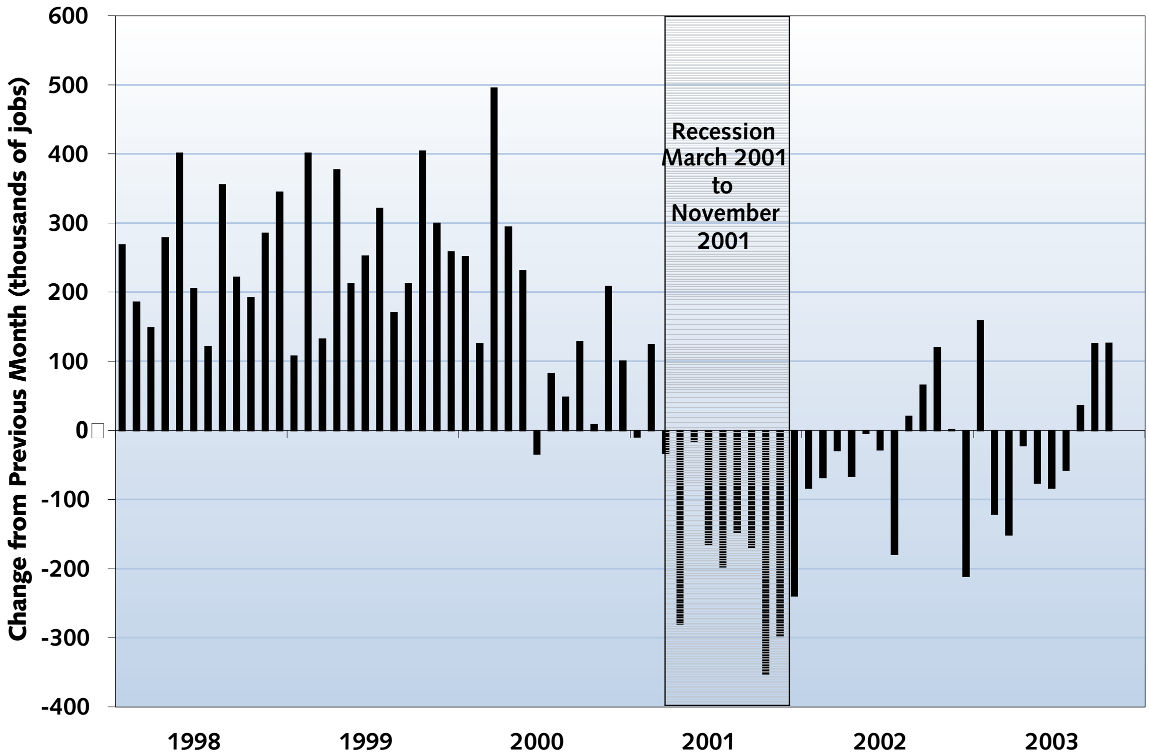
The Employment Situation

Job losses in the IT-producing sector are part of a larger picture of job losses and slow employment growth economy-wide that has been the conundrum of the post-recession period. (Figure 3.)

The current employment situation is complex. First, there is always churn in employment. Layoffs in one industry are often offset by new hires in another, and there are always people looking for work and firms seeking workers. Employment in the bioinformatics field is a case in point. (Chapter 6.) Even in the current, relatively slack job market, firms in this field—which merges IT capabilities with life science research and development—continue to seek workers.

Figure 3. Non-farm Payroll Employment

Change from previous month in thousands



Source: Bureau of Labor Statistics, Employment Situation, Table B.

Since the 2001 recession, U.S. workers have experienced a slack job market for an extended period. The employment picture has only recently begun to improve.

Second, there is some evidence that structural changes in employment may be occurring in the U.S. economy. A recent study by the Federal Reserve Bank of New York suggests that, during this recession and post-recession period, there have been permanent shifts in employment among various industries.[3] Research presented in Chapter 4 suggests some possibility of IT-driven structural changes. Among industries that invest intensively in IT, employees in management and office administrative support occupations appear to account for most of the 2001 employment losses. Anecdotal evidence has long suggested that occupations such as these are vulnerable to elimination when routine tasks are automated. In addition, this and previous *Digital Economy* reports have found evidence that, in a number of occupations, the use of IT is associated with demand for workers with higher skill levels.

Third, some businesses have moved certain operations overseas. The practice, called offshoring, has long been associated with manufacturing firms. Anecdotal evidence now suggests that

[3] Erica L. Groshen and Simon Potter, "Has Structural Changes Contributed to a Jobless Recovery?," *Current Issues in Economics and Finance*, Federal Reserve Bank of New York, 9–8 (2003) (http://www.newyorkfed.org/research/current_issues/ci9-8.html).

cheaper communications costs and increasing IT skills abroad enable the offshoring of some services. Many U.S. call centers, for example, are now located in countries like India that have a highly skilled, English-speaking labor pool. Although there are widely ranging private estimates of this phenomenon, hard statistical evidence is lacking.

U.S. foreign direct investment, which produces jobs in other countries, is part of a larger pattern of globalization. (Chapter 3.) The IT-producing sector, for example, is composed of firms that operate globally. The sector depends on a network of foreign affiliates to meet demand in both U.S. and foreign markets. It is clearly a vital and usually vibrant sector of the U.S. economy, yet it runs a large and increasing trade deficit.

Labor Productivity Growth and Firm Performance

A recent Bureau of Labor Statistics report indicates that overall layoffs peaked during 2001 and have since decreased. The current employment situation stems largely from slow job creation.[4] Businesses are simply not hiring. One factor in businesses' ability to delay hiring and simultaneously increase output is the continued strong growth of labor productivity.

Labor productivity is the amount of output produced by the labor force in a period of time (e.g., one widget per worker per hour). For example, the labor productivity growth rate measures the increase in output achieved using the same number of workers over time (or a stable output achieved using fewer workers). The trend rate of labor productivity growth is also a key long-run measure of the improvement in people's standards of living.

Around 1995, the labor productivity growth rate accelerated (see Chapter 4, Figure 4.1). Economists are keenly interested in determining what caused this acceleration and whether this new, faster rate of labor productivity growth is sustainable. Insights into these questions are emerging as the research has expanded.

A growing body of evidence suggests that investment in and use of IT have played a role in the recent, strong labor productivity growth. Analysis in Chapter 4 shows that U.S. industries that have invested relatively more in IT equipment contribute more to productivity growth than those that are less IT-intensive in their investments.

In addition, since the mid-1990s, popular consensus has held that businesses that invest in IT are more productive and perform better than businesses that do not invest in IT. Economists, however, have argued that simply purchasing IT will not necessarily yield benefits; additional investments, such as the reorganization of workflow and re-training the labor force are also necessary.

To understand more clearly the role of IT in this phenomenon, we need a clearer understanding

[4] U.S. Department of Labor, Bureau of Labor Statistics, *New Quarterly Data on Business Employment Dynamics from BLS* (Washington, DC, 30 Sept. 2003) (http://www.bls.gov/news.release/cewbd.toc.htm).

of how IT is being used within businesses. New micro-level research indicates that IT investments do contribute positively to firm performance in many, but not all, settings. They do so, however, in tandem with many other factors, such as firm ownership structure, management practices, worker training, and willingness to innovate. (Chapter 5.)

IT Continues to Transform the Economy

The lingering questions about long-term economic change and the difficulties that the IT-producing sector has faced since 2000 should not be confused with a decline in the importance of IT in the economy *today*. IT producers invest intensively in research and development (Chapter 1) and those investments have yielded dramatic advances in data processing, storage, and transmission capabilities. These IT-related innovations have and are diffusing through the U.S. economy in computers, communications equipment, software, and other products. Use of these technologies is transforming many aspects of our economy, our society, and our day-to-day lives.

Many of today's most important life sciences discoveries, such as the mapping of the human genome, can be traced back to the use of computers to process enormous quantities of data. The intersection of traditional life sciences with IT-enabled data processing capabilities has, in fact, spawned new fields, such as bioinformatics. This field is notable for the increasing number of collaborations between life science and IT researchers that seek to advance the frontier of IT capabilities in the interest of advancing life sciences research and development. (Chapter 6.)

Even in fields less closely wedded to IT capabilities, IT is widely used. For example, many businesses rely on IT equipment to support a substantial share of their transactions. In 2001, e-commerce shipments accounted for $725 billion or 18.3 percent of manufacturers' shipments (i.e., the businesses relied on computer networks for the exchange of shipping and purchasing data). Similarly, in 2001, e-commerce sales represented 10 percent of sales by merchant wholesalers.[5]

Individuals rely on these technologies as well. Over 60 percent of the U.S. population uses computers and over 50 percent of the U.S. population uses the Internet at home, work, or both.[6]

Like any new technology, the capabilities made possible by IT are accompanied by challenges that must be resolved in order to fully realize its benefits. (Chapter 7.) As individuals, we are now able to access a vast amount of data. However, many issues remain with regard to searching, archiving, and controlling or limiting access to certain information. New management challenges accompany new means of interaction, such as e-commerce and e-business processes (e.g., business-to-business data exchange). And, finally, issues related to identity—from identity theft to privacy and rights to anonymity—intersect with almost all IT capabilities.

[5] U.S. Bureau of the Census, *E-commerce 2001 Highlights*, 19 March 2003 (http://www.census.gov/eos/www/papers/2001/2001estatstext.pdf).

[6] U.S. Department of Commerce, *A Nation Online, How Americans Are Expanding Their Use of the Internet*, Feb. 2002 (http://www.ntia.doc.gov/ntiahome/dn/index.html).

CHAPTER I:

INFORMATION TECHNOLOGY PRODUCING INDUSTRIES—HOPEFUL SIGNS IN 2003

By David Henry and Donald Dalton*

After two years of retrenchment, IT-producing industries (Box 1.1.[1]) now show signs of resuming the dynamic role they played during 1996–2000. Based on evidence through the third quarter of 2003, we estimate that, during 2003, IT-producing industries, which account for about 8 percent of U.S. GDP, contributed 0.8 percentage points of the estimated 2.9 percent rate of real U.S. economic growth. (Table 1.1.)

Published data on recent spending for IT goods and services, and our estimates of IT production for 2002 and 2003 indicate: (1) while computer and semiconductor manufacturers have begun to rebound from major output losses suffered in 2001–2002, communications equipment makers show continued weakness; (2) IT service industries, which grew faster than IT manufacturing industries during 1996–2000, continued to grow during the economic slowdown of 2001–2002 though at a reduced rate, and contributed to the mildness of the recession; and (3), in 2003, IT producing industries became once again an important ingredient in an overall U.S. economic expansion. [2]

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* Mr. Henry (david.henry@esa.doc.gov) is a senior industry analyst and Mr. Dalton (donald.dalton@esa.doc.gov) is an economist in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

[1] The industries listed in Text Box 1, above, are classified under the 1997 North American Industry Classification System (NAICS). Production data do not yet exist based on the 2002 version of the NAICS.

[2] Estimates of IT industry output (GDP by industry) for 2002 and 2003 are based on quarterly National Income and Product Accounts data and monthly production indicators through the first nine months of 2003. The Bureau of Economic Analysis (BEA) publishes quarterly data on types of spending by businesses, consumers, and governments (Federal, state, and local) on IT equipment, software, and communication services. The Census Bureau publishes monthly shipments, new orders and changes in inventories for computers, semiconductors, and communications equipment. Annual industry data for 2003 will become available in 2005. Likewise, industry data from the Census Bureau's economic (business) census for 2002 will become available in 2004. (See the *Digital Economy 2003 Technical Appendices* (http://www.esa.doc.gov/reports.cfm) for the method used to estimate IT producing industry output in 2002 and 2003.)

Table 1.1. IT Producing Industries' Contribution to Real Economic Growth

Actual and Estimated

	1997	1998	1999	2000	2001	2002*	2003*
				(Percent)			
(1) Changes in Real Gross Domestic Product[3]	4.5	5.0	4.2	4.7	0.1**	2.3	2.9
				(Percentage Points)			
(2) IT Contribution	1.5	1.6	1.5	1.1	0.1	0.1	0.8
(3) All Other Industries	3.0	3.4	2.7	3.6	0.0	2.2	2.1

Notes: *Estimates based on Census and BEA data.

** The table attributes the entire 0.1 percent change in GDP in 2001 to IT industries because numbers have been rounded to the nearest tenth. In 2001, if we round to the nearest hundredth, the IT share of GDP change is 72 percent. Estimates for other years are not affected. See the Digital Economy 2003 Technical Appendices for additional information.

Box 1.1. Information Technology Producing Industries

Hardware Industries

Computers and equipment
Wholesale trade of computers and equipment*
Retail trade of computers and equipment*
Calculating and office machines
Magnetic and optical recording media
Electron tubes
Printed circuit boards
Semiconductors
Passive electronic components
Industrial instruments for measurement
Instruments for measuring electricity
Laboratory analytical instruments

Communications Equipment Industries

Household audio and video equipment
Telephone and telegraph equipment
Radio and TV communications equipment

Software/Services Industries

Computer programming
Prepackaged software
Wholesale trade of software*
Retail trade of software*
Computer-integrated system design
Computer processing, data preparation
Information retrieval services
Computer services management
Computer rental and leasing
Computer maintenance and repair
Computer related services, nec

Communications Services Industries

Telephone and telegraph communications
Cable and other TV services

*Wholesale and retail from computer manufacturer sales from branch offices. See the *Digital Economy 2003 Technical Appendices* (http://www.esa.doc.gov/reports.cfm).

[3] Gross domestic product is estimated by gross domestic income; see "Gross Domestic Product by Industry for 1999–2001," *Survey of Current Business* (November 22, 2002), p. 23, Box.

The following sections examine: the growth and recomposition of output of IT industries; recent indicators of increasing demand for IT goods and services (i.e., investment patterns and manufacturers' shipments, new orders and inventories); IT industries' contributions to output growth; and IT industries' contribution to U.S. research and development spending.

IT Producing Industries Weather the Recession and Recover Slowly

On average, between 1996 and 2000, IT producing industries, which represented between 8 and 9 percent of the economy,[4] supplied 1.4 percentage points of the Nation's 4.6 percent annual average real GDP growth.[5] In 2001, IT-producing industries grew a scant 0.9 percent, though in a recession year that was still enough to account for practically all of the Nation's 0.3 percent economic growth. Overall, continued strength in IT producing industries, particularly communications services, helped to keep the recession comparatively mild.

In 2002, the U.S. economy gathered momentum, growing at over 2 percent. Unlike the 1996–2000 period, however, developments in IT producing industries were not a driving force. Losses in these industries, which had begun in 2001, accelerated in 2002; in the sector as a whole, revenues declined almost as rapidly in these two years as they had increased in the prior four. The poor showing was due largely to the slow recovery of business spending for capital equipment. Unlike the investment-led expansion of 1996–2000, growth in 2002 was driven mainly by increases in personal consumption, changes in private inventories, and government spending. Almost none of the real growth of the U.S. economy in 2002 reflected output growth from the IT-producing industries.

Happily, the investment picture has begun to change. Recent evidence indicates that businesses are once again investing in IT capital equipment. However, the pattern of recovery in 2003 contrasts with experience in 1996–2000. In the goods producing sector, renewed strength is concentrated in computers and semiconductors; while shipments of communications equipment have continued to decline. (These trends are detailed below in the section on IT manufacturers' shipments, new orders, and inventories and in Table 1.3.)

The services and software component of the IT-producing sector—which continued to grow during the economic slowdown of 2001 and the slowly developing recovery of 2002—continued to grow as well in 2003. But because IT service industries weathered the recession and its aftermath without sharply declining output, they are unlikely to rebound to the double-digit growth rates achieved during 1997–2000 as the current recovery gains strength. (A possible exception is the communications services industry, which appeared to grow at about the same rate in 2003 as it did during 1997–2000.)

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[4] See Table A-1.2. *Digital Economy 2003 Technical Appendices* (http://www.esa.doc.gov/reports.cfm).

[5] Gross Domestic Income (GDI) is used in this calculation in place of GDP since we use GDP by industry as a measure of the industries' outputs. The sum of all industries' GDP by industry is equal to GDI. GDI and GDP should theoretically be the same, but are not because of some statistical discrepancies.

As a consequence of continued, if slower growth in IT service industries, and the period of negative growth in IT goods industries, the composition of IT-producing industry output has become significantly more concentrated in services. In 1996, IT software and computer services and communications services represented about 59 percent of the total output (nominal dollars) of IT-producing industries. We estimate that in 2003, the output share of software and IT services industries increased to 71 percent.

The shift toward services in the composition of IT output suggests that future growth in the IT sector may be more modest and less volatile than in the past. We estimate that, between 2001 and 2003, the output of the IT Software and Computer services sector, on average, increased by 1.3 percent per year. The IT Communications services sector increased, on average, 4.8 percent per year. In contrast, output growth in the IT Hardware and IT Communications equipment sectors fluctuated between double-digit declines and single-digit increases.

Our estimates of IT-producing industries' 2003 output are based on available first-, second-, and third-quarter data on demand for IT goods and services, and industry production indicators through the first nine months of the year. This section of the chapter and the one that follows look at available demand data and production indicators. A third section uses these data and indices to estimate the performance of IT producing industries for the year as a whole.

Demand for IT Goods and Services Through the Third Quarter of 2003

Business spending for equipment and software represents the largest source of demand for the hardware and communication equipment portion of the IT-producing sector. In the third quarter of 2003, businesses were buying IT equipment and software (information processing (IP) in Table 1.2) at a $446 billion annual rate (seasonally adjusted), with IT spending accounting for half of all business investment in new equipment. In the second quarter, business investment in IT equipment and software contributed about 21 percent of the overall 3.3 percent real GDP growth and in the third quarter contributed 10 percent of the 8.2 percent GDP growth. In contrast, during 2002 as a whole, business spending for IT equipment and software contributed only 4 percent of the total 2.4 percent increase in GDP.

Reversing declines in 2001–2002, business spending for IT equipment and software rose through the third quarter of 2003 by a quarterly average of 2.3 percent. (Table 1.2.) Spending in the second quarter was up 3.7 percent over the previous quarter and 4.5 percent in the third quarter. In the third quarter of 2003, spending on computers and equipment rose 7.3 percent following an 8.0 percent increase in the second quarter. Business spending for software rose over 2 percent in the second and 4 percent in the third quarter. In addition, following a 14 percent decline in 2001 and a 5 percent decline in 2002, spending for other IT equipment rose over 3 percent for each of the three quarters of 2003.

Table 1.2. Private Fixed Investment

2001 and 2002 Annual Growth Rates
and 2003-I, 2003-II, and 2003-III Quarterly Growth Rates* (percent)

	2001	2002	2003-1*	2003-II*	2003-III*
Private Fixed Investment	–2.7	–3.5	0.4	1.5	4.1
Nonresidential structures and equipment	–5.1	–7.0	–1.2	1.4	3.4
Nonresidential structures	3.3	–17.0	0.3	0.9	0.5
Nonresidential equipment and software	–7.8	–3.3	–1.7	1.5	4.2
Information processing (IP) equipment and software	–9.5	–1.1	1.4	3.7	4.5
Computers and peripheral equipment	–20.5	0.0	1.2	8.0	7.3
Software	0.6	1.3	0.2	2.1	4.0
Other IP equipment and software	–14.0	–4.7	3.0	3.4	3.5
Industrial equipment	–3.6	–4.3	–1.1	–0.1	1.5
Transportation equipment	–12.6	–10.2	–10.4	–2.6	4.2
Other equipment	–1.4	–0.4	–1.6	–1.1	6.3
Residential	4.4	6.1	4.3	1.7	5.7

Note: *Current quarter over previous quarter, billions of current dollars, seasonally adjusted at annual rates.

Source: BEA, Table 5.4, Private Fixed Investment by Type.

While business investment is the major source of IT demand, the market for IT goods and services is broad and varied. Non-investment sources of demand for IT goods and services include businesses' purchase of IT goods and services (e.g., computer and communications services), personal consumption, and government spending:

- In 2002, in addition to investing in IT equipment and software, businesses spent approximately $270 billion on communications services, up from $258 billion in 2001.[6] For accounting purposes, these expenditures are considered current expenses (i.e., costs of production) rather than investment spending. Nonetheless, business spending on communications services constitutes the second most important market for IT-producing industries (after business investment).

- Personal consumption provides a second and growing (non-investment) market for IT goods and services. In the second quarter of 2003, personal consumption of IT goods and services almost certainly continued to rise.[7] In the second quarter of 2003, personal consumption in

[6] We have not provided estimates of business spending for communications through the first half of 2003 since we have no current data available to make these estimates. This spending is, however, incorporated into our overall estimate of IT producing industry output for 2003. Business spending estimates for 2001 and 2002 are provided here to give the magnitude and direction of this type of spending in the previous two years. See the *Digital Economy 2003 Technical Appendices* (http://www.esa.doc.gov/reports.cfm).

[7] Table 2.2, Personal Consumption Expenditures by Major Type of Product and Table 2.6, Personal Consumption Expenditures by Type of Product, Bureau of Economic Analysis, http://www.bea.gov, interactive tables.

the category of durable goods that includes computers, computer peripherals and software (furniture and household equipment) rose by 7.4 percent. In the third quarter, consumption in this category of durables rose another 2.7 percent. In 2001, the latest year for which data are available, personal consumption of computers, computer peripherals and software was $32.9 billion representing about 11 percent of furniture and household equipment purchases.

- Through the third quarter of 2003, personal consumption of communications services, almost certainly continued to rise. In the second quarter of 2003, consumption in the non-energy category of personal spending on household operation (i.e., the category of personal spending that includes telephone service) increased by 0.3 percent. In the third quarter, it rose another 0.7 percent. In 2001, consumer spending for communications was $136.5 billion, about 54 percent of the non-energy portion of spending for household operation.

- Through the third quarter of 2003, growth in government spending for equipment, which includes IT equipment and software has remained positive.[8] Federal spending (defense and non-defense) for IT equipment and software during the period was about $14.8 billion; state and local government spending was about $8.3 billion.[9]

IT Manufacturers' Shipments, New Orders, and Inventories Show Positive Trends Through August

Production indicators for the first nine months of 2003 support the view that IT-producing industries are gaining strength. (Table 1.3.) Though manufacturers' shipments and new orders for communications equipment remained depressed, reports on shipments for the computer and semiconductor industries were generally positive. Shipments of computers, for the first nine months of 2003, were 14 percent higher than in the same period in 2002. Shipments of semiconductors were 22 percent higher. In contrast, over the same period, shipments of communication equipment dropped 9 percent. New orders for computers and communication equipment were up—by 7 percent and 8 percent, respectively.

Through September, manufacturers' inventories of computers and communication equipment continued to decline (by 11 percent and 23 percent, respectively). Inventories of computers appear to have reached a balance indicating that new production will be necessary to meet demand. However, inventories for communications equipment continue to decline, and it is unclear clear how long manufacturers will continue to rely on existing stocks.

[8] Table 3.7, Government Consumption Expenditures and Gross Investment By Type, Bureau of Economic Analysis, http://www.bea.gov, interactive tables.

[9] We made no estimates of government purchases of communications equipment, computer services, and communications services.

Table 1.3. Shipments, New Orders, and Total Inventories for Computers, Communications Equipment and Semiconductors, 2003

(Percent)*

	Month to Month 2003			
	August-September	July-August	June-July	January-September, (2003/2002)
Computer and related products				
Shipments	–1.3	5.6	25.1	13.9
New Orders	–3.2	8.3	9.2	7.0
Total Inventories	1.3	2.9	–6.7	–10.8
Communications equipment (non-defense)				
Shipments	–1.2	–0.8	–1.8	–8.9
New Orders	5.2	1.7	13.4	8.1
Total Inventories	0.0	–2.3	–1.9	–22.9
Semiconductors				
Shipments	–8.2	19.9	–12.8	22.3
New Orders	n.a.	n.a.	n.a.	n.a
Total Inventories	n.a.	n.a.	n.a.	n.a.

Note: *Based on current dollars, seasonally adjusted.

Source: Bureau of the Census, Manufacturer's Shipments, Orders, and Inventories (M3)

IT Producing Industry Performance in 2003

Based on assumptions and methods described in the *Digital Economy 2003 Technical Appendices* (http://www.esa.doc.gov/reports.cfm), we estimate that, after a decline of 5.6 percent in 2001 and 0.3 percent growth in 2002, output[10] in IT producing industries increased by 4.8 percent in 2003, *in nominal dollars*.[11] (Table 1.4) Our overall estimate for the year assumes a continuation of the recent turnaround in IT-producing manufacturing industries and continued slow but steady growth in IT-producing service industries.

We estimate that, in 2003, IT hardware industries (computers, semiconductors, electronic components, and electronic measuring instruments) increased their output by 9.8 percent. In addition, after steep declines in 2001 and 2002, output of communications equipment declined by 5.6 percent, a slowdown in the decline in the previous years.

[10] GDP by industry equals an industry's total output less the cost of goods and services used to produce it. Basically, GDP by industry is used here as a measure of the industry's performance because it can be compared directly to the growth of the economy, as measured by its Gross Domestic Income (GDI). GDI is the income side measurement of the economy while Gross Domestic Product (GDP) is expenditures. In theory, GDI should equal GDP. In practice, they do not because of some accounting differences.

[11] Estimates of GDP by industry and GDP by industry growth for each IT producing industry that make up the aggregate industries—Hardware, Software and computer services, Communications equipment, and Communications services—are provided in Tables A-1.2 and A-1.3, *Digital Economy 2003 Technical Appendices* (http://www.esa.doc.gov/reports.cfm).

Table 1.4. IT-Producing Industries Gross Domestic Product (GDP) by Sector

Actual and Estimated

	1996	1997	1998	1999	2000	2001	2002*	2003*
			Billions of Current Dollars					
Total	589.0	666.1	739.5	821.7	877.8	828.9	831.6	871.9
Hardware	201.1	231.6	242.2	252.2	244.1	189.6	189.3	208.0
Software and Services	166.3	193.6	238.0	278.3	316.6	320.3	323.7	328.8
Communications Equipment	39.0	52.7	53.2	60.6	67.3	54.9	46.6	43.5
Communications Services	182.6	188.2	206.1	230.6	249.8	264.3	272.1	291.6
			Annual Change-Percent					
Total	n.a.	13.1	11.0	11.1	6.8	–5.6	0.3	4.8
Hardware	n.a.	15.2	4.6	4.1	–3.2	–22.4	–0.2	9.8
Software and Services	n.a.	16.4	22.9	16.9	13.8	1.2	1.0	1.6
Communications Equipment	n.a.	35.1	0.8	14.0	10.9	–18.4	–15.1	–5.6
Communications Services	n.a.	3.1	9.5	11.9	8.3	5.8	3.0	7.2

Source: Estimates are derived from BEA and Census data for 1996 through 2001.

*Estimates for 2002 are based on BEA data on GDP and the INFORUM LIFT model to estimate outputs. Estimates for 2003 are based on the Global Insights' economic forecast.

Output from the IT-producing services sectors continued to grow in 2003, though at a pace that was significantly slower than the double-digit growth of the latter 1990s. Our overall estimate reflects industry-level estimates of 1.6 percent growth in software and computer services and 7.2 percent growth in communications services.

Adjusting output estimates for inflation results in a similar picture of modest improvement. (Table 1.5.) Prices of computers fell by about 24 percent per year, from 1997 through 2000, then 16 percent through 2002. Semiconductor prices fell an average 15 percent per year during 1997–2000, followed by an average 9 percent reduction through 2002. For the purpose of estimating real output in 2003, we have assumed that computer and semiconductor prices declined throughout 2003 at the 2002 rate (16 percent and 9 percent, respectively). Reflecting these continuing price declines, in 2003, *real* growth in the IT hardware sector increased sharply.[12]

The average inflation-adjusted annual growth for IT producing industries between 1997 and 1999 was about 20 percent. In 2000, growth dropped to 13 percent. And in 2001 and 2002, despite the continued decline in prices in hardware, there was virtually no real growth in output. In 2003, however, reversing this trend, real growth in IT producing industries was about 6 percent.

[12] For BEA's use of hedonic price indexes, see "*A Note on the Impact of Hedonics and Computers on Real GDP*" by Steven Landefeld and Bruce Grimm, Survey of Current Business, December 2000, pgs. 17 to 22 and "*Measuring the New Economy*" by Steven Landefeld and Barbara Fraumeni, Survey of Current Business, March 2001, pgs. 23–40.

Table 1.5. IT-Producing Industries Inflation Adjusted Output

Actual and Estimated

	1996	1997	1998	1999	2000	2001	2002*	2003*
				Billions of Chained (1996) Dollars				
Total	589.0	706.4	849.0	1,012.0	1,138.4	1,149.1	1,167.3	1,241.5
Hardware	201.1	275.5	364.1	464.5	524.5	485.6	527.7	665.4
Software and Services	166.3	192.7	236.1	271.1	300.2	302.5	301.7	306.3
Communications Equipment	39.0	53.3	56.0	66.3	76.2	64.1	52.4	48.9
Communications Services	182.6	187.8	204.0	235.7	267.7	304.0	313.7	318.7
				Annual Change-Percent				
Total	n.a.	19.9	20.2	19.2	12.5	0.9	1.6	6.4
Hardware	n.a.	37.0	32.2	27.6	12.9	–7.4	8.7	26.0
Software and Services	n.a.	15.9	22.5	14.8	10.7	0.8	–0.3	1.5
Communications Equipment	n.a.	36.6	5.2	18.3	14.9	–15.9	–18.3	–6.7
Communications Services	n.a.	2.8	8.7	15.5	13.6	13.5	3.2	1.6

Source: Estimates are derived from BEA and Census data for 1996 through 2001.

*Estimates for 2002 are based on BEA data on GDP and the INFORUM LIFT model to estimate outputs. Estimates for 2003 are based on the Global Insights' economic forecast.

IT Research and Development Expenditures Remain Strong

The rapid pace of technological change in IT producing industries, particularly IT hardware industries, drives a high rate of spending on investment in research and development (R&D) in these industries. The sector uses more R&D inputs than other areas of the economy and its R&D intensity (i.e., R&D spending divided by industry sales) is three times the national average. Recent growth patterns in R&D investment by the IT sector are influenced by the transition to digital technology in several large markets: television, photography, and motion picture reproduction (DVD).

IT companies accounted for a disproportionate share of company-funded R&D (31 percent), relative to the sector's small share of the economy. Moreover, R&D investment has funded innovations that contributed to the rapid decline in the price indexes for computers and semiconductors. R&D spending by the IT sector has contributed to economic growth—through R&D's role in technological change[13]—and created spillovers to local communities by creating high paid jobs for 300,000 scientists and engineers in all IT industries.

In contrast to the cyclical swings in IT industry production and employment, IT industry investment in R&D has shown greater stability. Strong growth in R&D spending by the IT

[13] A brief survey of the literature on technological change and growth is discussed in Subodh Kumar and R. Robert Russell. "Technological Change, Technological Catch-up, and Capital Deepening: Relative Contributions to Growth and Convergence." *American Economic Review*, June 2002.

Table 1.6. R&D Expenditures, Company-funded

$ billions

Industry	1997	1998	1999	2000	2001
Total U.S. R&D (including federal)	212.4	226.9	244.1	264.6	281.1
Company-funded R&D	133.6	145.0	160.2	180.4	181.6
IT R&D, total	35.2	38.4	36.2	46.9	56.5
Computers and peripheral equipment	7.7	8.3	4.1	5.2	5.2
Communications equipment	2.8	8.4	5.8	11.1	15.2
Semiconductors, other components	14.0	9.1	10.6	12.8	14.2
Other electronics	0.5	0.6	0.8	0.3	0.3
Total, IT equipment	25.0	26.4	21.3	29.4	34.9
Software publishing	7.2	9.2	10.9	12.6	13.0
Computer systems design	3.0	2.9	4.0	4.9	8.7
Total, IT services	10.2	12.0	14.9	17.5	21.7
IT Share of Company R&D (percent)	26.4	26.5	22.6	26.0	31.2

Source: National Science Foundation, Survey of Industrial R&D

sector occurred in 2001 and R&D investment reached $56.5 billion, according to the latest available data from the National Science Foundation.[14] (See Table 1.6.) Compared with company-funded R&D by all industries, which was flat in 2001, growth in R&D by the IT sector boosted the IT share of total R&D to 31 percent from an average share of 26 percent in previous years. Another year of growth in R&D investment by IT industries is likely to be reported in 2002, because the NSF estimates an increase in R&D spending by all industries.[15]

A variety of factors contributed to the growth in R&D expenditures in 2001 that occurred despite the decline in IT industry sales. R&D investment was required to develop products for new applications with rapid growth potential. Semiconductor industries increased investment in R&D to meet demand for a number of rapidly growing markets, such as a new generation of televisions with thin screen features (LCD and plasma displays and high-definition TV (HDTV) with much better resolution), digital cameras, camera-equipped cell phones, video game machines, and personal computers with editing features for video and digital photos. In the communications equipment industry, R&D growth was stimulated by rapidly growing markets, such as broadband (including computer modems), wireless networks, HDTV broadcasting, instant messaging, and enhanced mobile phone equipment to allow users to send and receive photos and video.

[14] Infobrief. “U.S. Industry Sustains R&D Expenditures During 2001 Despite Decline in Performers’ Aggregate Sales.” National Science Foundation, October 2003.

[15] Infobrief. “Slowing R&D Growth Expected in 2002.” National Science Foundation, December 2002.

CHAPTER II:

INFORMATION TECHNOLOGY WORKERS IN THE DIGITAL ECONOMY

By Sandra D. Cooke*

The rapid diffusion of information and communications technologies throughout the U.S. economy and globally during the 1990s led to unprecedented demand for information technology (IT) workers. From 1993 to 2000, employment in IT-producing industries grew more than twice as fast as employment in all private industries and added over 1.8 million jobs. But, since 2000, this trend has reversed. During the 2000–2002 period, IT-producing industries lost over 600,000 jobs.

In recent years, the IT workforce has endured a number of events that have negatively affected the demand for IT workers. The recession of 2001 and subsequent slow recovery have depressed demand for workers in IT industries and IT-related occupations. However, foreign outsourcing of IT jobs and labor saving productivity improvements are among other factors that have contributed to a weak job market for IT workers.

This chapter begins with a section that profiles employment in IT-producing industries and then compares trends in employment and wages during the 1993 to 2000 period with the past two years (2001 and 2002) when IT-producing industry employment declined. The next section examines trends in IT occupational employment and wages according to education and training requirements. The remainder of the chapter discusses the factors that have contributed to recent declining demand for IT workers.

IT-Producing Industries

IT workers develop, design, manufacture, operate, repair and maintain the IT infrastructure that supports e-commerce, the Internet or network-related activities, and IT-enabled processes throughout businesses and organizations. IT-producing industries consist of four major

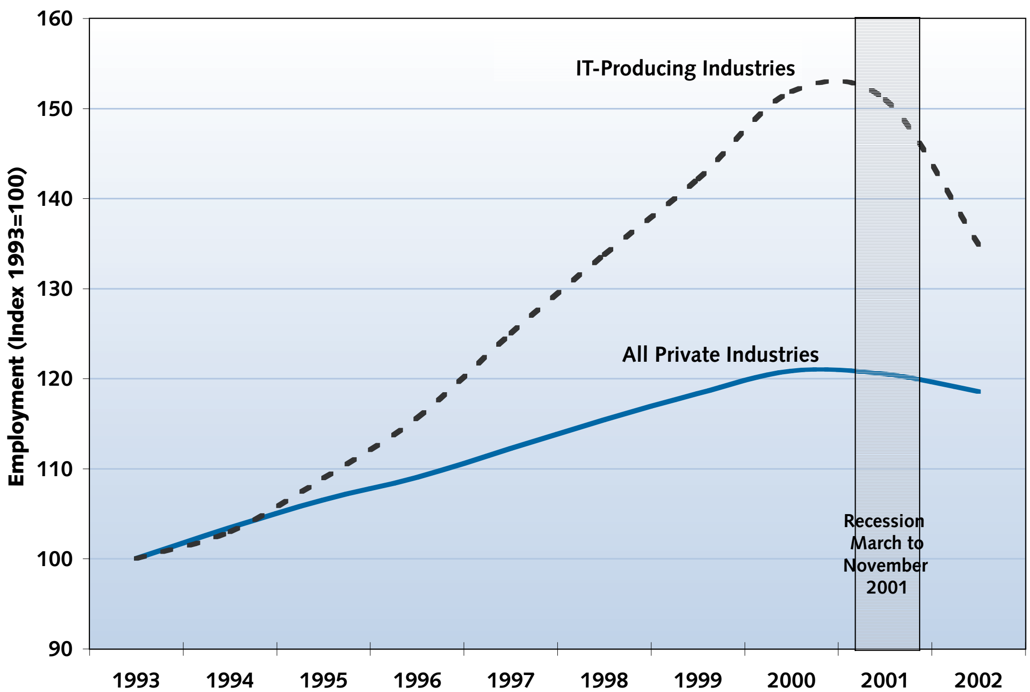
* Ms. Cooke (sandra.cooke@esa.doc.gov) is an economist in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

segments: computer hardware, software and computer services, communications equipment, and communications services. (See Box A-2.1 in the appendix to this chapter for a list of IT-producing industries.)[1] Workers in IT-producing industries cover a broad range of occupations (e.g., management, production, and administrative occupations in addition to IT-related occupations).

IT-PRODUCING INDUSTRIES EXPERIENCE MAJOR JOB LOSSES

After several years of unprecedented job creation, employment in IT-producing industries has fallen sharply. From 1993 to 2000, employment in IT-producing industries grew more than twice as fast as employment in all private industries (annually 6.2 percent and 3.2 percent respectively). (Figure 2.1A) Over the period, IT-producing industries added over 1.8 million jobs. (Figure 2.1B) But, since 2000, employment in IT-producing industries has fallen more than six times faster than all private industries. Between 2000 and 2002, IT-producing industries lost over 600,000 jobs, about one-fourth of the total private industry jobs lost over the same period. (Table 2.1)

Figure 2.1.A. Index of Changes in Industry Employment: IT-Producing Industries and All Private Industries

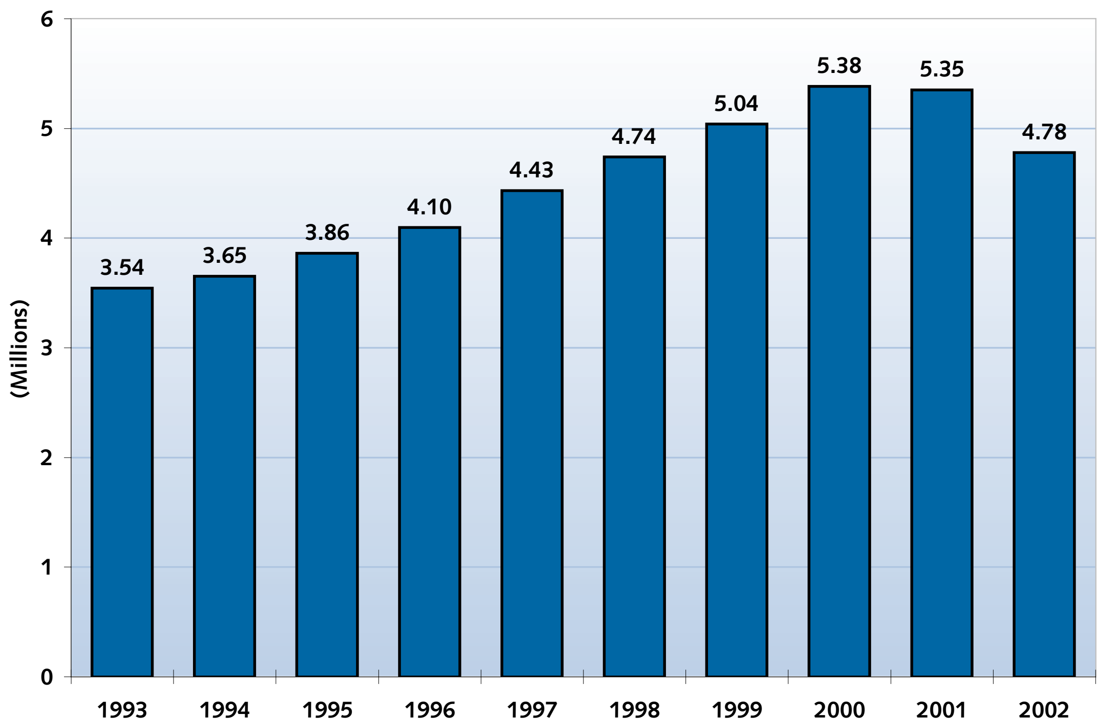


Source: Estimates derived from BLS data.

[1] IT-producing industries referenced in this Chapter do not exactly match those in Chapter 1. Chapter 1 uses Census Bureau data based on the 1997 North American Industrial Classification System (NAICS) and this chapter uses Bureau of Labor Statistics (BLS) data based on the 2002 NAICS. See the Appendix at the end of this chapter for additional information.

IT-producing industry employment increased from 3.5 million workers in 1993 to a peak of 5.4 million in 2000 and then fell to 4.8 million in 2002. Until 2000, IT-producing industry employment was characterized by "churning," meaning that most sub-industries especially in IT services industries gained jobs while many IT manufacturing sub-industries lost jobs. However, during the most recent period, job losses have occurred across the board. Figure 2.2 shows that, from 1993 to 2002, IT services employment outpaced IT manufacturing employment growth, but, since 2000, both IT manufacturing and IT services industries have been rapidly shedding jobs.

Figure 2.1.B. IT-Producing Industry Employment Levels (1993 to 2002)

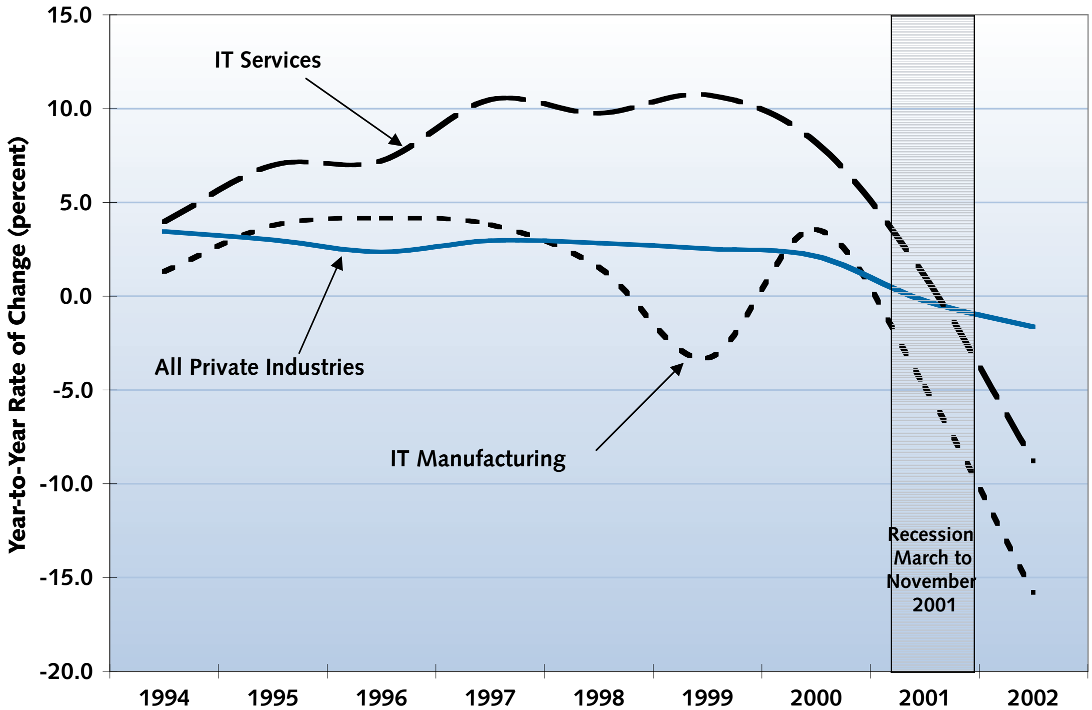


Source: Estimates derived from BLS data.

Employment in IT manufacturing industries declined from 1998 to 1999 because of declining exports to countries affected by the Asian financial crisis, but quickly rebounded in 2000. As recently as mid-2001, while the economy at large had started shedding jobs, many IT services industries were still adding jobs. However, in 2002, almost all IT-producing industries lost jobs.[2] From 2001 to 2002, employment declined 8.8 percent for IT services and 15.8 percent for

[2] See Appendix Table 2.1 in *Digital Economy 2003 Technical Appendices* for a complete list of employment in IT services and IT manufacturing industries. (http://www.esa.doc.gov/reports.cfm)

Figure 2.2. IT-Services and IT-Manufacturing Employment Year-to-Year Rates of Change



Source: Estimates derived from BLS data.

IT manufacturing industries, much faster than the 1.6 percent average rate of job loss for all private industries. Some individual industries have seen employment fall by more than 20 percent in one year. These industries include telephone apparatus, electrical capacitors, bare printed circuits, electrical components, and fiber optic cable manufacturing. The only IT-producing industries that added jobs in 2002 were satellite and related telecommunications and office machine rental and leasing, two relatively small industries.

At a more disaggregated level, we find similar trends. Of all IT-producing industries, software and services industry employment grew the fastest over the 1993 to 2000 period, (more than 12 percent per year), adding over 1 million jobs. Since 2000, this IT group has lost 166,000 jobs.[3] (Table 2.1.) Communications services, fueled by growth in Internet, fax, pager, and cell phone use, grew at 4 percent per year from 1993 to 2000. Expectations of future high demand led to rapid investment in fiber optic networks and equipment during the 1990s. By 2002, excess capacity without the expected demand led to increased competition and industry consolidation. As a result, the communications services industry has eliminated almost 60,000 jobs since 2000.[4] Employment of both computer equipment and communications equipment workers grew

[3] See Appendix Table 2.2 in *Digital Economy 2003 Technical Appendices* for a complete list of employment in IT-producing industry groupings. (http://www.esa.doc.gov/reports.cfm)

[4] Terence M. McMenamin, Rachel Krantz, and Thomas J. Krolik, "U.S. Labor Market in 2002: Continued Weakness," *Monthly Labor Review.* February 2003: 6.

over the earlier period, but started to decline before the two IT services groups. In 2002, computer and related exports slowed and the communications equipment industry continued to suffer from excess capacity.

Table 2.1. IT-Producing Industry Employment By Major IT Sector

Major IT Sectors[1]	Employment (000s)				Average Annual Rate of Change (%)		
	1993	2000	2001	2002	93-00	00-01	01-02
Computer Hardware	1,357.2	1,679.6	1,596.4	1,376.4	3.1	–5.0	–13.8
Software and Computer Services	951.9	2,127.5	2,160.8	1,961.0	12.2	1.6	–9.2
Communications Equipment	283.3	322.0	301.5	248.4	1.8	–6.4	–17.6
Communications Services	951.4	1,252.5	1,291.8	1,193.1	4.0	3.1	–7.6
All IT-Producing Industries	3,543.8	5,381.6	5,350.4	4,779.0	6.2	–0.6	–10.7
All Private Industries	91,855.0	110,996.0	110,707.0	108,886.0	2.7	–0.3	–1.6

Note: [1]Based on 2002 NAICS.

Source: Estimates derived from BLS data.

IT-PRODUCING INDUSTRY WAGES DECLINE SLIGHTLY

In 2002, the average annual wage for workers in IT-producing industries was $67,440, down 1.3 percent from the average of $68,330 for 2001. In contrast, the average annual wage for all private workers increased 1 percent to $36,520 in 2002.[5] One explanation for the much higher than average wages in IT-producing industries relative to all private industries is that most IT jobs tend to be high skilled, high wage jobs as explained in the next section.

In 2002, software publishing and software reproducing ranked among the IT-producing industries with the highest annual wages, ($99,440 and $92,260, respectively).[6] Reflecting the dot com shakeout, workers in the Internet service provider and web search portal industry saw annual wages decline by 16.6 percent.

[5] Previous analyses showed that the gap between IT-producing industry wages and the average for private industries has widened over time. See for example, Figure 5.3 on page 43 of *Digital Economy 2002*. (http://www.esa.doc.gov/pdf/DE2002_CH5.pdf) NAICS-based industry wages are only available for 2001 and 2002.

[6] See Appendix Table 2.3 in *Digital Economy 2003 Technical Appendices* for the complete ranking of IT-producing industries. (http://www.esa.doc.gov/reports.cfm)

IT-Related Occupations

Workers in IT-related occupations develop, design, manufacture, operate, maintain, and repair IT products and provide related services across all industries, including IT-producing industries. For example, network administrators work in education, health, legal, engineering and government services industries as well as in IT-producing industries. Our definition is broader than other definitions of IT-related occupations and includes workers in occupations that build, maintain, and repair the IT infrastructure such as telecommunications and computer equipment operators, repairers, and installers as described in Box 2.1.

Box 2.1. IT-Related Occupations

Skill Level: High

Computer and information systems managers

Engineering managers

Computer and information scientists, research

Computer programmers

Computer software engineers, applications

Computer software engineers, systems software

Computer support specialists

Computer systems analysts

Database administrators

Network and computer systems administrators

Network systems and data communications analysts

Computer hardware engineers

Electrical engineers

Electronics engineers, except computer

Electrical and electronic engineering technicians

Skill Level: Moderate

Data entry keyers

Computer, automated teller, and office machine repairers

Telecommunications equipment installers and repairers, exc. line installers

Electrical and electronics repairers, commercial and industrial equipment

Electrical power-line installers and repairers

Telecommunications line installers and repairers

Electrical and electronic equiptment assemblers

Electromechanical equipment assemblers

Semiconductor processors

Skill Level: Low

Communications equipment operators

Billing and posting clerks and machine operators

Computer operators

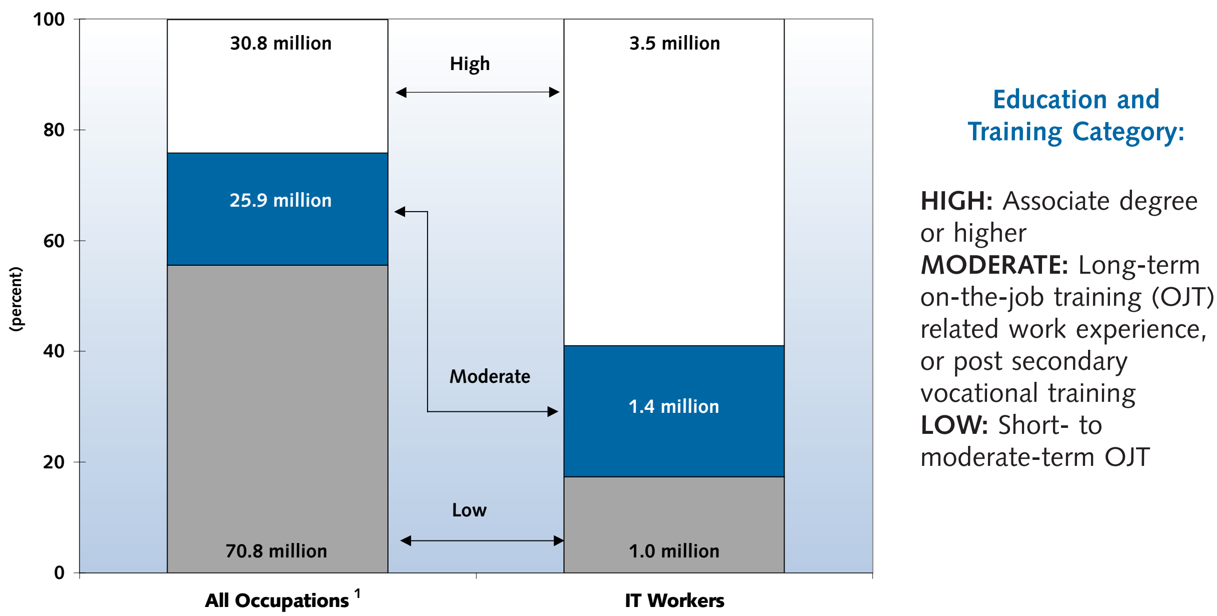
Other office machine operators, exc. computer

IT OCCUPATIONAL EMPLOYMENT IS ALSO DECLINING

As in IT-producing industries, job losses in IT-related occupations began after 2000. In 2002, workers in IT-related occupations totaled 5.9 million, roughly 3.2 percent (197,000) fewer than in 2001. Most IT jobs are highly skilled; i.e., occupations that require formal education and training and/or work experience. For the nation as a whole, the opposite is true. Proportionately more workers fall into the low-skilled category that requires much less formal education and training. (Figure 2.3) Education and training requirements for IT occupations have increased over time, as they have for the workforce at large. In contrast to past years when IT job losses were concentrated in low-skilled categories, since 2000, IT occupations have experienced job losses across all skill levels.

More than half of the jobs in IT-related occupations (3.5 million) require an associate degree or higher.[7] (Table 2.2)[8] Occupations in the high educational and training category include computer engineers, systems analysts, programmers and support specialists. From 1999 to 2000, all high skilled occupations gained jobs except engineering managers and computer and information scientists in research. After 2000, all high skilled occupations lost jobs except

Figure 2.3. IT Occupational Employment, by Education and Training Requirement, 2002



[1]Estimate based on 2000 employment distribution.

Source: Estimates derived from BLS data.

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[7] The grouping of the nine official BLS education and training categories into High, Moderate, and Low reflects the author's interpretation of training intensity of IT-related occupations and therefore, are not official BLS estimates.

[8] Analysis is limited to four years (1999–2002) because of recent changes to the occupational classification system.

network systems and data communications analysts and computer hardware engineers. The high skilled group as a whole accounted for almost half of the 516,000 IT-related jobs lost since 2000.[9]

IT workers that fall into the moderate education and training category generally require long-term on-the-job training, related work experience, or post secondary vocational training. Moderately skilled IT workers totaled 1.4 million in 2002 and included such occupations as telecommunications and electronic equipment installers and repairers. Although this group accounts for only a fourth of all IT workers, from 1999 to 2002, it suffered more than a third of the total IT occupational job losses. Semiconductor processors, data entry keyers and electronic equipment assemblers led the job losses in this group.

Table 2.2. IT Occupational Employment by Education and Training Requirement 1999 to 2002

Education and Training Category[1]	Employment (000s)				Average Annual Rate of Change (%)		
	1999	2000	2001	2002	99-00	00-01	01-02
High	3,434.7	3,763.0	3,595.0	3,512.5	9.6	–4.5	–2.3
Moderate	1,652.0	1,646.7	1,522.2	1,410.7	–0.3	–7.6	–7.3
Low	1,150.8	1,060.1	1,034.0	1,030.3	–7.9	–2.5	–0.4
IT-related occupations	6,237.5	6,469.9	6,151.2	5,953.5	3.7	–4.9	–3.2
All occupations	127,274.0	129,739.0	127,980.4	127,523.7	1.9	–1.4	–0.4

Notes: [1]HIGH: Associate degree or higher;
MODERATE: Long-term on-the-job training (OJT), related work experience or post secondary vocational training
LOW: Short- to moderate-term OJT

Source: Estimates derived from BLS data.

Low skilled IT jobs such as communications equipment operators and billing and posting machine operators, require only short- or moderate-term job training. This group lost the fewest jobs during 2000–2002 mainly because low skilled jobs have been declining over time. IT jobs requiring little training are more apt to be replaced by technology. For example, voice recognition technology and on-line telephone directories likely have reduced the need for telephone operators and directory assistants. Similarly, sophisticated billing and sales tracking software can eliminate some functions performed by billing and posting clerks.

[9] See Appendix Table 2.4 in *Digital Economy 2003 Technical Appendices* for a complete list of IT occupational employment and Appendix Table 2.6 for a description of duties of each IT-related occupation. (http://www.esa.doc.gov/reports.cfm)

Despite high requirements for formal education and training for IT occupations, a recent study by the Commerce Department's Technology Administration found that formal education in an IT field only provides part of what employers seem to be requiring.[10] In addition to formal education, employers are seeking IT workers with specific technical skills, certifications, work experience and soft skills such as interpersonal or business skills. This is evident in an emerging IT occupation called the "IT business technologist or IT business analyst," which requires technical, business, and communication skills. A worker in this occupation would serve as a liaison between non-IT workers who have a business problem and the IT department, which is charged with solving the problem.[11]

OCCUPATIONAL WAGE GROWTH HAS SLOWED

Earnings of IT workers vary based on their skills and educational levels. For specific occupations, we find that in 2002, average earnings ranged from $95,740 for highly skilled engineering managers, who typically have a bachelor's degree plus experience, to $23,220 for communications equipment operators, positions that require little formal training.[12] Although wages continue to increase, the rate of growth slowed starting in 1999 for most IT occupations. Annual wages of both computer and engineering managers increased by almost 8 percent since 2001.

A survey by Foote Partners LLC found that, on average, IT earnings are down from previous years and large signing bonuses are much less common. During 2002, base salaries in 85 IT occupations studied, declined by an average of 2.8 percent while bonuses declined by 32 percent. Only a few occupations experienced increased demand, including IT security specialists, whose earnings increased by 5.5 percent.[13]

The National Association of Colleges and Employers reports that average starting salaries for 2003 computer sciences graduates declined 4.1 percent to $47,109 (but computer science remains the highest paid specialty). The average offer to information sciences and systems graduates fell by 7.5 percent to $38,282.[14]

[10] U.S. Department of Commerce, Technology Administration, Office of Technology Policy, *Education and Training for the Information Technology Workforce*, Report to Congress from the Secretary of Commerce (Washington, DC: U.S. Department of Commerce, June 2003): 57.

[11] Mary Stevens, "Bridging the Gap," *E-Week* April 14, 2003. (http://www.eweek.com/print_article/0,3048,a=40332,00.asp)

[12] See Appendix Table 2.5 in *Digital Economy 2003 Technical Appendices* for a complete list of IT occupational earnings and Appendix Table 2.6 for a description of duties of each IT-related occupation. (http://www.esa.doc.gov/reports.cfm)

[13] David Foote, "IT Job Trends Yield Surprises," *Computerworld,* February 10, 2003. (http://www.computerworld.com/careertopics/careers/story/0,10801,78304,00.html)

[14] NACE's Fall 2003 Salary Survey, National Association of Colleges and Employers (http://www.naceweb.org)

IT Employment Demand and the Recession of 2001

IT-PRODUCING INDUSTRIES

Overall weakness in the economy has affected workers across all industries and occupations, including IT workers. Since 2001, the U.S. economy has lost 1.8 million private sector jobs and the decline in IT employment has been a part of this overall trend. IT-producing industries have lost over 570,000 jobs since 2001. During the 1991 business cycle, IT-producing industry employment sank lower than other industries and was slower to recover, but grew much faster than average after that. By 1992, the economy on average was adding jobs, but employment growth only turned positive for IT-producing industries in 1993.[15] Since the 2001 recession ended, IT-producing industry employment has continued to decline.

A recent report by the Federal Reserve Bank of New York compares the current "jobless" recovery with the previous one (1991) to determine whether job losses were cyclical or structural.[16] The authors examined industry job flows before and after the past recessions. If employment recovered quickly, they determined the change in employment was cyclical. If the industries lost jobs during the recession and continued to lose jobs afterwards, they concluded that the job losses were structural. Some IT-producing industries ranked among the industries that lost jobs during the recent recession and that continue to lose jobs, indicating a permanent relocation or loss of jobs.

The authors suggest that despite some structural job losses, the similarities between the current and previous recoveries, specifically, a recovery driven by productivity growth, with little initial job creation, could bode well for the future. Thus, if the current recovery eventually follows the pattern of the previous one, once the economy does turn around, we can expect a lengthy period of economic growth.

IT-RELATED OCCUPATIONS

IT occupational employment does not show consistent patterns across the last two business cycles. During the 1990–91 recession, the average unemployment rate of all computer related occupations (computer scientists, systems analysts, and engineers and computer programmers) was 2.7 percent.[17] The unemployment rate for these occupations was higher during the 2001 recession (3.7 percent), but has since continued to climb to a historically high rate of 5.2 percent in 2002. From 1993 to 2000, the unemployment rate for computer-related occupations was much lower than the national average and basically tracked the national average in direction and

[15] See Table A-4.1 in U.S. Department of Commerce, Economics and Statistics Administration, *Appendices to the Emerging Digital Economy II* (Washington, DC: U.S. Department of Commerce, June 1999): 26. (http://www.esa.doc.gov/pdf/EDE2appendix.pdf)

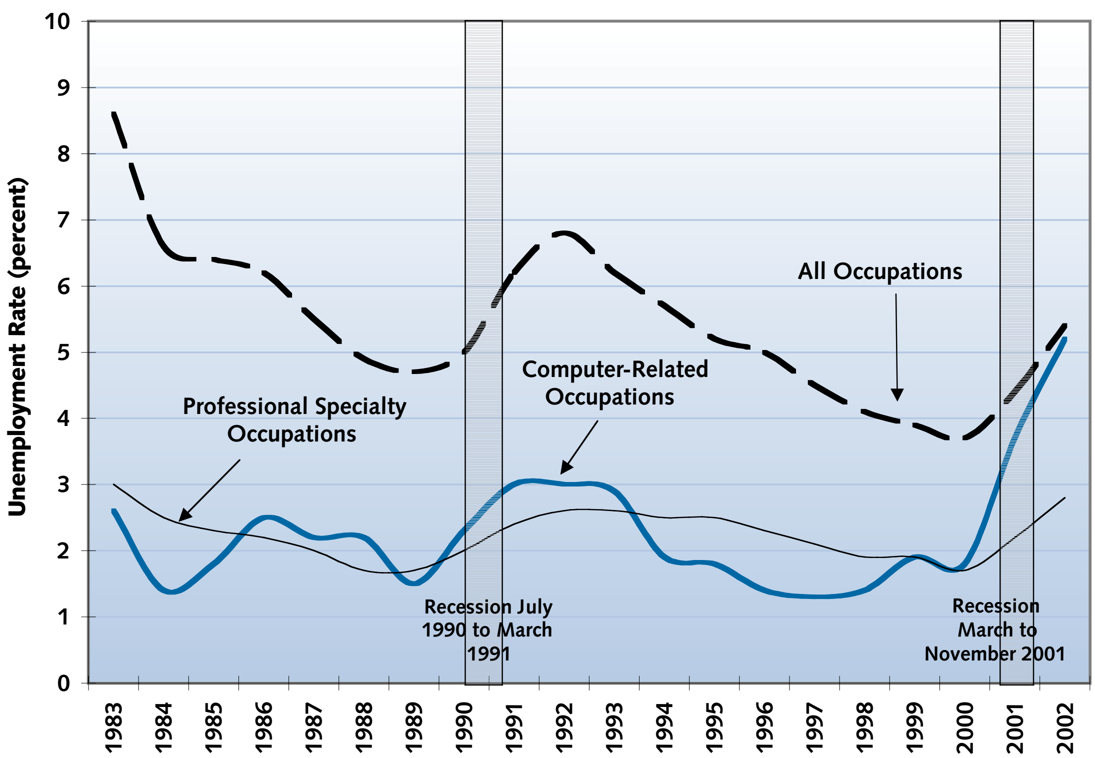
[16] Erica Groshen and Simon Potter, "Has Structural Change Contributed to a Jobless Recovery?" in *Current Issues in Economics and Finance* Federal Reserve Bank of New York, Vol. 9, No. 8, August 2003: 2–4. (http://www.newyorkfed.org/research/current_issues/ci9-8.html)

[17] These computer-related occupations account for about one-third of all IT-related occupations.

magnitude of change. During the same period, the unemployment rate for professional specialty occupations—a category that includes computer-related, engineering, legal, health, and other professional occupations that require similar, high levels of education and training—followed a similar trend. (Figure 2.4). After 2000, the unemployment rate of workers in computer occupations started to converge with the national average and diverge from the rate for professional specialty occupations.

The rapid increase in the unemployment rate in computer related occupations (between 2000 and 2002) relative to the national average suggests that factors in addition to the economic cycle could be influencing demand for workers in these occupations. The slowdown following the Y2K buildup is one likely explanation for the decline in demand, especially for computer programmers. Subsequently, the bursting of the dot.com bubble resulted in the loss of IT-related jobs. Also, recent growth in the number of foreign workers in computer and related occupations,

Figure 2.4. Unemployment Rates in Computer-Related Occupations Compared with Professional Specialty Occupations and the National Average



Note: Computer occupations include computer analyst, computer scientist, computer-systems planning, computer-systems analyst, data processing consultant, information scientist, software specialist, computer programmer, and related occupations. Professional specialty occupations include computer, engineering, legal, health, and other professional occupations that require similar education and training.

Source: Bureau of Labor Statistics Current Population Survey data.

specifically H-1B workers, could have displaced some IT workers.[18] Given the non-cyclical factors that have influenced the IT labor market (including offshoring discussed in the next section), it is unclear how soon unemployment rates for workers in computer-related occupations will return to pre-2000 levels.

Offshoring and IT Job Losses

The information technology revolution that gave rise to the growth in demand for IT workers is now enabling the shift of some types of IT jobs to other countries. This practice of "offshoring" or "foreign outsourcing" occurs when a U.S. company either relocates part of its operations physically outside of U.S. borders, outsources work to a company located in another country, or outsources to another U.S.-based company that then sends the work offshore. Lack of adequate data makes it difficult to determine the extent of offshoring, but press reports of company announcements and private surveys support the contention that IT offshoring has contributed to the recent decline in demand for IT workers.[19]

According to most accounts, offshoring is occurring in countries where many people speak English as a first or second language such as Canada, India, Ireland, Israel, and the Philippines. Some IT jobs have also moved to China. The types of jobs being outsourced abroad have evolved from low skilled, low wage call-center jobs to high skilled, high wage programming and software development jobs. The availability and declining cost of high speed communications systems are facilitating this trend.

No government data measure the extent to which U.S. companies are moving jobs to other countries. However, a growing number of private research firms are offering forecasts of IT job losses based on proprietary surveys of U.S. companies. These research studies are not comparable in scope or measurement techniques and the findings vary widely, indicating the difficulty in tracking labor mobility and its economic effects. But the common theme throughout is that many U.S. companies that are not already offshoring are planning to do so in the near future.

- Forrester Research estimates that 3.3 million U.S. services jobs will be relocated abroad over the next 15 years, accounting for $136 billion in wages. Over 400,000 will be IT-related jobs, with the greatest level of outsourcing expected in software development and customer service/call centers.[20]

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[18] The H-1B visa program allows foreign workers to enter the country for the purpose of temporarily filling skilled jobs (a large share of which are IT jobs). The original annual limit on visa approvals was set at 65,000. Congress raised the limit to 115,000 for FY1999 and FY2000 and to 195,000 in FYs 2001, 2002 and 2003. The cap reverted to 65,000 on October 1, 2003.

According to the Office of Immigration Statistics, H-1B petitions increased each year the cap was raised until FY2002, when H-1B petition approvals dropped by more than half to 89,000. This suggests that H-1B workers in computer-related occupations are beginning to feel the impact of the weak economy, too.

[19] In light of concern about offshoring, Congress has requested that the General Accounting Office conduct a study of the economic implications of offshoring.

[20] John McCarthy, *et al.*, "3.3 Million U.S. Services Jobs to go Offshore," *Forrester Research Tech Strategy Brief* (November 11, 2002): 1. (http://www.forrester.com)

- Goldman Sachs estimates the cumulative services jobs lost to offshoring at 200,000, but projected job losses could reach 6 million over the next decade. They suggest that while businesses could realize cost savings and higher profits in the short-term, over time competition will erode the cost savings. In the end, they contend increased offshoring would reduce labor demand, raise imports, and place downward pressure on the value of the dollar.[21]
- A survey of hiring managers conducted by the Information Technology Association of America (ITAA) found that 12 percent of IT companies had opened outsourcing operations overseas. The ITAA survey also revealed that most of the foreign outsourcing was being conducted by large IT companies and that programming and software engineering positions topped the list of types of positions most likely to be outsourced.[22]
- Gartner Inc. expects one in 10 jobs at IT services firms to move offshore by the end of 2004 and that many of the job losses will be structural. Despite the short-term fiscal advantages of offshoring, they warn that companies need to consider the long-term implications of offshoring including the loss of seasoned IT professionals, the loss of intellectual assets, and the effect of offshoring on the functioning of their organizations.[23]

McKinsey Global Institute (MGI) attempted to quantify the benefits from offshoring. For example, despite the job losses associated with offshoring, U.S. consumers could benefit from lower prices as businesses pass on the cost savings. Also, offshoring could raise the standard of living in other countries, whose residents would be able to import goods and services from the United States. MGI found that overall, the positive effects outweigh the costs in lost jobs. In addition, MGI notes that Forrester Research's estimated job losses over the next 10 years (about 200,000 per year) are less than the number of mass layoffs that typically occur in a dynamic, global economy for reasons other than offshoring. MGI also suggests that offshoring might help to ease domestic labor supply issues expected to result as the U.S. population ages.[24]

Effects of Productivity Improvements and Automation

Despite the positive benefits of technological advances such as higher productivity growth, which leads to faster economic and wage growth, job displacement can occur. Technological advances can contribute to job displacement by either eliminating the job or automating processes so that they require fewer workers. Such labor saving innovations result in productivity improvements that allow firms to produce more with the same number of workers or maintain current output with fewer workers. Often the types of jobs displaced by technology

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[21] Andrew Tilton, "Offshoring: Where have all the Jobs Gone?" *Goldman, Sachs & Co. U.S. Economics Analyst, Issue 03/38* (September 19, 2003): 6.

[22] Information Technology Association of America, *2003 IT Workforce Survey* (Arlington, VA: ITAA, May 5, 2003): 11. (http://www.itaa.org/workforce/studies/03execsumm.pdf)

[23] Diane Morello, "U.S. Offshore Outsourcing: Structural Changes, Big Impact," *Gartner Research Note Commentary COM-20-4837* (July 15, 2003): 2. (http://www4.gartner.com/Init)

[24] McKinsey Global Institute, "Offshoring: Is It a Win-Win Game?" August 2003: 10–12. (http://www.mckinsey.com/knowledge/mgi/)

are low-skilled jobs or repetitive tasks that become automated. Office and administrative functions that were once performed by workers in those occupations can now be done by individual staff members. For example, software and the Internet can allow workers to secure travel, training, and other services directly rather than using administrative personnel. In Chapter IV of this report, the authors describe job losses in office and administrative occupations among IT-intensive industries.[25]

High skilled IT occupations can also be affected by changes in technology. For example, an occupation that requires narrowly specialized training can become obsolete when a platform or operating system changes. Newer generations of software provide self-testing features that once required someone to conduct the testing. In the case of communications, repairing a problem with a telephone line used to require that a person physically go to the site and inspect the telephones and lines. Now testing and problem-solving can be done remotely. In Chapter IV, the authors note that within businesses services, an IT-intensive industry, job losses were not only concentrated among office and administrative occupations, but in higher skilled installation, maintenance, and repair occupations and computer and mathematical occupations.

Sprint PCS is a firm-level example of how technology has increased productivity and replaced workers. Sprint PCS, a wireless carrier, substituted voice recognition software for human operators. Sprint's productivity increased by 15 percent from 2001 to 2002 as it shed 11,500 workers.[26]

Conclusion

After almost a decade of rapid job growth during the 1990s, demand for IT workers has fallen sharply during the past two years. Recent job losses have been widespread across almost all IT-producing industries and IT-related occupations. Job losses have been both cyclical and structural. The recent recession and continued economic sluggishness have slowed the return of some IT jobs. However, productivity improvements and foreign outsourcing of IT jobs mean some types of IT job losses may be permanent.

[25] See Chapter IV, Digital Economy 2003, Appendix Table 4.B for a complete ranking of IT-intensive industries.

[26] Del Jones and Barbara Hansen, "Companies Do More With Less," *USAToday online*, 14 August 2003: 3.

Appendix 2.A
The North American Industrial Classification System

In 1997, the North American Industrial Classification System (NAICS) was created from a joint effort by the statistical agencies of the United States, Canada, and Mexico. NAICS classifies in the same industry, establishments with similar production processes. Thus, NAICS focuses on how products and services are created, as opposed to the Standard Industrial Classification (SIC), which focused on what is produced.

The NAICS approach created significantly different industry groupings than those under the SIC system, especially for services, and thus more accurately reflects the workings of the U.S. economy. The pace of NAICS adoption has differed across statistical organizations. The Bureau of the Census was the first U.S. statistical agency to adopt NAICS; however, since 1997, NAICS has been revised and the Bureau of Labor Statistics (BLS), which had not implemented the 1997 NAICS, went directly to the 2002 NAICS. The 2002 NAICS includes further revisions that include new industries. Therefore, the industry classifications listed in Box A-2.1 and used in this chapter are not exactly comparable to those used in Chapter 1, which are grouped according to the 1997 NAICS.

BLS revised *some* of their estimates historically according to NAICS (e.g., the Current Employment Survey (CES) data used to estimate IT-producing industry employment). However, the Covered Employment and Wages (CEW) survey that is used to compile IT-producing industry wages have not been revised historically and are currently available for only 2001 and 2002.

Box A-2.1. Information Technology-Producing Industries (2002 NAICS)

NAICS CODE	Computer Hardware
334111	Electronic Computers
334112	Computer Storage Devices
334113	Computer Terminals
334119	Other Computer Peripheral Equipment
423430	Computer and Software Wholesalers (part)
443120	Computer and Software Stores (part)
334411	Electron Tubes
334412	Bare Printed Circuit Boards
334413	Semiconductor and Related Devices
334414	Electronic Capacitors
334417	Electronic Connectors
334418	Printed Circuit Assembly
334415,6,9	Miscellaneous Electronic Components
334513	Industrial Process Control Instruments
334515	Electricity Measuring and Testing Equipment
334516	Analytical Laboratory Instruments
333295	Semiconductor Machinery
333313	Office Machinery Manufacturing
	Communications Equipment
334210	Telephone Apparatus
334220	Broadcast and Wireless Communications Equipment
334310	Audio and Video Equipment
335921	Fiber Optic Cables
334611	Software Reproducing
334613	Magnetic and Optical Recording Media

NAICS CODE	Software and Computer Services
511210	Software Publishers
518111,2	Internet Service Providers and Web Search Portals
518210	Data Processing, Hosting, and Related Services
423430	Computer and Software Wholesalers (part)
443120	Computer and Software Stores (part)
541511	Custom Computer Programming
541512	Computer Systems Design
541513	Computer Facilities Management
541519	Other Computer Related Services
532420	Office Machinery and Equipment Rental and Leasing
811212	Computer and Office Machine Repair and Maintenance
	Communications Services
517110	Wired Telecommunications Carriers
517212	Cellular and Other Wireless Carriers
517310	Telecommunications Resellers
517510	Cable and Other Program Distribution
517410,910	Satellite and Other Telecommunications
811213	Communications Equipment Repair and Maintenance

CHAPTER III:

INTERNATIONAL SALES OF INFORMATION TECHNOLOGY GOODS AND SERVICES

By Dennis Pastore and Donald Dalton*

In an increasingly integrated world economy, U.S. IT industries illustrate a paradox of industrial competitiveness. American-owned IT companies lead their foreign rivals in almost every segment of business activity—from research and development to design, production, and marketing. The United States remains the world's largest exporter of IT goods and services; and, in 2002 (the most recent year for which data are available), estimated sales by U.S. IT companies and their overseas affiliates topped $1 trillion.[1] Yet, in 2002, the United States registered a deficit in IT goods trade of more than $86 billion—the nation's thirteenth consecutive deficit in IT goods since 1990, and the largest on record.

To help explain this contrast, the present chapter examines recent developments in U.S. IT goods and services trade and indices of the globalization of U.S.- and foreign-owned IT production. The chapter focuses especially on sales abroad by foreign affiliates of U.S. IT companies, and intra-firm trade by U.S.- and foreign-owned IT firms, as well as the globalization of U.S. R&D investments. The analysis links the large deficits in U.S. IT goods trade to the fact that U.S. IT producers are global companies that supply foreign markets from foreign production sites. It lends support to the view that, in some industries at least, the global deployment of production and distribution capacity is both a requirement and an indication of competitive success.

Trade in IT Manufactured Goods

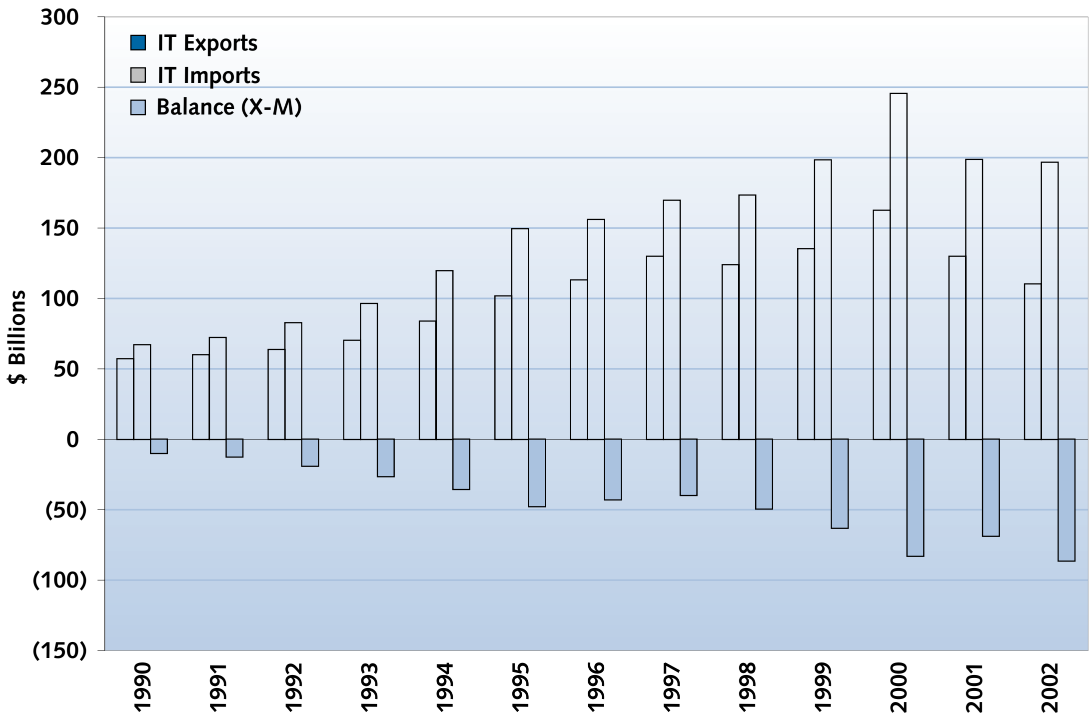
Lackluster U.S. trade performance in IT manufactured goods during 2001 and 2002 reflected the global economic response to the events of September 2001 and the end of the IT investment

* Mr. Pastore (dennis.pastore@esa.doc.gov) and Mr. Dalton (donald.dalton@esa.doc.gov) are economists in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

[1] Based on Chapter 1's estimate of total IT producing industry output and the present chapter's estimate of sales by foreign affiliates of U.S. IT companies.

boom of the 1990s. In 2002, for the second year in a row, exports of U.S.-made IT products declined. IT imports also fell sharply, by almost 20 percent in 2001, before leveling off in 2002. The combination of continuing export declines and the stability of imports in 2002 pushed that year's deficit in IT-goods trade to an all-time high of $86.5 billion—26 percent over the 2001 level ($68.7 billion) and 4 percent above the previous high of $82.8 billion in 2000. (Figure 3.1.)

Figure 3.1. U.S. Trade in IT Goods



Sources: Calculations based on data from Census Bureau and Bureau of Economic Analysis (BEA).

At a more disaggregated level, the largest negative balances appeared in cross-border sales of computer and peripheral equipment ($33.2 billion) and audio and video equipment ($26.8 billion). Smaller imbalances persisted in sales of IT-related communications equipment ($15.4 billion), and semiconductors and other electronic components ($13.7 billion). The deficit in semiconductors trade continues to contract. The balances on sales of IT-related instruments, software, semiconductor machinery, and fiber optic cable remained positive. (Table 3.1.)

While the deficit in IT goods trade continues to expand, this trend has occurred in a period of rising trade deficits for the overall economy. Growth in the IT trade deficit was less than the upward trend in the national trade deficit from 1995 to 2002. Measured as a ratio of the IT trade deficit to the total trade deficit in goods, the IT share of the overall deficit peaked at 27.8 percent in 1995 and declined almost every year since then to 17.8 percent in 2002. See Table 3.1.

Table 3.1. U.S. Trade in IT Goods

$Billions	1990	1995	1998	1999	2000	2001	2002
			Exports				
Computer and Peripheral Equipment	23.0	34.4	38.3	38.5	44.3	37.2	29.1
Semiconductors and Other Electronic Components	17.2	34.3	44.1	52.7	65.2	49.8	44.7
Audio and Video Equipment	2.1	3.4	4.6	3.8	4.2	4.1	4.0
IT-related Communications Equipment	4.9	11.2	15.4	16.6	18.4	15.0	11.8
IT-related Instruments	5.7	9.5	11.6	12.7	15.7	13.7	12.5
Other IT	4.2	8.8	10.0	11.1	14.7	10.1	8.3
Software	1.2	3.2	3.2	3.3	3.3	2.9	2.8
Total IT Exports	57.1	101.6	123.9	135.4	162.5	129.8	110.3
			Imports				
Computer and Peripheral Equipment	15.0	40.8	54.8	61.2	68.5	59.1	62.3
Semiconductors and Other Electronic Components	27.0	67.8	68.2	78.3	98.1	66.7	58.4
Audio and Video Equipment	11.0	18.2	21.5	24.2	28.7	27.3	30.8
IT-related Communications Equipment	7.6	10.6	14.2	19.3	30.2	26.4	27.2
IT-related Instruments	2.9	5.8	7.5	8.3	10.5	10.2	9.8
Other IT	3.4	6.1	7.2	7.1	9.3	8.9	8.3
Software	0.2	0.6	0.6	0.5	0.5	0.5	0.4
Total IT Imports	66.9	149.4	173.4	198.4	245.3	198.5	196.7
			IT Goods Trade Balance				
Computer and Peripheral Equipment	8.0	–6.5	–16.5	–22.7	–24.3	–21.9	–33.2
Semiconductors and Other Electronic Components	–9.8	–33.5	–24.1	–25.6	–32.9	–16.9	–13.7
Audio and Video Equipment	–8.9	–14.8	–16.9	–20.4	–24.5	–23.2	–26.8
IT-related Communications Equipment	–2.8	0.6	1.2	–2.7	–11.8	–11.4	–15.4
IT-related Instruments	2.8	3.7	4.1	4.4	5.2	3.5	2.7
Other IT	0.8	2.7	2.8	4.0	5.4	1.2	0.0
Software	1.0	2.6	2.6	2.8	2.7	2.4	2.4
Overall IT Trade Balance	–9.8	–47.8	–49.5	–63.0	–82.8	–68.7	–86.5
			IT Goods Trade Relative to Total U.S. Goods Trade				
Total U.S. Trade Balance	–111.0	–174.2	–246.8	–346.0	–452.4	–427.2	–482.9
IT Share of U.S. Trade Balance (percent)	8.9	27.4	20.0	18.2	18.3	16.1	17.8

Sources: Calculations based on Census data obtained via the Trade Policy Information System (TPIS), International Trade Administration (ITA), U.S. Department of Commerce. Data on software trade from BEA, Balance of Trade Division.

Table 3.2. U.S. Trade in IT Services

$Billions	1995	1996	1997	1998	1999	2000	2001	2002
Exports								
Telecommunications	3.2	3.3	3.9	5.6	4.5	3.9	4.5	4.1
Computer and data processing services	1.3	1.6	2.0	1.9	3.3	3.3	3.2	3.0
Data base and other information services	1.1	1.2	1.5	1.8	2.1	2.4	2.2	2.4
Software royalties and license fees (unaffiliated)	1.7	2.1	2.7	3.2	3.7	4.8	5.0	4.8
Total IT Services Exports	7.4	8.2	10.1	12.5	13.7	14.4	14.9	14.3
Imports								
Telecommunications	7.3	8.3	8.3	7.7	6.6	5.4	4.8	4.2
Computer and data processing services	0.1	0.3	0.6	0.9	1.0	1.4	1.4	1.0
Data base and other information services	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Software royalties and license fees (unaffiliated)[1]	0.3	0.2	0.5	0.5	0.5	0.5	0.4	0.5
IT Services Imports	7.9	8.9	9.6	9.2	8.3	7.5	6.8	5.9
IT Services Trade Balance (X-M)								
Telecommunications	–4.1	–5.0	–4.4	–2.1	–2.1	–0.9	–0.3	–0.1
Computer and data processing services	1.2	1.3	1.4	1.0	2.3	1.9	1.8	2.0
Data base and other information services	0.9	1.0	1.4	1.6	2.0	2.2	2.0	2.2
Software royalties and license fees (unaffiliated)[1]	1.4	2.0	2.2	2.7	3.2	4.3	4.6	4.3
IT Services Balance (X-M)	–0.5	–0.7	0.5	3.2	5.4	6.9	8.1	8.4

Note: The Bureau of Economic Analysis does not separately identify intrafirm payments involving software royalties and license fees. However, unpublished data indicate that net payments to U.S. companies are substantial and could add a few billion dollars a year to the trade surplus.

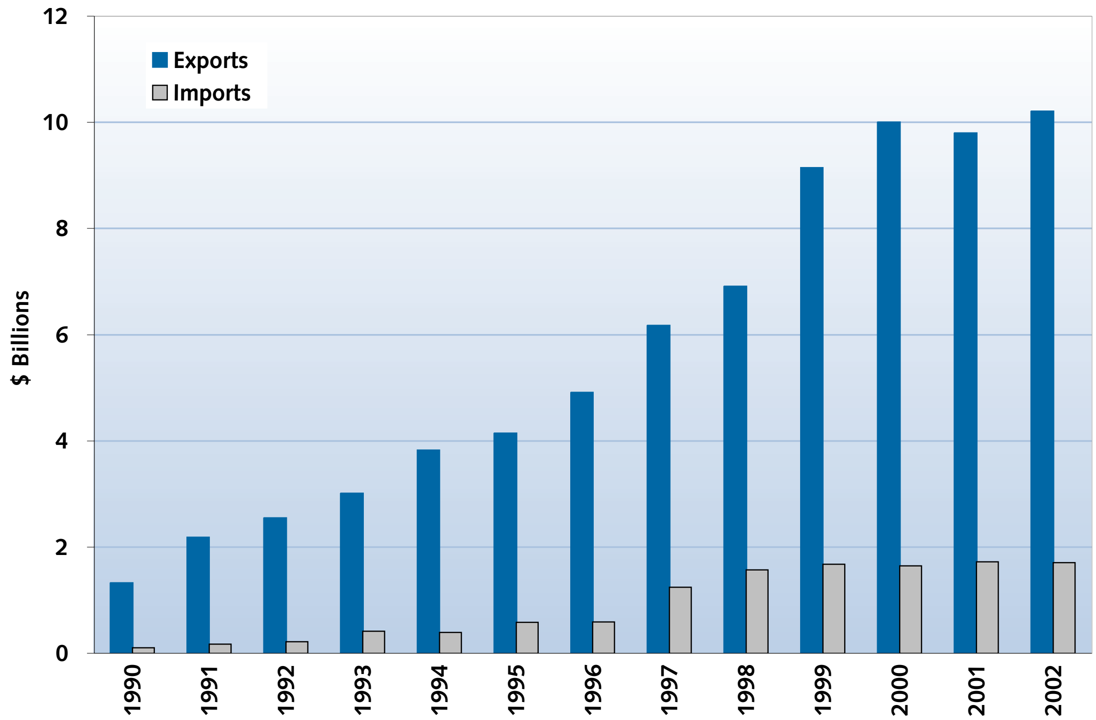
Source: Tabulations based on data in Maria Borga and Michael Mann, "U.S. International Services: Cross-Border Trade in 2002 and Sales Through Affiliates in 2001," Survey of Current Business 82 (October 2003).

Trade in IT Services

Despite a persistently negative balance in IT goods trade, the United States has regularly posted a trade surplus in IT services. In 2002 (the most recent year for which data are available), the surplus in U.S. IT services trade continued for the sixth consecutive year, reaching $8.4 billion.[2] This strong showing reflected a continuation of the recent pattern of sharp reductions in U.S. payments for foreign telecommunications services, along with increased earnings on software and license fees. (Table 3.2 and Figure 3.2.)

[2] The charts and discussion in this section are based on data and analysis in Maria Borga and Michael Mann, "U.S. International Services: Cross-Border Trade in 2001 and Sales Through Affiliates in 2001," *Survey of Current Business* 82 (October 2003): 67–124.

Figure 3.2. U.S. Trade in Computer-Related Services[3]



Source: Calculations based on data in Maria Borga and Michael Mann, "U.S. International Services: Cross-Border Trade in 2002 and Sales through Affiliates in 2001," *Survey of Current Business* 82 (October 2003).

At a more disaggregated level, in 2002, the United States posted a near balance in telecommunications services—the second surplus after a long string of deficits. This improvement owed much to the influence of the WTO Basic Telecommunications Agreement and the FCC Benchmarks Order (both of 1997). As a result of these measures, even as the volume of international calls originating in the United States continues to increase, the rates that foreign providers charge for basic services have been falling. Lower import bills for U.S. customers also reflect a shift toward alternative channels of communication, including e-mail.

Although U.S. receipts on cross-border sales of computer and information services were roughly flat in 2001 and 2002, computer services and software royalty payments still account for the lion's share of U.S. cross-border sales of IT services. Income from software royalties dropped in 2002, and the growth rate of database and other information services exports remained positive.

[3] Consist of cross-border payments for computer and data processing services and database and other information services between unaffiliated parties as well as income from software royalties and license fees.

Globalization of Production and Distribution of IT Goods and Services

The side-by-side occurrence of world-class U.S. IT-producing companies and the nation's chronic deficit in IT goods trade appears to be largely a result of the globalization of production and distribution of IT goods and services. U.S. IT companies often supply foreign and U.S. markets from off-shore production centers. These companies also increasingly conduct intra-firm IT trade.

Table 3.3 shows that U.S. IT firms are more likely to service foreign markets by locating production capacity overseas than by exporting from production facilities in the United States. Indeed, the value of U.S. IT firms' direct sales through foreign affiliates to overseas customer has generally exceeded earnings from exports by a wide margin. In 2000 (the most recent year for which data are available), sales through foreign affiliates by U.S. manufacturers of computers and peripheral equipment, semiconductors and other electronic components, communications equipment, and audio and video equipment totaled nearly $200 billion. By contrast, in the same year, U.S. companies exported $132 billion worth of these IT goods.

In the case of IT services, the relative differences are even more striking. In 2000, foreign affiliates of U.S. computer services providers sold more than fifteen times the value of computer services exported that year by all U.S.-based companies; for telecommunications affiliates, the multiple was about four. In both instances, the data are consistent with the observed tendency for service providers to base operations in close proximity to their customers.

The growing imbalance in U.S. IT goods trade also reflects an increasing deficit in cross-border trade *within* U.S. and foreign-owned multinational IT firms. More than two-thirds of U.S. IT goods imports in 2002, or $131.2 billion, involved shipments from affiliated companies.[4] Thus, the deficit in trade with affiliated firms more than accounted for the negative overall balance of U.S. IT goods trade. (Table 3.4.)

At a more disaggregated level, some imbalances in intra-firm trade seem especially salient. For example, in 2002 related firms accounted for more than 90 percent of U.S. imports of portable computers ($10.4 billion). Most of these imports came from affiliates in Malaysia ($2.8 billion), Mexico ($1.3 billion), Taiwan ($1.0 billion), the Philippines ($0.7 billion), and Japan ($0.6 billion). Shipments from affiliates made up over 90 percent of the value of portable computers entering the United States from Malaysia, Mexico, the Philippines, and Japan. In contrast, well over half of the value of those arriving from Taiwan came from non-affiliated firms. The same

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[4] For purposes of imports, firms are affiliated if the firm on either end of the transaction controls 6 percent or more of the voting stock of the other. For exports, the ownership threshold is 10 percent. The analysis of affiliated trade is based on a special tabulation of the related-party trade data provided to OPD by the Foreign Trade Division of the Census Bureau. It is not possible from these data to determine the direction of the ownership relationship; i.e., to distinguish between transactions involving U.S. firms or parents and their overseas affiliates, on the one hand, and those involving foreign companies and their affiliates in the United States. Tabulations based on the related-party data also do not take into consideration cross-border shipments of software products, for which a breakdown between affiliated and unaffiliated parties is not available.

Table 3.3. Sales of Foreign Affiliates versus U.S. Exports in 2000

$billions

FOREIGN AFFILIATES			U.S.-BASED ENTITIES
Foreign Sales (1) of Majority-Owned Affiliates	195.1	132.1	**Merchandise Exports (2)**
Industry of U.S. Parent (3)			*IT Goods (4)*
Computers and peripheral equipment	100.1	44.3	Computers and peripheral equipment
Semiconductors and other electronic components	59.1	65.2	Semiconductors and other electronic components
Communications equipment	33.1	18.4	Communications equipment (5)
Audio and video equipment	2.8	4.2	Audio and video equipment
Foreign Sales (6) of Majority-Owned Affiliates	99.6	10.0	**Services (7) Exports**
Industry of U.S. Parent (3)			*IT Service*
Telecommunications	20.9	4.8	Telecommunications
Computer services (8)	78.7	5.2	Computer services (9)

Notes: (1) Local (i.e., host country) and other foreign (non-U.S.) sales net of imports from U.S.
(2) Census merchandise trade obtained through the Trade Policy Information System, ITA.
(3) Affiliates of U.S. parent firms in the IT industries listed. Sales include both goods and services sold by these firms. Affiliates may be in other industries (e.g., wholesale).
(4) Exports of these kinds of goods regardless of the industry classification of the firm exporting them.
(5) Includes telephone apparatus as well as radio and TV broadcasting and wireless communications equipment.
(6) Sales are gross sales to unaffiliated firms including unaffiliated U.S. firms. Disclosure restrictions make it impossible to net out purchases by affiliated firms in the U.S. for all segments. However, it seems reasonable to assume that the figures for the computer systems design and related services segment of the industry are broadly representative. In that industry, over 90 percent of sales are local, and imports from the U.S., negligible.
(7) U.S. receipts for cross-border sales. BEA data on services trade is classified by type of service regardless of the industry of the service provider.
(8) Consist of information services and data processing services and computer systems design and related services.
(9) Consist of computer and data processing services and database and other information services. These are conceptually same, since BEA includes computer system design and related services in reporting trade in computer and data processing services.

Source: Bureau of Economic Analysis, U.S. Direct Investment Abroad: Operations of U.S. Parent Companies and Their Foreign Affiliates, Preliminary 2000 Estimates, Tables III.F 9 and II.T 1. (http://www.bea.doc.gov/).

was also true for portables shipped from China, South Korea, Singapore, and Hungary, although the combined value of shipments from these four countries amounted to less than a third of those entering from Taiwan.

GLOBALIZATION OF INDUSTRIAL R&D

Multinational involvement in overseas research and development (R&D) has increased significantly during the past decade, particularly in information technology. Overseas R&D has historically followed foreign investment in the later stages of the international product life cycle, but U.S. and foreign multinational companies have recently increased the pace of overseas investment in R&D and are integrating these laboratories into global R&D networks.

Table 3.4. Computer Goods Trade Between Related Parties

$Millions

		2002 Total	To/From Related Party	Unrelated Party	Relation Not Specified
IT Exports		107,473.4	41,568.4	63,362.7	2,542.3
IT Imports		193,867.0	131,154.5	62,650.1	62.3
Balance (X-M)		–86,393.5	–89,586.1	712.6	2,480.0
		Exports			
Computer and Peripheral Equipment		29,059.6	11,665.9	16,664.6	729.1
Portable computers		1,045.8	375.6	640.2	30.0
Destination:	Malaysia	7.4	1.2	6.1	0.0
	Mexico	218.1	112.7	104.9	0.6
	Taiwan	26.2	0.6	24.4	1.1
	Philippines	1.6	0.3	1.3	0.0
	Japan	52.5	11.6	40.9	0.1
	China	13.3	1.7	11.4	0.2
	Ireland	35.6	20.1	15.3	0.1
	South Korea	12.3	0.3	12.0	0.1
	Singapore	26.4	4.4	22.0	0.0
	Israel	7.5	0.3	7.2	0.0
	Hungary	0.5	0.0	0.5	0.0
		Imports			
Computer and Peripheral Equipment		62,284.2	43,699.2	18,568.3	16.6
Portable computers		10,442.1	6,804.6	3,637.4	0.1
Source:	Malaysia	2,911.7	2,764.5	147.2	0.0
	Mexico	1,368.6	1,276.7	91.9	0.0
	Taiwan	3,407.8	988.7	2,419.1	0.0
	Philippines	927.4	747.0	180.4	0.0
	Japan	651.5	590.8	60.7	0.0
	China	632.2	214.3	417.9	0.0
	Ireland	93.0	214.3	0.4	0.0
	South Korea	232.9	45.2	187.7	0.0
	Singapore	122.4	44.9	77.5	0.0
	Israel	8.2	7.2	1.0	0.0
	Hungary	15.5	5.1	10.4	0.0

Source: Calculations based on special tabulation by Census Bureau of related party trade data. Tallies may differ slightly from those in Table 3.1 above due to rounding and the use of a more recent concordance between HS commodity codes and NAICS.

These networks are expanding rapidly into Asia and Latin America—e.g., Singapore, Korea, China, India, Mexico, and Brazil. U.S. firms invest in R&D abroad to gain access to educated workers at lower salaries than the home country, but also to gain access to technology and skilled workers in areas where the United States lags other countries.

The United States appears to be the primary host country beneficiary of the globalization of R&D. In 2001, the most recent year for which Bureau of Economic Analysis (BEA) data are available, foreign-owned IT companies invested $7.1 billion in R&D in the United States, about 13 percent of total company-funded R&D in the U.S. IT sector. In addition, foreign-owned IT companies in the United States employed about 35,600 R&D workers.[5]

U.S. R&D funded by foreign-owned companies tends to be concentrated in a few IT industries in which these companies have a competitive advantage and substantial U.S. market share. About half of foreign company R&D spending goes to telephone communications equipment (central office and cellular switching), followed by R&D in memory semiconductors, and consumer electronics.

Foreign-owned companies' decisions about where to locate U.S. R&D facilities seem to be governed by considerations of proximity to U.S. universities and availability of skilled workers. Many foreign-owned R&D facilities are located in Silicon Valley, CA, Research Triangle Park, NC, Princeton, NJ, and Richardson, TX.[6]

In 2001, U.S. companies spent less on R&D abroad than foreign-owned companies spent in the United States. In the IT sector, U.S. companies spent $6.7 billion on overseas R&D according to BEA, or 12 percent of their total R&D investment. Makers of communications equipment for computer networks and the Internet accounted for a majority of this overseas spending ($3.9 billion in 2001), followed by semiconductor companies ($0.9 billion).[7]

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[5] William J. Zeile, "U.S. Affiliates of Foreign Companies' Operations in 2001," *Survey of Current Business*, August 2003. R&D data include Computers and electronic products, Information, and Computer systems design.

[6] Donald H. Dalton and Manuel Serapio. *Globalizing Industrial Research and Development.* U.S. Department of Commerce, Technology Administration, September 1999.

[7] Raymond J. Mataloni, Jr., "U.S. Multinational Companies: Operations in 2001," *Survey of Current Business*, November 2003.

CHAPTER IV:

INDUSTRY-LEVEL EFFECTS OF INFORMATION TECHNOLOGY USE ON OVERALL PRODUCTIVITY

By Jesus Dumagan, Gurmukh Gill and Cassandra Ingram*

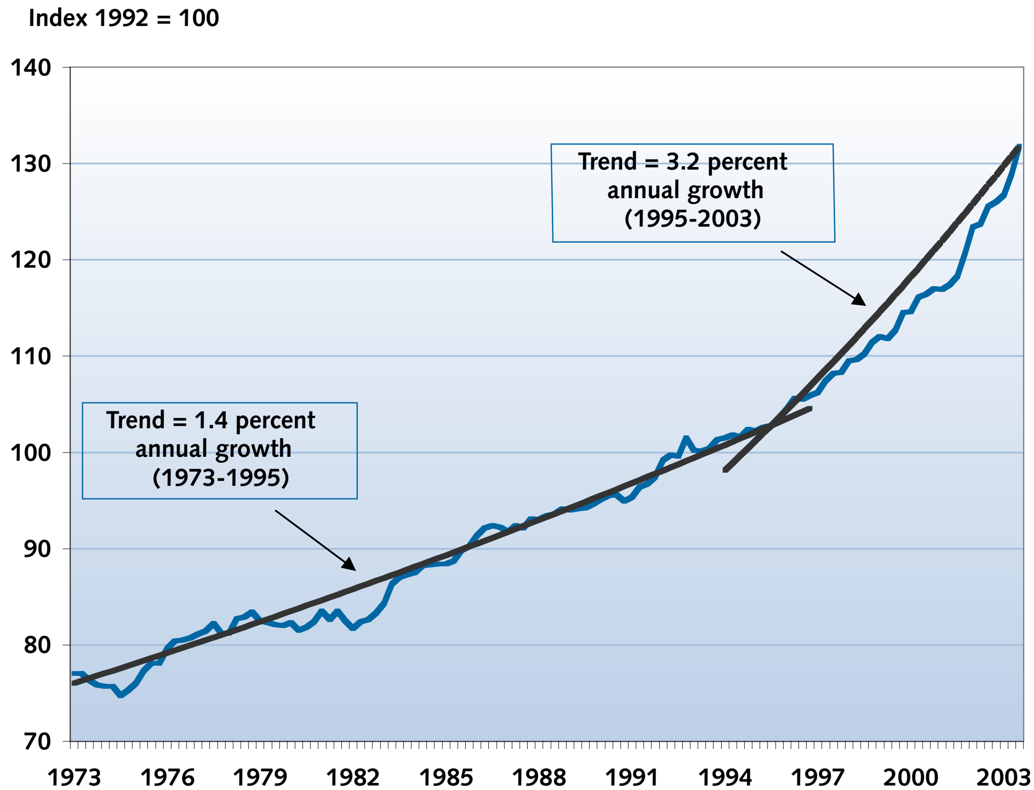
Beginning in the mid-1990s and continuing until mid-2000, the U.S. economy experienced a resurgence of labor productivity growth—accompanied by high output growth, low overall price growth, and low unemployment. (Figure 4.1.) This resurgence in labor productivity growth stemmed mostly from investment in and use of information technology (IT). Using industry-level BEA data, this chapter examines the role of IT in reviving and spreading productivity growth in the U.S. non-farm economy during 1989–2001.

The widespread dispersion of productivity growth across major sectors of the economy—largely paralleling the spread of IT—suggests that massive IT investments by U.S. industries are producing positive and probably lasting changes in the nation's economic potential. These conclusions add to recent findings by other economists concerning the widespread and lasting impacts of IT on the revival of U.S. productivity growth.[1]

* Mr. Dumagan (jess.dumagan@esa.doc.gov) is a senior economist; Mr. Gill (gurmukh.gill@esa.doc.gov) is senior executive for economic research; and Ms. Ingram (cassandra.ingram@esa.doc.gov) is an economist, all in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

[1] The findings in this chapter are consistent with those of recent studies by Baily and Lawrence, *ibid*.; Council of Economic Advisers, "Annual Report of the Council of Economic Advisers," in *Economic Report of the President* (January 2001); Kevin J. Stiroh, "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?," Federal Reserve Bank of New York, *Staff Reports*, no. 115 (January 2001); Kevin J. Stiroh, "Investing in Information Technology: Productivity Payoffs for U.S. Industries," Federal Reserve Bank of New York, *Current Issues in Economics and Finance*, vol. 7, no. 6 (June 2001), pp. 1–6; McKinsey Global Institute, "US Productivity Growth 1995–2000: Understanding the Contribution of Information Technology Relative to Other Factors," Washington, DC (October 2001); Stephen D. Oliner and Daniel E. Sichel, "Information Technology and Productivity: Where Are We Now and Where Are We Going?" The Federal Reserve Board, Washington, DC (May 10, 2002), available at http://www.federalreserve.gov//pubs/feds/2002/200229/200229abs.html; and Dale W. Jorgenson, Mun S. Ho, and Kevin J. Stiroh, "Lessons from the U.S. Growth Resurgence," presented at the U.S. Department of Commerce Transforming Enterprise Conference, Washington, DC (January 27–28, 2003), available at http://post.economics.harvard.edu/faculty/jorgenson/papers/CESIfo6final.pdf.

Figure 4.1. Average Annual Productivity Growth Accelerated in Non-farm Business Sector after 1995



Source: Bureau of Labor Statistics. Index on logarithmic scale

Productivity growth from 1973 to 1995 averaged about 1.4 percent annually. After mid-1995, including the recession year and the strong productivity growth experienced during 2002 and 2003, productivity growth has been robust and maintained a trend growth rate of 3.2 percent annually.

Data and Methods

In this study we calculate the contributions of individual industries to the growth of gross domestic product (GDP), total full-time equivalent (FTE) workers, and overall productivity (GDP/FTE). This industry-by-industry approach provides building blocks for reviewing the performance of individual industries, sectors or selected groups of industries across time and across industries. The analysis is based on BEA annual data for the period 1989–2001 on industry-level GDP and FTE workers for 55 industries of the U.S. private non-farm business sector.[2]

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[2] Since this study is an update, we start from 1989, the starting year of our earlier analysis in Chapter 4 of *DE 2002*, and add one more year 2001 for which the latest data are available. (See Appendix 4.A and Appendix 4.B for more details.) As in *Digital Economy 2002*, Chapter 4, the nonfarm business sector industries include those classified by BEA under *mining*, *construction*, *manufacturing durables*, *manufacturing nondurables*, *transportation and public utilities*, *wholesale trade*, *retail trade*, *finance and insurance*, and *services*. *Real estate* in the usual *FIRE* group of industries (consisting of *finance*, *insurance*, and *real estate*) is excluded in this analysis because real estate includes value-added from owner-occupied housing for which there is no corresponding FTE.

To determine IT's effects on productivity growth, we ranked industries based on the intensity in their use of IT equipment[3] per worker (FTE). We then grouped these industries into two groups, either IT-intensive or less IT-intensive, each group accounting for 50 percent of aggregate GDP. This grouping enables us to compare the performance of the IT-intensive to less IT-intensive industries.

Appendix 4.A explains in more detail the method used in this chapter to estimate each industry's contribution to the economy's productivity growth and to calculate IT-intensities. Appendix 4.B presents the industry rankings. Appendix 4.C compares the methods used in this study with those used in similar studies that analyze the impacts of IT on productivity growth revival and acceleration (see footnote 1).

IT and Growth in GDP and FTE

Overall productivity growth is growth in the economy's GDP/FTE ratio. Alternatively, productivity growth is the difference between GDP growth and FTE growth. Thus, as a background to the analysis of the effects of IT on productivity growth, we first review growth trends in GDP and FTE separately for the IT-intensive group of industries, the less IT-intensive group, and for all industries in the non-farm business sector.

GDP Growth

Table 4.1 presents real GDP growth figures for various analytically interesting time periods and by IT-intensity grouping. From 1989 to 2001, the average annual GDP growth of 4.41 percent in the IT-intensive industries was almost twice the 2.44 percent growth in the less IT-intensive industries. During sub-periods in the time span 1989 to 2001, GDP growth in the IT-intensive industries was consistently greater than GDP growth in less IT-intensive industries.

Average annual GDP growth also accelerated (1995–2001 over 1989–1995) more in IT-intensive industries (2.55 percentage points) than in less IT-intensive industries (1.29 percentage points). In the economic downturn of 2001, however, GDP growth was weak and slowed to 0.29 percent in IT-intensive and to 0.17 percent in less IT-intensive industries.

Table 4.1. GDP Growth, 1989–2001

Industry	Avg GDP Growth 1989–2001	Avg GDP Growth 1989–1995	Avg GDP Growth 1995–2000	2000–01	Avg GDP Growth 1995–2001
IT-Intensive	4.41	3.13	6.76	0.29	5.68
Less IT-Intensive	2.44	1.80	3.68	0.17	3.09
All Industries	3.41	2.45	5.20	0.23	4.37

Note: GDP is gross domestic product. The industries covered are those in the non-farm business sector excluding real estate, as explained in footnote 2.

Source: ESA estimates derived from BEA data.

[3] IT equipment covers computers and peripheral equipment, software, and other information processing equipment.

Table 4.2. FTE Growth, 1989–2001

Industry	Avg FTE Growth 1989–2001	Avg FTE Growth 1989–1995	Avg FTE Growth 1995–2000	2000–01	Avg FTE Growth 1995–2001
IT-Intensive	1.33	0.73	2.87	–2.73	1.93
Less IT-Intensive	2.01	1.80	2.59	0.43	2.23
All Industries	1.77	1.42	2.69	–0.68	2.13

Note: FTE is full-time equivalent worker. The industries covered are those in the non-farm business sector excluding real estate, as explained in footnote 2.

Source: ESA estimates derived from BEA data.

FTE Growth

Table 4.2 presents information on employment growth, as measured by change in the number of FTE workers for various time periods, highlighting differences between IT-intensive and less IT-intensive industries. From 1989 to 2001, average annual FTE growth was lower in the IT-intensive industries (1.33 percent) than in less IT-intensive industries (2.01 percent). This changed during the 1995 to 2000 period, when average annual FTE growth was somewhat greater in the IT-intensive industries (2.87 percent) compared to the less IT-intensive industries (2.59 percent). During the economic downturn of 2001, however, FTE growth in IT-intensive industries declined dramatically to –2.73 percent, whereas FTE growth in less IT-intensive industries recorded a modest increase of 0.43 percent.

Major Findings

Productivity Growth Remains High in IT-intensive Industries

Our industry-level analysis shows that between 1989 and 2001 average productivity growth for all industries was 1.60 percent (Table 4.3 and Figure 4.2). Average growth for IT-intensive industries for this period was 3.03 percent, far exceeding growth in the less IT-intensive industries which averaged 0.42 percent. During the economic downturn of 2001, productivity growth in IT-intensive industries remained strong and relatively stable at 3.10 percent, buoying productivity growth for all industries into positive territory at 0.91 percent.[4] Growth in the less IT-intensive industries, however, fell to –0.26 percent.

[4] The calculations in this chapter are based on BEA industry-level GDP and FTE data for nonfarm business sector industries (defined in footnote 2) available at the start of this year. BEA has not updated these data since then. At the time we calculated the above 2001 GDP per FTE annual growth rate of 0.91 percent, BLS released a comparable 2001 annual output per hour growth rate of 1.1 percent for the nonfarm business sector. The slight difference could be explained by differences in industry coverage. This could lead to differences (1) between our aggregate GDP and the aggregate output used by BLS and (2) between our total FTE and the equivalent total hours used by BLS. However, BLS has since updated the 2001 annual output per hour growth from 1.1 to 1.9 percent based largely on BLS' revised estimates of 2001 total hours. However, we are unable to update our 2001 GDP per FTE annual growth rate of 0.91 percent, or any of our calculations, because the next updates will be released after the release of this report. BEA's NIPA Comprehensive Revision will be released in December 2003 and BEA's GDP-by industry Comprehensive Revision will be released in June 2004.

Table 4.3. Productivity (GDP per FTE) Growth, 1989–2001

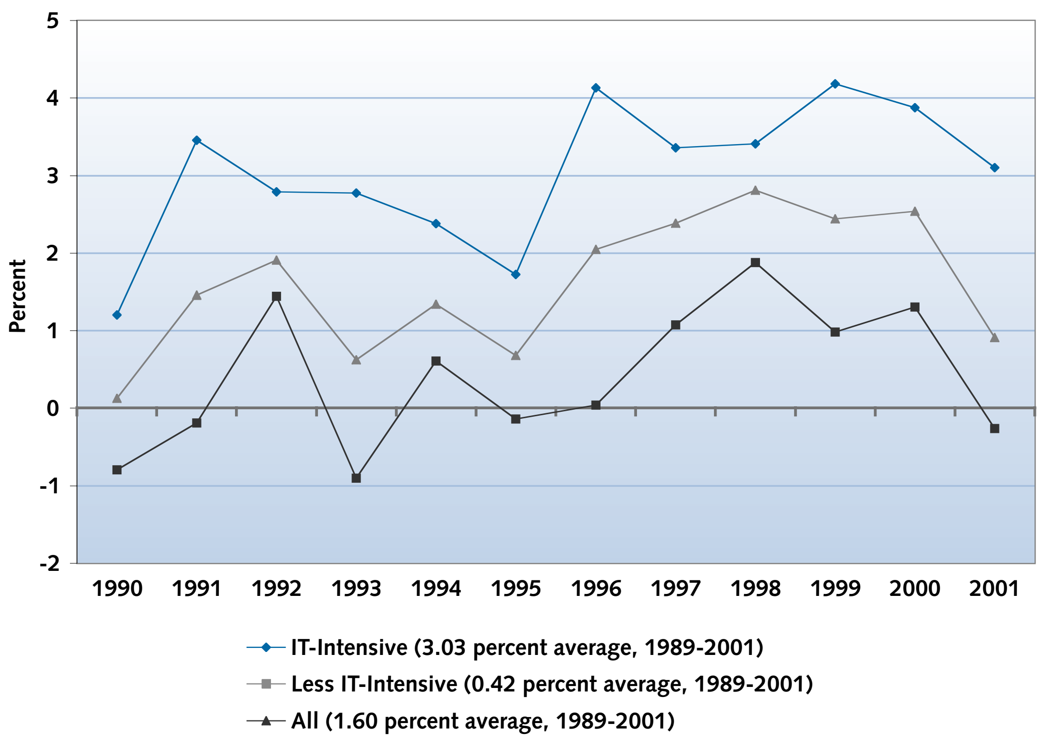
Industry	Avg GDP/FTE Growth 1989–2001	Avg GDP/FTE Growth 1989–1995	Avg GDP/FTE Growth 1995–2000	2000–01	Avg GDP/FTE Growth 1995–2001
IT-Intensive	3.03	2.39	3.79	3.10	3.67
Less IT-Intensive	0.42	0.00	1.05	–0.26	0.83
All Industries	1.60	1.02	2.44	0.91	2.19

Note: GDP is gross domestic product. FTE is full-time equivalent worker. The industries covered are those in the non-farm business sector excluding real estate, as explained in footnote 2.

Source: ESA estimates derived from BEA data.

For comparison purposes, Table 4.3 and Figure 4.2 also present productivity growth for the above grouping of industries by IT-intensity for analytically interesting time periods. All post-1995 groupings, for IT-intensive industries, including even the recession year of 2001, exhibit stronger productivity growth than the pre-1995 groupings, suggesting that the increase in labor productivity growth in IT-intensive industries is not transitory.

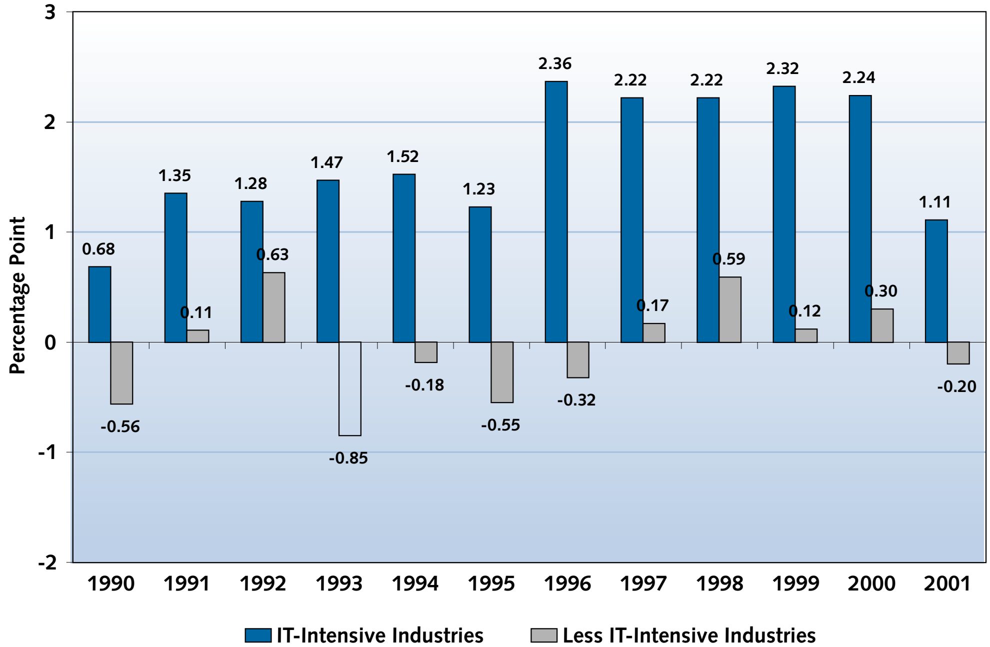
Figure 4.2. Labor Productivity Growth in IT-Intensive, Less IT-Intensive and All Industries of the U.S. Non-Farm Business Sector 1989–2001



Note: The industries covered are those in the non-farm business sector, excluding real estate.

Source: ESA estimates derived from BEA data.

Figure 4.3. Contributions to Overall Labor Productivity Growth by IT-Intensive and Less IT-Intensive Industries of the U.S. Non-farm Business Sector 1990–2001



Note: The industries covered are those in the non-farm business sector, excluding real estate.

Source: ESA estimates derived from BEA data.

IT's Contribution to Productivity Growth Also Significant

Annual comparisons of contributions to overall productivity growth further demonstrate that contributions of IT-intensive industries to productivity growth were much greater than those of less IT-intensive industries (Figure 4.3).

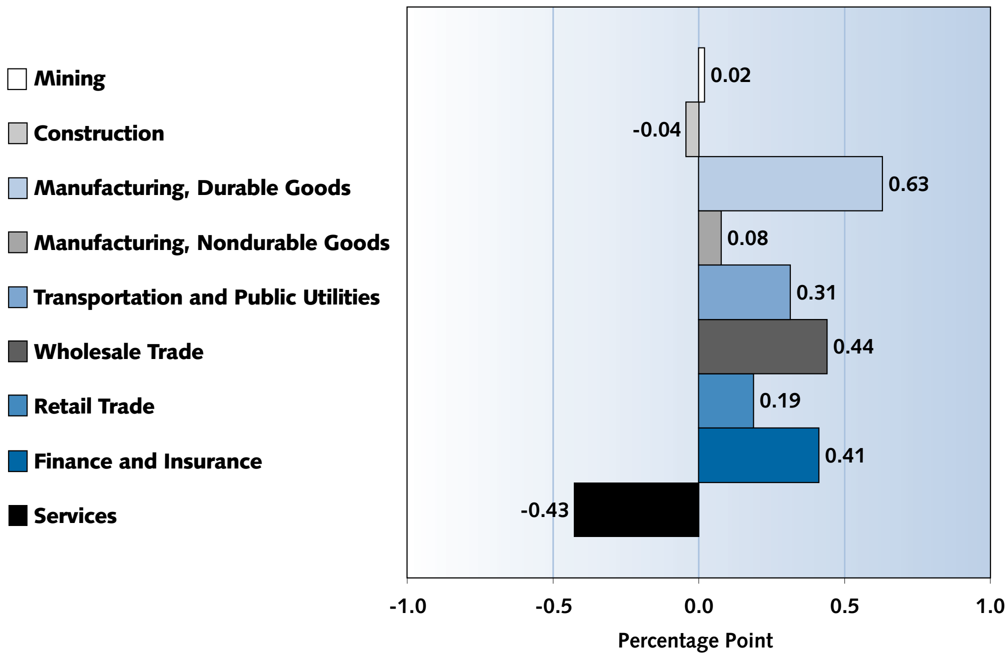
For the 1989–2001 period as a whole, the contribution of IT-intensive industries to the average annual labor productivity growth for the non-farm economy of 1.60 percent was 1.67 percentage points. This was more than 100 percent of this overall labor productivity growth. Less IT-intensive industries had a slightly negative contribution of –0.06 percentage points.[5]

Labor Productivity Growth Widely Spread Across Industries

Contributions to long-run productivity growth (1989 to 2001) are widely dispersed among industries (Figure 4.4.) While manufacturing durables made the largest contribution, 0.63 percentage points (39 percent), to the average annual growth of 1.60 percent, sectors outside of manufacturing durables also made significant contributions. Wholesale trade contributed 0.44 percentage points (28 percent) to productivity growth and accounts for a larger percent of productivity growth contribution than even the finance and insurance industry.

[5] Because Figure 4.3 involves *additive* "contributions," productivity growth of all industries for each year can be calculated by adding the IT-intensive industries' contribution to the less IT-intensive industries' contribution. For example, in 2001, productivity growth was 0.91 percent or 1.11 percentage points plus –0.20 percentage points. To get the average growth contribution by either the IT-intensive or less IT-intensive industries over the 1989–2001 period, simply sum the contributions for each industry group across 12 years and then divide by twelve.

Figure 4.4. Contributions to Labor Productivity Growth in U.S. Non-Farm Business Sector by Major Industry Group 1989–2001



Note: The Finance and Insurance group excludes real estate.

Source: ESA estimates derived from BEA data.

Other recent studies have reached similar conclusions.[6] McKinsey Global Institute (MGI) found that 38 industry sectors recorded productivity increases after 1995; together, these sectors accounted for 70 percent of GDP. Analyses by the Council of Economic Advisers (CEA) and Kevin Stiroh, each found that more than half of the industry sectors registered productivity increases. Robert Gordon, who asserted in 2000 that labor productivity growth was narrowly concentrated in durable manufacturing sectors has updated his analysis. He now also finds evidence of acceleration of productivity growth well beyond the durable goods sector.[7] Finally, a 2002 study by Jack Triplett and Barry Bosworth took a detailed look at the service sector (examining 27 industries in this sector) and concluded that IT-intensive industries in the US economy are predominantly services industries and that the labor productivity growth in this sector has been comparable with that in the overall economy. Moreover, within services, productivity is broad-based and not just limited to a few large industries.[8]

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[6] For a review and synthesis of the relevant literature, see Jason Dedrick, Vijay Gurbuxani, and Kenneth L. Kraemer, "Information Technology and Economic Performance: A Critical Review of Empirical Evidence," Center for Research on Information Technology and Organization, University of California, Irvine (March 2003).

[7] See the studies by Kevin Stiroh, CEA, MGI noted in footnote 1, Robert J. Gordon, "Does the 'New Economy' Measure Up to the Great Inventions of the Past?," *Journal of Economic Perspectives* (Fall 2000), 49–74 and Robert J. Gordon, "Technology and Economic Performance in the American Economy," National Bureau of Economic Research, Working Paper, no. 8771 (2002).

[8] Jack Triplett and Barry Bosworth, "Services Industries and U.S. Productivity Acceleration: Contributions of IT and MFP," presented at the Brookings Institution Workshop on Economic Measurement, Washington, DC (May 17, 2002).

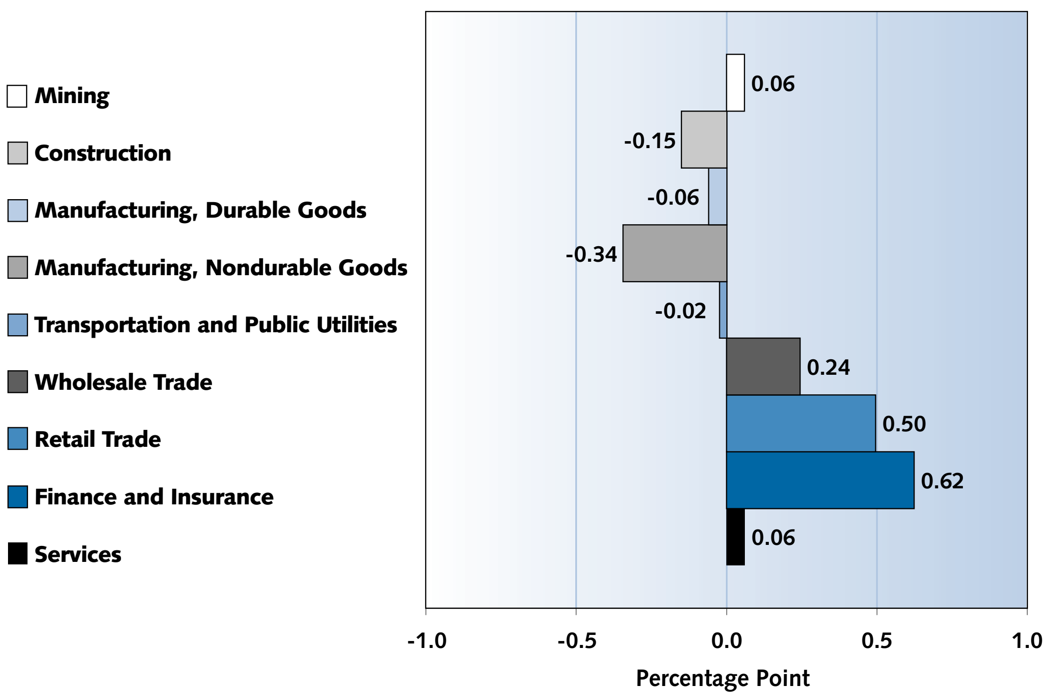
LABOR PRODUCTIVITY GROWTH WIDELY SPREAD EVEN DURING THE 2001 RECESSION

During the 2001 recession, productivity growth for all industries averaged 0.91 percent. Positive growth contributions were widely spread among 29 of the 55 industries comprising the U.S. non-farm economy. Five major sectors (mining, wholesale trade, retail trade, finance and insurance, and services) had positive contributions while four major sectors (construction, durable manufacturing, nondurable manufacturing, and transportation and public utilities) made negative contributions to productivity growth in 2001. (Figure 4.5.)

Among major sectors that made positive contributions, the finance and insurance sector contributed most. It contributed about 0.62 percentage points (68 percent) of the 0.91 percent productivity growth in 2001. A more detailed analysis of this sector showed that the largest contributions came from IT-intensive industries, namely, securities and commodity brokers (26 percent), holdings and other investment offices (26 percent) and nondepository institutions (15 percent).

Among the remaining major industry sectors, retail trade (one of the less IT-intensive industries) made the second highest contribution (54 percent)—largely because of its large weight in the economy—followed by IT-intensive wholesale trade (27 percent). The mining and services sectors made small positive contributions to productivity growth in 2001.

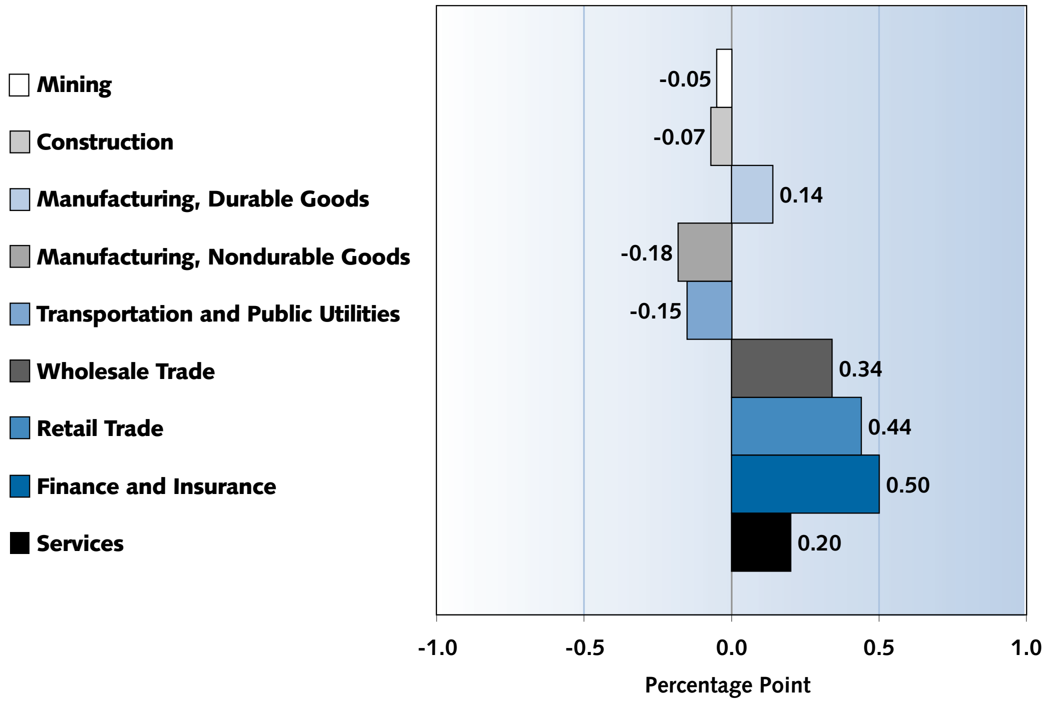
Figure 4.5. Contributions to Labor Productivity Growth in U.S. Non-Farm Business Sector by Major Industry Group, 2001



Note: The Finance and Insurance group excludes real estate.

Source: ESA estimates derived from BEA data.

Figure 4.6. Contributions to Productivity Growth Acceleration in U.S. Non-Farm Business Sector by Major Industry Group 1995–2001 Over 1989–1995



Note: The Finance and Insurance group excludes real estate.

Source: ESA estimates derived from BEA data.

Within the services sector, IT-intensive business services stood out with a large positive contribution of 0.37 percentage points (41 percent). This was mostly offset by the negative contributions of many other industries in this sector.

Even within sectors that made negative contributions overall, some individual IT-intensive industries had notable positive contributions. For example, the electronic and other electric equipment industry (which includes IT-producers among others in the durable manufacturing sector) made a robust 0.24 percentage points (26 percent) contribution to the 0.91 percent productivity growth in 2001. Likewise, the telephone and telegraph along with the radio and television industries (in the transportation and public utilities sector) made robust contributions of 0.31 percentage points (34 percent) and 0.11 percentage points (12 percent), respectively, to overall productivity growth.

Acceleration in Labor Productivity Growth Widely Spread Across Industries

Contributions to productivity growth acceleration (i.e., growth during 1995–2001 over that during 1989–1995) of 1.17 percentage points were also widely distributed across industries and also differed from the analysis of long-run (1989–2001) and 2001 growth contributions. (Figure 4.6.) The bulk of this acceleration during the post-1995 period can be attributed to IT-intensive industries, which accounted for 0.82 percentage points (71 percent) of this growth acceleration. In contrast, the less IT-intensive half of industries contributed only 0.34 percentage points (29 percent) to overall acceleration in productivity growth.

Twenty-nine industries contributed positively to the 1.17 percentage point growth acceleration during 1995 to 2001 over growth during 1989 to 1995. Productivity growth accelerated not only in manufacturing durables but also in wholesale trade, retail trade, finance and insurance and services. Manufacturing durables contributed 0.14 percentage points (12 percent) to the overall 1.17 percentage point productivity growth acceleration. The largest contribution came from finance and insurance (42 percent), followed by retail trade (38 percent), wholesale trade (29 percent) and services (17 percent).

EMPLOYMENT AND PRODUCTIVITY GROWTH IN 2001—THE RECESSION YEAR

Our analysis of the components of productivity growth, finds that modest GDP growth coupled with a sharp decline in FTE growth in the 2001 recession year kept productivity growth in IT-intensive industries high. Therefore, productivity growth in the IT-intensive industries in 2001 appears to arise largely from the ability of these industries to shed jobs during lean periods.

Moreover, some of this job shedding may be related directly to IT. A review of Occupational Employment Statistics data in some industries suggests that management and office and administrative support occupations represent the bulk of employment losses in a number of IT-intensive industries.[9]

For example, of the IT-intensive industries that contributed significantly to productivity growth, wholesale trade and business services had the largest job losses or reductions in employment growth and only a slight decline in GDP growth. The shares of total jobs eliminated in wholesale trade, by occupation, were office and administrative services (24 percent), management occupations (18 percent), and transportation and material moving occupations (16 percent). Similarly, in business services, the largest decline in jobs was in the office and administrative support occupations (27 percent), followed by installation, maintenance and repair occupations (20 percent) and computer and mathematical occupations (12 percent). While occupations, such as office and administrative occupations, were clearly IT-displaceable, others such as management occupations also appear susceptible to IT-enabled cost-cutting during a recessionary environment. Many of these occupations also have been susceptible to outsourcing/offshoring.

[9] Bureau of Labor Statistics, "Occupational Employment Statistics by Industry" (January 2003) at http://www.bls.gov/oes/home.htm.

Appendix 4.A. Data and Methods

The present analysis applies the growth decomposition methodology of Chapter 4, U.S. Department of Commerce, *Digital Economy 2002*, Washington, DC (February 2002), to *more* data over a *longer* period. [The *DE 2002* report is available at http://www.esa.doc.gov/pdf/DE2002r1.pdf.] A description of this methodology is included in Box 4.1, p. 32, of that report and spelled out in a separate mathematical Appendix to Chapter 4. The methodology follows BEA's chained-dollar procedures to determine aggregate real (chained 1996 dollars) GDP and to decompose real GDP growth into the contributions of industries. The appendix also presents a decomposition of total FTE growth into the contributions of industries. These two decompositions are then combined to show the decomposition of aggregate GDP/FTE growth into industry-level contributions. The procedure is described below.

Decomposing Aggregate Productivity Growth (GDP per FTE) Into Industry-Level Contributions

The contribution of an industry to growth of aggregate GDP equals the growth of the industry's GDP multiplied by its share in aggregate GDP. Similarly, an industry's contribution to total FTE growth equals the growth of the industry's FTE multiplied by its share in total FTE. In this study, overall labor productivity growth equals growth of aggregate GDP minus growth of total FTE. Therefore, an industry's contribution to overall labor productivity growth equals the *growth of the industry's GDP multiplied by its share in aggregate GDP* minus the *growth of the industry's FTE multiplied by its share in total FTE*. Contrast this, however, with the labor productivity growth of an industry viewed in isolation. In the latter case, the industry's productivity growth equals the growth of its GDP minus the growth of its FTE. Thus, it can be seen that an industry with a *positive* productivity growth viewed in isolation could make a *negative* contribution to overall productivity growth if the industry has a *smaller* share in aggregate GDP than its share in total FTE. The converse case is possible that an industry with a *negative* productivity growth viewed in isolation could make a *positive* contribution to overall productivity growth if the industry has a *larger* share in aggregate GDP than its share in total FTE. In general, these possibilities imply that it could be misleading to gauge an industry's contribution to the overall performance of the economy simply by looking at the performance of the industry in isolation. These considerations underlie this chapter's decomposition of overall productivity growth into the contributions of individual industries.

Determining More IT-Intensive Top-Half and Less IT-Intensive Bottom-Half Groups of Industries

In Chapter 4 of *DE 2002*, the IT-intensity ranking was determined for 55 two-digit SIC industries based on the highest to lowest *1996 value* of the *ratio* of IT capital to FTE workers for *each* industry divided by the *overall ratio* of IT capital to FTE workers for *all* industries. Industries were then divided into a top-half group (i.e., those relatively more IT-intensive industries accounting for a 50 percent share of aggregate nominal GDP) and a bottom-half group (i.e., those relatively less IT-intensive industries accounting for the remaining 50 percent of GDP). Each industry's share is the *average* of its annual shares of nominal GDP during 1989–2000. Data on IT capital, GDP and FTE are from BEA. IT data are net stocks at current cost that include 15 of BEA's nonresidential fixed asset types from mainframe computers to office and accounting equipment.

In this analysis, the IT-intensity ranking of industries is new in that it is no longer based only on the 1996 value defined above but on the *average* of similar annual values for each industry during 1989–2001. This matches the determination of the top-half and bottom-half groups of industries above based on the *average* of annual shares of nominal GDP for the period 1989–2001, which adds 2001 to the period covered by Chapter 4, *DE 2002*. As a result, three industries that were close to the cut-off between the top-half and bottom-half groups in the previous ranking were shifted in this new ranking. (See Appendix 4.B for a listing of industries based on the new ranking.) Two industries [nonmetallic minerals, except fuels (SIC 14) and miscellaneous repair services (SIC 76)] that were in the top-half group of industries in the earlier analysis of Chapter 4 above are now in the bottom-half. In exchange, one industry group [primary metal industries (SIC 33)] that was in the bottom-half of Chapter 4 is in the top-half group in the present analysis.

Appendix 4.B. IT-Intensity Rankings

Table 4.B. Part 1. IT-Intensity Rankings by Ratio of Individual Industry Average ITEQ/FTE to Overall Average ITEQ/FTE and Cumulative Sum of Average Shares of Nominal GDP

Industry	SIC	Industry Average ITEQ/FTE over Overall Average ITEQ/FTE (1989–2001)	Cumulative Sum of Average Shares of Nominal GDP (%) (1989–2001)
Top-Half IT-intensive Industries with 50 Percent Nominal GDP Shares			
Telephone and telegraph	481,482,489	22.21	2.82
Nondepository institutions	61	11.41	3.55
Pipelines, except natural gas	46	9.96	3.65
Radio and television	483,484	9.70	4.49
Electric, gas, and sanitary services	49	6.22	8.08
Petroleum and coal products	29	5.80	8.66
Oil and gas extraction	13	3.59	10.11
Chemicals and allied products	28	3.23	12.67
Transportation services	47	2.27	13.11
Depository institutions	60	2.17	17.48
Holding and other investment offices	67	2.13	17.69
Security and commodity brokers	62	2.12	19.30
Motion pictures	78	2.00	19.73
Tobacco products	21	1.99	20.00
Metal mining	10	1.98	20.10
Insurance carriers	63	1.73	22.17
Railroad transportation	40	1.71	22.59
Instruments and related products	38	1.51	23.56
Wholesale trade	50,51	1.44	32.73
Transportation by air	45	1.35	33.92
Electronic and other electric equipment	36	1.19	36.40
Paper and allied products	26	0.93	37.35
Printing and publishing	27	0.85	38.93
Industrial machinery and equipment	35	0.83	41.35
Business services	73	0.79	47.20
Other transportation equipment	37exc 371	0.77	48.28
Primary metal industries	33	0.57	49.15
Coal mining	12	0.57	49.35

Note: BEA's industry GDP at the 2-digit SIC level is too broad or lumpy for our purposes. IT intensity within a 2-digit industry varies a great deal because some component 3-digit or 4-digit industries are IT-intensive while other are not. However, because of data constraints, we had to apply our IT intensity criterion at the 2-digit level. Thus, IT intensive and non-IT intensive industries within a 2-digit level are assigned the same 2-digit ranking. For example, SIC 35 and SIC 36 include the IT-producing industries in this report (see Chapter I) that are IT-intensive. However, the IT intensity ranking of SIC 35 and SIC 36 puts them near the bottom of the Top-Half group above because these 2-digit categories include 3-digit and 4-digit industries that are non-IT-intensive.

Source: ESA estimates derived from BEA data.

Table 4.B. Part 2. IT-Intensity Rankings by Ratio of Individual Industry Average ITEQ/FTE to Overall Average ITEQ/FTE and Cumulative Sum of Average Shares of Nominal GDP

Industry	SIC	Industry Average ITEQ/FTE over Overall Average ITEQ/FTE (1989–2001)	Cumulative Sum of Average Shares of Nominal GDP (%) (1989–2001)
Bottom-Half Less IT-intensive Industries with 50 Percent Nominal GDP Share			
Food and kindred products	20	0.57	51.44
Personal services	72	0.56	52.31
Nonmetallic minerals, except fuels	14	0.55	52.48
Legal services	81	0.55	54.35
Miscellaneous repair services	76	0.52	54.73
Motor vehicles and equipment	371	0.47	56.25
Stone, clay, and glass products	32	0.45	56.83
Water transportation	44	0.43	57.05
Health services	80	0.41	64.81
Other services, n.e.c.	83,84,86,87,89	0.37	70.21
Insurance agents, brokers, and service	64	0.37	71.07
Local and interurban passenger transit	41	0.34	71.31
Trucking and warehousing	42	0.32	72.98
Fabricated metal products	34	0.29	74.54
Miscellaneous manufacturing industries	39	0.27	74.97
Rubber and miscellaneous plastics products	30	0.24	75.81
Textile mill products	22	0.24	76.26
Auto repair, services, and parking	75	0.21	77.46
Retail trade	52–59	0.17	89.54
Lumber and wood products	24	0.17	90.24
Hotels and other lodging places	70	0.15	91.37
Leather and leather products	31	0.15	91.45
Furniture and fixtures	25	0.15	91.82
Amusement and recreation services	79	0.13	92.80
Apparel and other textile products	23	0.12	93.29
Construction	15,16,17	0.08	98.98
Educational services	82	0.06	100.00

Note: BEA's industry GDP at the 2-digit SIC level is too broad or lumpy for our purposes. IT intensity within a 2-digit industry varies a great deal because some component 3-digit or 4-digit industries are IT-intensive while other are not. However, because of data constraints, we had to apply our IT intensity criterion at the 2-digit level. Thus, IT intensive and non-IT intensive industries within a 2-digit level are assigned the same 2-digit ranking. For example, SIC 35 and SIC 36 include the IT-producing industries in this report (see Chapter I) that are IT-intensive. However, the IT intensity ranking of SIC 35 and SIC 36 puts them near the bottom of the Top-Half group above because these 2-digit categories include 3-digit and 4-digit industries that are non-IT-intensive.

Source: ESA estimates derived from BEA data.

Appendix 4.C. Comparison With Other Studies on IT's Role in U.S. Productivity Growth Acceleration

This study decomposes overall productivity (aggregate GDP over total FTE) growth into the *percentage point contributions* of individual industries (see Appendix 4.A) for each year during 1989–01. This entire period is then broken into two sub-periods, 1989–95 and 1995–01, and the simple averages of each industry's annual percentage point contributions are computed for each sub-period. The difference between the 1995–2001 average and the 1989–95 average is the industry's contribution to the *acceleration* (i.e., average overall growth during 1995–2001 less the average overall growth during 1989–95) in overall productivity growth. IT's role in this acceleration is assessed by classifying the industries into two groups, the *more* IT-intensive top-half group and the *less* IT-intensive bottom-half group. (See Appendix 4.B.) Because the contributions above are additive across industries, the sum of the contributions of the industries in each sub-group can be obtained and compared as a basis for gauging IT's role in productivity growth acceleration.

Kevin J. Stiroh, "Information Technology and the U.S. Productivity Revival: What Do the Industry Data Say?," *Federal Reserve Bank of New York*, Staff Reports, no. 115 (January 2001) provides alternative methods for determining IT's productivity impacts both at the aggregate level (employing separately a growth accounting framework, regression analysis, as well as production function estimation) and at the industry level, implementing a decomposition of overall productivity growth into percentage point contributions of individual industries. Stiroh's decomposition is conceptually *similar* to the decomposition framework of this chapter, but there are some differences. One is that he defines productivity as output per hour where output is a value-added measure, as it should be, for aggregate productivity but is either gross output (his preferred definition) or value-added at the industry level. In contrast, in this chapter, productivity is defined as GDP per FTE for both aggregate and industry level productivity. Our use of GDP is based on the fact that GDP is value-added and, by definition, is the industry's *contribution* to aggregate output. Moreover, the use of GDP at the industry level makes the decomposition simpler because it does not involve intermediate inputs that cancel out at the aggregate level.

To assess IT's growth impacts in his decomposition framework, Stiroh classifies industries into IT-producing, IT-using, and others. IT-using industries are those that have an "above-median value for the preferred IT-intensity indicator, the 1995 nominal IT share of capital services." In contrast, IT-producing industries are not separated in this chapter but are part of the more IT-intensive group defined above. On the whole, Stiroh's IT-producing and IT-using groups correspond to this chapter's *more* IT-intensive group and his "other industries" correspond to the *less* IT-intensive group. Finally, he employs a similar framework for analyzing contributions to productivity growth acceleration comparing average growth during 1987–95 to that during 1995–99.

Martin Neil Baily and Robert Z. Lawrence, "Do We Have a New E-conomy," presented at the American Economic Association Meetings, New Orleans, LA (January 5, 2001) also assess at the industry level the role of IT in aggregate productivity growth. However, they do not decompose aggregate productivity growth into industry-level contributions. Instead, they determine the acceleration in productivity (an income-side measure of value-added per FTE) growth for each industry by the difference between an industry's average productivity growth during 1995–99 and the average during 1989–95. Then they compare each industry's productivity growth acceleration to the *overall* (for all private industries) average productivity growth acceleration from 1989–95 to 1995–99. The role of IT is then assessed by showing that those industries that are "intense IT users" (based on "IT spending relative to value added") generally have higher individual productivity growth acceleration compared to the overall acceleration.

McKinsey Global Institute, *US Productivity Growth*, 1995–2000, Washington, DC (October 2001) implemented a procedure similar to this chapter's framework for decomposing aggregate productivity growth into individual industry contributions where at both the aggregate and industry levels output is a value-added measure (GDP) from BEA. One difference is that MGI uses BEA's "persons engaged in production" (PEP) for employment while this chapter uses BEA's FTE. The other difference is that, as part of the decomposition of aggregate productivity growth, this chapter uses BEA's *exact* formula for an industry's contribution to the growth of aggregate chained dollar GDP, while MGI uses an approximate formula (MGI, *op. cit.*, Exhibit A4 of the chapter on "Objectives & Approach.") Overall, however, this chapter's and MGI's empirical findings are quantitatively similar.

A more recent study by Dale Jorgenson, Mun Ho, and Kevin Stiroh, "Lessons from the U.S. Growth Resurgence" (January 17, 2003), presented at the First International Conference on the Economic and Social Implications of Information Technology, Department of Commerce, Washington DC, January 27–28, 2003, re-examined the role of IT during 1995 to 2000 when the U.S. experienced the unusual combination of rapid growth and lower inflation. They conclude that the U.S. productivity revival remains intact and that IT is the predominant source of this revival. Specifically, they found that the contribution of IT capital deepening from computer hardware, software, and telecommunications equipment greatly exceeded the contribution from all other forms of investment to labor productivity growth after 1995. Their findings are consistent with those of this chapter.

CHAPTER V:

IT AND ECONOMIC PERFORMANCE: EVIDENCE FROM MICRO DATA STUDIES

By B.K. Atrostic and Ron Jarmin*

Micro data—that is, data on individual businesses that underlie key economic indicators—allow us to go behind published statistics and ask how IT affects businesses' economic performance. Years ago, analyses indicated a positive relationship between IT and productivity, even when official aggregate statistics still pointed towards a "productivity paradox." Now, such analyses shed light on how varied that relationship is across businesses, and how IT makes its impacts. This chapter focuses on research about businesses based on micro data collected by the U.S. Census Bureau. We highlight the kinds of questions about the use and impact of IT that only micro data allow us to address.

Micro data studies in the United States and in other OECD countries show that IT affects the productivity and growth of individual economic units. Specific estimates of the size of the effect vary among studies. Researchers comparing manufacturing plants in the United States and Germany, for example, find that in each country investing heavily in IT yields a productivity premium, but that the premium is higher in the United States than it is in Germany. They also find that the productivity premium varies much more for U.S. manufacturers. This greater variability is consistent with the view that the U.S. policy and institutional environments may be more conducive to experimentation by U.S. businesses.

What kind of IT investments do U.S. businesses make? Census Bureau data on U.S. manufacturing establishments show that they invest in both computer networks and the kind of complex software that coordinates multiple business processes within and among establishments. About 50 percent of these plants have networks, while fewer than 10 percent have invested in this complex software. Such a wide difference between the presence of networks and

* Ms Atrostic (barbara.kathryn.atrostic@census.gov) is Senior Economist, and Mr. Jarmin (ron.s.jarmin@census.gov) is Acting Director, Center for Economic Studies, U.S. Census Bureau.

complex software in manufacturing, and equally wide-ranging differences in their presence among detailed manufacturing industries, highlight the diversity of IT use among businesses. Plants with networks have higher productivity, even after controlling for many of the plant's economic characteristics in the current and prior periods. Similar results are found in other OECD countries. Some studies suggest that businesses need to make parallel investments in worker training and revised workplace practices before IT investments yield productivity gains.

Careful micro data research shows that the relationship between IT and economic performance is complex. "IT" emerges as a suite of alternatives from which businesses make different choices. Estimates of the size of the effect, and how IT makes its impact, remain hard to pinpoint. Data gaps make it hard to conduct careful analyses on the effect of IT. Continuing efforts by researchers and statistical organizations are filling some of the data gaps, but the gaps remain largest for the sectors outside manufacturing—the sectors that are the most IT-intensive. More definitive research requires that statistical agencies make producing micro data a priority.

What Are Micro Data?

Micro data generally contain information about many characteristics of the economic unit, such as plant employment, years in business, share of IT in costs, ways it uses IT, and its economic performance. Micro data exist for both businesses and individuals, and can be developed by private and public organizations. This chapter focuses on research using micro data about businesses that are collected by the U.S. Bureau of the Census.

BENEFITS OF MICRO DATA RESEARCH

Standard analyses of productivity and similar economic phenomena frequently assume that businesses are identical, at least within an industry, and therefore also respond similarly to changes in economic circumstances. However, it is easy to challenge this assumption simply by observing the variety of businesses in any industry, no matter how narrowly the industry is defined, and how diverse their responses appear to be. Case studies in specific industries repeatedly bear out this observation.

Micro data allow us to assess the diversity of businesses and track behaviors such as their entry and exit into an industry. They also allow us to document changes in businesses' performance, such as employment, sales, and productivity, and see whether those changes are uniform among industries, within industries, or among businesses of given ages, sizes, and so forth. Two decades of research using micro data reveal tremendous variety in the economic characteristics and performance of businesses at any time, and over time.[1]

[1] An excellent summary is E. Barltesman and M. Doms, "Understanding Productivity: Lessons from Longitudinal Microdata," *Journal of Economic Literature*, Vol. 38 (September 2000). It reviews research conducted at the U.S. Census Bureau and gives references for reviews of micro data research conducted elsewhere. A detailed report on initial micro data research on productivity is provided in M. Baily, C. Hulten, and D. Campbell, "Productivity Dynamics in Manufacturing Plants," *Brookings Papers on Economic Activity: Microeconomics 1992*.

Micro data can paint a clearer picture of how aggregate economic statistics change. They also allow researchers to apply econometric techniques that take account of the kinds of complex relationships that simply cannot be presented in tables or other aggregated formats. Comparing findings from research studies using different data sets allows us to see which estimates appear to be robust, and which ones seem to depend on the specific data we use, and on the specific equations we estimate.

RESEARCH REQUIRES GOOD MICRO DATA

Micro data research takes advantage of the high-quality information about individual businesses that underlies major economic indicators. The micro data sets typically are large and nationally representative, making it more likely that they capture the tremendous diversity among businesses.[2]

Researchers often are able to link data at the micro level across surveys and over time. For example, consider the new information on whether businesses have computer networks, and how they use those networks that was collected in the Computer Network Use Supplement (CNUS) to the 1999 Annual Survey of Manufactures (ASM).[3] The plant-level micro data about computer networks collected in the CNUS can be linked to information about employment, shipments, use of other inputs, etc., collected about the same plants in the 1999 ASM and to ASMs for other years, and to data that was collected about the same plants in the 1997 Economic Census. Such exact linkages yield much richer information bases than any single supplement, survey, or census alone. When micro data can be linked, researchers also can use econometric techniques to control for unobserved characteristics that are specific to an individual plant or business. These techniques allow researchers to have more confidence that findings, such as the effect of IT actually are due to IT and not to related but unmeasured characteristics, such as good management or a skilled work force.

The Role of Information Technologies in Business Performance

Recent research using micro data generally concludes that IT and productivity are related. Indeed, micro data analyses indicated a positive relationship between IT and productivity when official aggregate statistics still pointed towards a “productivity paradox.” Two recent reviews of plant- or firm-level empirical studies of information technology (including but not limited to computers) and economic performance conclude that the literature shows positive relationships between information technology and productivity. However, specific estimates of the size of the effect vary widely among studies. How IT makes its impact also remains hard to pinpoint.

[2] While micro data provide raw material for important analyses, they are not a panacea. Researchers must address significant challenges when using existing micro data to analyze questions about the economic performance of businesses. See Z. Griliches, “Productivity, R&D, and the Data Constraint,” *American Economic Review*, Vol. 84 No. 1 (March 1994); and Z. Griliches, and J. Mairesse, “Production functions: The Search for Identification,” NBER Working Paper 5067 (March 1995).

[3] More information on these surveys is available at http://www.census.gov/eos/www/ebusiness614.htm.

THE ROLE OF IT IN PRODUCTIVITY—A BRIEF SURVEY OF THE LITERATURE

Many recent studies use micro data to document and describe the productivity of different kinds of businesses, and to examine its sources. The simple model that suggests productivity growth occurs among all existing plants simply does not fit with what the micro data show. Instead, the micro data show that much of aggregate productivity growth comes about through a much more diversified and dynamic process. Less productive plants go out of business, relatively productive plants continue, and the new entrants that survive are more productive than either. Micro data research on the effect of IT explores how IT fits into this complex picture of business behavior.

Dozens of research papers over the last decade examine various facets of the relationship between IT and productivity. Two recent reviews summarizing the current literature on IT and productivity conclude that there is an impact, although there is much variation among studies in the estimated magnitudes of that effect (Dedrick, J., Gurbaxani, V., and K. Kraemer, 2003, "Information Technology and Economic Performance: A Critical Review of the Empirical Evidence," *ACM Computing Surveys*, Vol. 35, No. 1, March and Stiroh, K. J., 2002, "Reassessing the Impact of IT in the Production Function: A Meta-Analysis," Federal Reserve Band of New York, November).[4]

Dedrick *et al.* (2003) review over 50 articles published between 1985 and 2002, many of which are firm-level studies with productivity as the performance measure. They conclude that firm-level studies show positive relationships, and that gross returns to information technology investments exceed returns to other investments. They warn against concluding that higher gross returns mean that plants are under-investing in information technology. Most studies do not adjust for the high obsolescence rate of information technology capital, which lowers net returns. Also, total investment in information technology may be understated because most studies measure only computer hardware, but not related labor or software, or costs of co-invention, such as re-engineering business processes to take advantage of the new information technology.

Stiroh (2002) reviews twenty recent empirical studies of the relationship between information technology and output and productivity. The studies generally find a positive effect of information technology on output. However, the estimates differ across studies, and the studies differ in many dimensions, including time periods covered and specific estimation techniques used. Stiroh looks for predictable effects of differences in characteristics of the studies, such as time periods, level of aggregation (e.g., industry, sector, or entire economy), and estimation techniques. He finds that much of the variation across studies in the estimates of the effect of information technology probably reflects differences in characteristics of the studies.

[4] Many of those studies, including many studies discussed in this chapter, were conducted at the Center for Economic Studies (CES) at the U.S. Census Bureau. Appendix 5.A describes both CES, a research unit that conducts research and supports the needs of researchers and decision makers throughout government, academia, and business, and some of the major data sources available there for micro data research on the impact of IT.

Stiroh also reports the findings of additional research he conducts using a single industry-level database to estimate many of the different equations used in the studies he reviewed. His research finds that information technology matters, but that even within a single database, estimates of the magnitude of that effect depend on the particular equation that is estimated.

Finally, Stiroh notes a potential for publication bias. Because theory predicts a positive relationship between IT and productivity, researchers may tend to report, and editors may tend to accept for publication, only those papers with the "right" results on the impact of IT. However, as his research demonstrates, estimates are sensitive to both the data used and the particular equation that is estimated. He concludes that information technology matters, but the wide variation in empirical estimates means that much "depends on the details of the estimation" and "one must be careful about putting too much weight on any given estimates."

The conclusion that recent studies show a positive effect of information technology stands in contrast to earlier studies, many of which found no relationship. Both Dedrick (2003) and Stiroh (2002) note that the best data available to early researchers suffered from small sample sizes, few or no small firms or plants, and lack of data on information technology investment. These data gaps may be why early micro data studies failed to find a relationship between IT and performance.

Cause and Effect: Does Using IT Make Businesses More Productive?

The literature so far yields mixed findings on cause and effect between IT and plant-level economic performance. Early research is limited to manufacturing. The first findings in this area were that more productive plants may be more likely to adopt best practices, including new technologies, and that they are able to afford to do so.[5] However, later research suggests that *less* productive plants may invest in those technologies, perhaps trying to boost their productivity.[6]

Recent research expands the scope of analysis of the effect of IT in the retail sector. It examines the relationship between investments in information technology and two performance measures for retail firms, productivity and growth in the number of establishments. The research finds that, in retail, IT is closely related to productivity growth, but not to growth in the number of establishments that retail firms operate.[7]

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[5] R.H. McGuckin, M.L. Streitwieser, and M.E. Doms, "The Effect of Technology Use on Productivity Growth," *Economic Innovation and New Technology Journal*, 7 (October 1998).

[6] Stolarick Kevin M., "Are Some Firms Better at IT? Differing Relationships between Productivity and IT Spending," Center for Economic Studies Working Paper CES-WP-99-13, U.S. Census Bureau, Washington, DC (1999); and B.K. Atrostic, and S. Nguyen, "IT and Productivity in U.S. Manufacturing: Do Computer Networks Matter," Center for Economic Studies Working Paper CES-02-01, U.S. Bureau of the Census, Washington, DC (2002).

[7] M. Doms, R. Jarmin, and S. Klimek, "IT Investment and Firm Performance in U.S. Retail Trade," Center for Economic Studies Working Paper CES-WP-02-14, U.S. Bureau of the Census, Washington, DC (2002).

Does the Business Environment Matter?—International Comparisons

Although researchers have found evidence of the effect of IT on productivity at the micro level across many countries, the effect on aggregate productivity and economic growth has varied across countries. This is true even though IT is universally available. While the United States and a few other economies enjoyed the boom of the late 90s, many European economies experienced sluggish growth. Several explanations have been put forward including differences in the policy and institutional settings across countries, measurement issues, and time lags (micro data research showed positive effects of IT in the United States before aggregate statistics). Some have hypothesized that the U.S. economy was able to make more effective use of the new general-purpose technology of IT because its regulatory and institutional environment permits firms to experiment more. An important component of the U.S. ability in this regard is the efficient reallocation of resources away from firms whose experiments in the marketplace fail, to those whose experiments succeed.

The OECD's Growth Project (Box 5.1) study found evidence that the Schumpeterian processes of churning and creative destruction (or market selection) yield greater economic effects in the United States than in other OECD countries. These processes affect aggregate productivity growth as lower productivity firms shrink and exit and higher productivity firms enter and grow. Is it the case that IT has had a greater impact on business performance in the United States because the U.S. policy and institutional environment is more conducive to market selection and learning?

Box 5.1. OECD International Micro Data Initiative

No single country has the resources and technical expertise to independently resolve all the measurement issues and fill all the information gaps associated with measuring the impact of IT. The OECD Growth Project provided a comprehensive analysis of the impact of information and communication technology (ICT) on productivity and economic growth in several OECD countries, using aggregate, industry-level, and plant-level data. Based on that project's success, U.S. Commerce Secretary Evans requested additional micro data research, and provided the OECD with seed money. This new project seeks to build on efforts already under way in several OECD member countries. One facet of the OECD micro data project on ICT is a series of multi-national collaborations, with a small number of countries involved in each collaboration. Each group is developing its own way of reconciling the differences in each country's existing micro data that are important to comparative studies, such as the sectors covered, the scope of businesses included in each sector, and the specific questions asked. The OECD project also seeks explicitly to foster coordination and collaboration on e-business issues between data producers and data users in each country. Project members are from both the OECD's Statistical Working Party of the Committee on Industry and Business Environment (largely data users focused on productivity and growth statistics) and the new Working Party on Indicators on the Information Society (largely producers of statistical indicators).

Recent research using micro data from the United States and Germany attempts to address this question.[8] The analysis first compares the differences between various groups (e.g., young vs. old, or those that invest heavily in IT vs. those that do not) of manufacturing establishments within each country. These differences are then compared across the two countries. This allows the researchers to contrast the impact of IT on economic performance between the two countries. The results suggest that U.S. manufacturing establishments benefit more from investing in IT and are more likely to experiment with different ways of conducting business than their German counterparts even after controlling for several plant specific factors such as industry, age, size, and so on.

Figure 5.1 summarizes results from an analysis of the impact of changing technologies on productivity outcomes. For the analysis, businesses undergoing an episode of high investment are assumed to be actively changing their technology. Manufacturers in both countries were grouped according to investment intensity as defined by investment per worker. The researchers examined investment in both general and IT-specific equipment. The core comparison group had no investment. The other two groups—with investment in any equipment, and investment in IT equipment—were split into "high" and "low" investment groups at the 75th percentile of the investment intensity distributions. Plants with "high" investment intensities were those with intensities exceeding at least 75 percent of all other investing plants. These computations were done for both overall investment in equipment (excluding structures) and for IT equipment, giving a combined seven investment intensity categories. Businesses undergoing an episode of high investment intensity can be thought of as actively changing their technologies. The market will reward some of these and punish others.

The crux of the analysis summarized in Figure 5.1 is to first compare the performance of plants across the various investment intensity groups to a baseline of firms with no investment within each country (i.e., the bars for the listed investment intensity categories in the figure represent the percent difference from the omitted zero investment category for each country). Then the researchers compared the within country differences across the United States and Germany to see in which country the reward for experimentation (as measured by high investment episodes) is highest.

Panel A shows that U.S. businesses that invest heavily, both overall and in IT, are much more productive than those that invest little or none at all. The same holds true for Germany, but the productivity premium is much higher in the United States. Panel B shows that U.S. businesses that invest heavily (i.e., are experimenting with new technologies) have more varied productivity outcomes as measured by the standard deviation than do firms that invest little or not at all. This is not the case in Germany. In fact, the German data show that firms that invest intensively have less varied productivity outcomes. This is consistent with the notion that the U.S. policy and institutional environment is more conducive to market experimentation. These results should be viewed with caution as they relate to only two countries and there are many factors the researchers do not control for.

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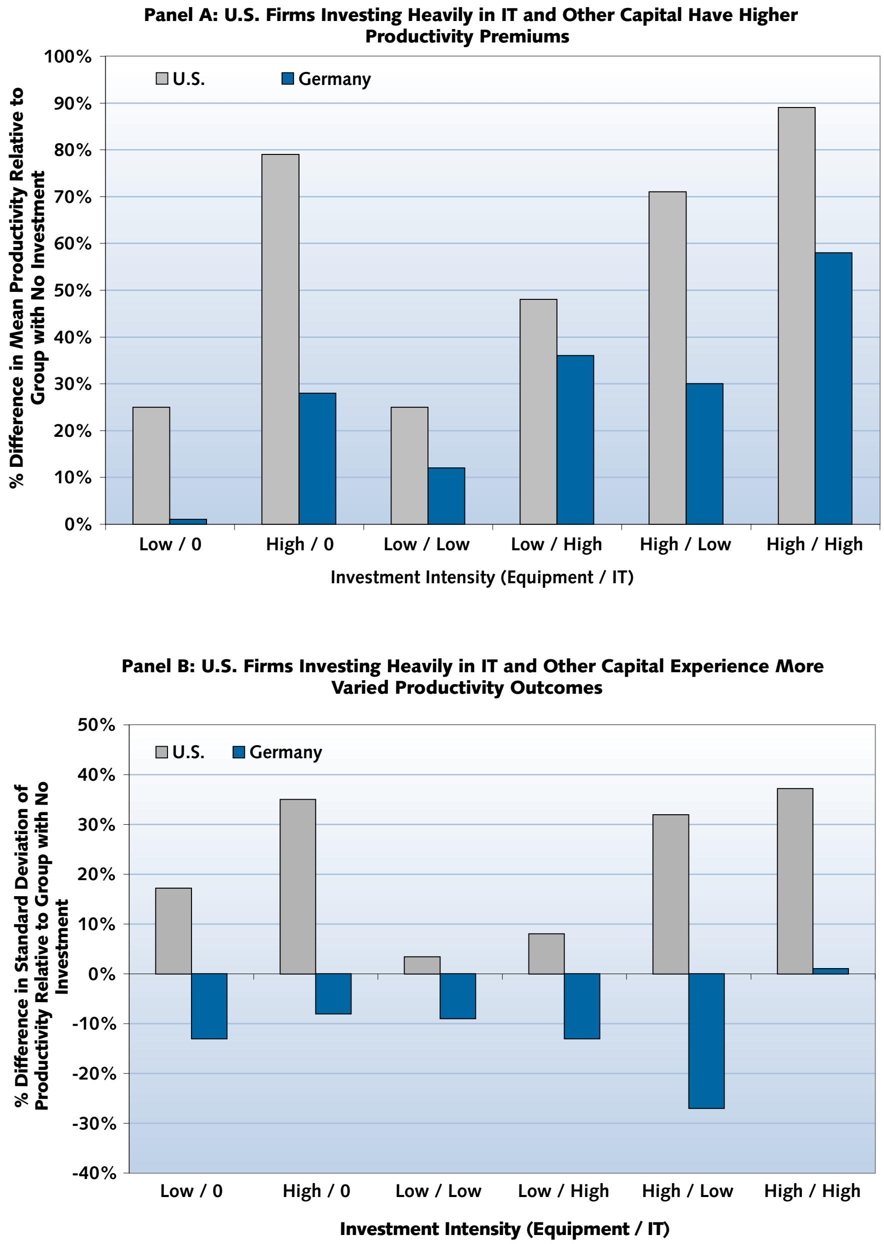
[8] J. Haltiwanger, R. Jarmin, and T. Schank, "Productivity, Investment in ICT and Market Experimentation: Micro Evidence from Germany and the U.S.," Center for Economic Studies Working Paper CES-03-06, U.S. Bureau of the Census, Washington, DC (2003).

Figure 5.1. Differences in Productivity Outcomes between Germany and the United States



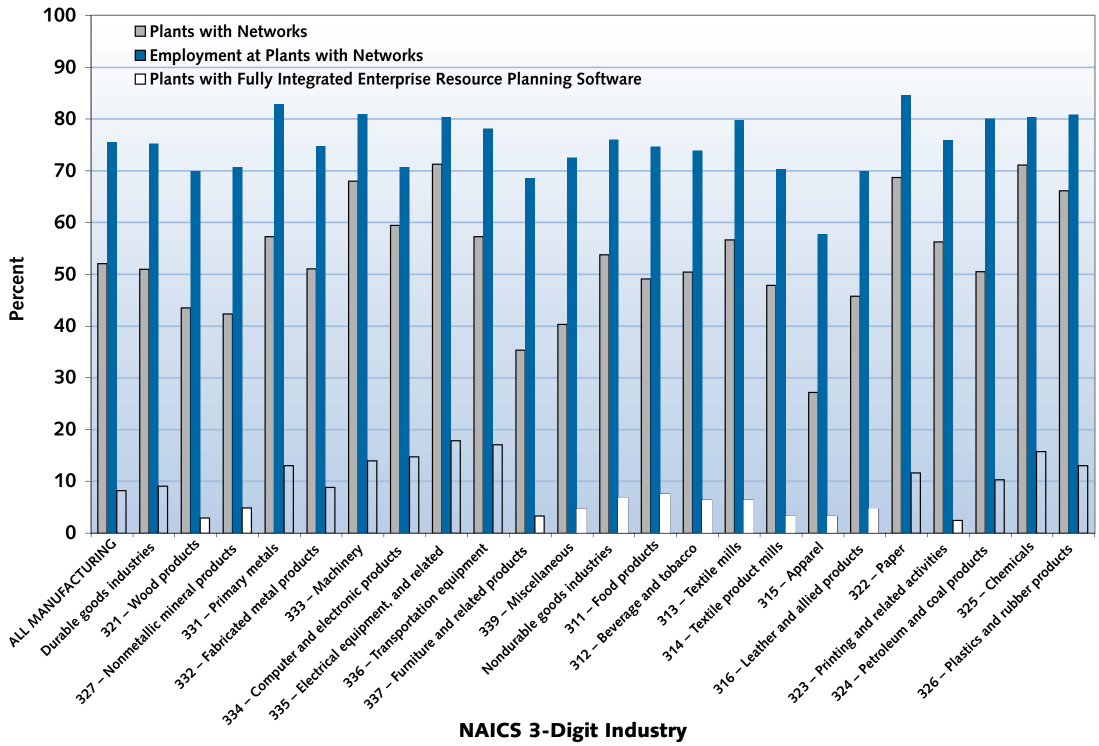
Note: Differences are in logs and are shown relative to a reference group of firm with zero total investment.

Source: Haltiwanger, Jarmin and Schank 2003.

DOES IT MATTER HOW IT IS USED?

Businesses in the United States have used IT for fifty years. Originally, firms that used IT may have had advantage over competitors who did not. But today, simply investing in IT may no longer be enough. The question for economic performance is no longer whether IT is used, but how it is used.

Figure 5.2. Computer Networks Were Common in U.S. Manufacturing Industries in 1999, But Sophisticated Network Software Was Not



Source: Atrostic, B.K. and J. Gates, 2001, "U.S. Productivity and Electronic Business Processes in Manufacturing," CES-WP-01-11, Center for Economic Studies, U.S. Bureau of the Census, Washington, DC.

New data from the 1999 Computer Network Use Supplement (CNUS) to the 1999 Annual Survey of Manufactures (ASM) are beginning to be used to model how manufacturing plants use computer networks in the United States. Respondents' answers to questions about processes can be linked to the information the same respondents reported on regular ASM survey forms, such as the value of shipments, employment, and product class shipments. Figure 5.2 presents researchers' estimates of the diffusion of computer networks. The research finds that computer networks are widely diffused within manufacturing, with networks at about half of all plants. The share of employment at plants with networks is almost identical in durable and non-durable manufacturing. Use of networks varies a great deal within those sub-sectors; the share of plants with networks ranges from lows of about 30 percent to highs of about 70 percent.

The CNUS also provides new information about some aspects of how plants use computer networks. Figure 5.2 reports estimates of the diffusion of fully integrated enterprise resource planning software (FIERP); that is, the kind of software that links different kinds of applications (such as inventory, tracking, and payroll) within and across businesses. Plants in all manufacturing industries use this complex software. However, FEIRP software remains relatively rare compared to computer networks. While about half of all manufacturing plants have networks, fewer than 10 percent have this kind of software.

Initial research finds that computer networks have a positive and significant effect on plant's labor productivity. After accounting for multiple factors of production and plant characteristics, productivity is about five percent higher in plants with networks.[9] When economic characteristics in prior periods and investment in computers are also accounted for, there continues to be a positive and statistically significant relationship between computer networks and U.S. manufacturing plant productivity.[10]

These initial findings for the United States are consistent with findings for other countries. Recent research for Canada, the Netherlands, and the United Kingdom, for example, all find positive relationships between using computer networks and productivity.[11] Research for Japan finds that computer expenditures and computer networks both affected productivity between 1990 and 2001. In more recent years, the effects are larger, but they also vary much more among industries.[12]

Some micro data research for the United States during the 1990s suggests that IT needs to be used together with worker training and revised workplace practices to yield productivity gains. These findings are based on data containing detailed information about the use of computers in the workplace. They also contain information rarely available in other sources on the employers' management and worker training policies.[13] Research for Australia and Canada, previously cited, also finds that returns to IT are intertwined with the use of R&D, innovation, and changes in workplace practices and organization. This line of research suggests that IT is important, but that it makes its impact when accompanied by changes in other factors and practices.

IS THE IMPACT OF IT THE SAME FOR ALL KINDS OF IT, EVERYWHERE?—EVIDENCE FROM STUDIES OF MARKET STRUCTURE

IT was widely expected to alter the structure of markets. The direction, however, was unclear. Lower information costs might make it easier for smaller businesses to collect, analyze, and use information and so allow them to enter distant markets or compete more effectively with larger firms. At the same time, the lower information costs might make it easier for larger businesses

[9] Atrostic and Nguyen (2002).

[10] Atrostic and Nguyen, "The Impact Of Computer Investment And Computer Network Use On Productivity," paper presented NBER-CRIW Conference on "Hard-to-Measure Goods and Services: Essays in Memory of Zvi Griliches," Washington, DC (September 2003).

[11] J. Baldwin, and D. Sabourin, "Impact of the Adoption of Advanced Information and Communication Technologies on Firm Performance in the Canadian Manufacturing Sector," *Research Paper Series*, 174, Analytical Studies Branch, Statistics Canada (October 2001) present findings for Canada. E. Bartlesman, G. van Leeuwen, and H.R. Nieuwenhuijsen, "Advanced Manufacturing Technology and Firm Performance in the Netherlands," *Netherlands Official Statistics*, Vol. 11 (Autumn 1996) present findings for the Netherlands. C. Criscuolo and K. Waldron, "e-Commerce use and firm productivity," *Economic Trends* (November 2003) present findings for the United Kingdom.

[12] K. Motohashi, "Firm level analysis of information network use and productivity in Japan," presented at the conference on Comparative Analysis of Enterprise (micro) Data, London (September 2003).

[13] S. Black, and L. Lynch, "How to Compete: The Impact of Workplace Practices and Information Technology on Productivity," *Review of Economics and Statistics*, Vol. 83 No. 3 (August 2001); and D. Neumark and P. Cappelli, "Do 'High Performance' Work Practices Improve Establishment-Level Outcomes?" *Industrial and Labor Relations Review* (July 2001).

to retain a competitive advantage. Similarly, use of the Internet might make it easier for consumers to compare prices, and so lead to a reduction in prices for products sold on-line or in “bricks and mortar” establishments. At the same time, a firm building an on-line sales-based business may incur costs that brick and mortar businesses might not, such as cost associated with having inventories available for immediate delivery anywhere in the United States (or the world). The issues are scarcely settled. In this section, selected examples from micro data research illustrate IT’s multifaceted nature and complex economic effects.

Trucking

A series of studies make use of public-use truck-level data from the Census’ Vehicle Inventory and Use Surveys to examine how IT has affected the trucking industry. Each of these studies indicates the importance of knowing not just that IT is used, but also the details of the IT and how it is used.

These studies examine the impact of two classes of on-board computers (OBCs). Standard OBCs function as trucks’ “black boxes,” recording how drivers operate the trucks. These enable dispatchers to verify how truck drivers drive. Advanced OBCs also contain capabilities that, among other things, allow dispatchers to determine where trucks are in real time and communicate schedule changes to drivers while drivers are out on the road. These advanced capabilities help dispatchers make and implement better scheduling decisions, and help them avoid situations where trucks and drivers are idle, awaiting their next haul.

One of these studies assesses OBCs’ impact on productivity by estimating how much they have increased individual trucks’ utilization rate, as measured by their loaded miles during the time they are in service.[14] It finds that advanced OBCs have increased truck utilization by 13 percent among trucks that adopt them; overall, this effect implies a three percent increase in capacity utilization industry-wide, which translates to about $16 billion in annual benefits. The vast majority of this increase comes from trucks in the for-hire, long-haul segment of the industry, and most of these returns only began to accrue years after trucking firms first began to adopt OBCs. In contrast, the study finds no evidence that standard OBCs have led to increased truck utilization. Combined, these results indicate not just the magnitude of IT’s impact on productivity in the industry but also its nature and timing. IT adoption has led to large productivity gains due to advanced OBCs’ real-time communication capabilities, which enable trucking firms to ensure that trucks operating far from their base are on the road and loaded. These gains, however, appear to have lagged adoption by several years.

The other two studies examine how OBCs have affected how the industry is organized. One study investigates how OBCs affect whether shippers use internal fleets or for-hire carriers to ship goods.[15] This study finds that the different classes of OBCs have different effects on this

[14] T. Hubbard, 2003, “Information, Decisions, and Productivity: On-Board Computers and Capacity Utilization in Trucking,” *American Economic Review*, September.

[15] G. Baker and T. Hubbard, “Make Versus Buy in Trucking: Asset Ownership, Job Design, and Information,” *American Economic Review*, Vol. 93 No. 3 (June 2003).

decision. The diffusion of standard OBCs has tended to increase shippers' use of internal fleets, but the diffusion of advanced OBCs has tended to increase their use of for-hire fleets. This implies that IT-enabled improvements in monitoring drivers have led shippers to integrate more into trucking, but IT-enabled improvements in scheduling capabilities have led to more contracting-out of trucking. This systematic difference indicates that whether IT tends to lead to larger, more integrated firms or to smaller, more focused firms depends critically on the new capabilities the IT provides.

The second of the two organizational studies is similar: it investigates how OBCs have affected whether drivers own the trucks they operate.[16] Traditionally, "owner-operators" have been an important part of the industry. An advantage associated with owner-operators is that they have strong incentives to drive in ways that preserve their trucks' value; these incentives have traditionally been far weaker for "company drivers," who do not own their trucks. This study shows that OBC diffusion has diminished the use of owner-operators. By allowing firms to monitor how drivers drive, OBCs have eliminated an important incentive advantage of owner-operators, and have led trucking firms to subcontract fewer hauls out to such individuals.

Residential Real Estate

The Internet vastly increases the amount of information on housing vacancies that is readily available to consumers. Previous research had shown that high costs of information and lack of access to information limited housing searches. The best information available to consumers tended to be for properties near their current location. In addition, research found that information intermediaries such as real estate agents influenced the options that consumers considered. The increased information that the Internet makes available to consumers potentially reduces or eliminates those limits. Consumers can readily learn about properties far from their current locations, and can do so relatively directly (there still may be some influence exerted in how web sites are set up, for example, and consumers may not immediately, or ever, get to the best web site for their needs).

Two recent studies use micro data to assess the effect of using the Internet to search for housing. In these cases, micro data from the public-use Current Population Survey provide basic information on what kinds of consumers use the Internet to search for housing. However, the CPS does not have information about the homes that Internet users purchased. To address questions about the kinds of homes purchased, the researchers surveyed a sample of recent home purchasers in a county in North Carolina. Characteristics of buyers who used the Internet as a source of information about housing vacancies were generally similar to those of buyers who only used conventional information sources, except that Internet users were younger. The researchers conclude that using the Internet to shop for housing does not seem to effect geographic search patterns, or to lead consumers to pay lower prices for comparable homes. Although using the Internet might be expected to decrease the number of homes buyers visited, because they would have more information about the houses and neighborhoods, the studies

[16] G. Baker and T. Hubbard, "Contractibility and Asset Ownership: On-Board Computers and governance in U.S. Trucking," http://gsbwww.uchicago.edu/fac/thomas.hubbard/research/papers/paper_424.pdf (April 2003).

instead find that homebuyers who use the Internet as an information source make personal visits to more houses.[17]

The Impact of IT on Wages

Do "knowledge workers" receive wage premiums because they use computers? Does the use of IT increase the demand for more-educated workers? Does the growing use of computers by workers in some sectors of the economy explain shifts in the distribution of wages? Initial micro data research answered the first question with a resounding "yes." One early study, for example, found that the pay of workers who used computers was 10 to 15 percent higher than the pay of similar workers who did not.[18] However, more recent studies that make use of more detailed information about workers and jobs over multiple periods find that the answer is more nuanced.

IT potentially affects many aspects of the performance of businesses. It also may affect the wages, and other characteristics of jobs. Asking how IT affects wages is actually asking two questions. The first question is whether jobs where workers use computers pay higher wages. If the answer is yes, the second question is why.

As with IT use in businesses, determining cause and effect of IT use on wages is hard. The jobs might pay higher wages because they require high skill levels. Some IT-using jobs, such as computer programmers and systems analysts, clearly require high skill levels, as do jobs such as architects who use computer-assisted design programs. However, computers appear throughout many workplaces. Workers may use computerized diagnostic equipment and programmable logic controllers, for example, in production applications. Office and service workers may use word processors and spreadsheets, e-mail, computerized billing systems, and so forth. Such jobs might pay higher wages if using a computer makes a worker with a given skill level more productive, but they generally do not require the workers to know much about principles of programming, or system or network design. Finally, the use of IT may allow computers to substitute for low-skilled workers performing repetitive tasks.

Micro data studies in the United States, Europe, and Canada all find that workers using computers at work have much higher wages than workers who do not. The difference typically is on the order of 10 to 20 percent. However, these studies all used data from a single period, and many of them lack information about other aspects of the job, the worker, and the employer. This makes it hard to determine whether the workers have higher wages because they use a computer, or because important unobserved characteristics of the employer (is it highly productive regardless of the use of computers?) or the worker (is the worker already highly skilled before using a computer?) may affect managers' decisions on investing in computers and

[17] R. Palm and M. Danis, "Residential Mobility: The Impacts of Web-Based Information on the Search Process and Spatial Housing Choice Patterns," *Urban Geography,* Vol. 22, No. 7 (2001); and R. Palm and M. Danis, "The Internet and Home Purchase," *Journal of Economic and Social Geography,* Vol. 93, No. 5 (2002).

[18] A. Krueger, "How Computers Have Changed the Wage Structure: Evidence from Microdata, 1984–1989," *Quarterly Journal of Economics*, Vol. 108 No. 1 (February 1993).

assigning them to which employees. A new study reviewing recent research on the impact of IT on employment, skills, and wages concludes that the story is complex.[19]

Studies find that having information on plant characteristics and work practices matters. For example, a study finding that workers using computers in Germany had higher wages than workers who did not also found that a similar wage differential accrued to workers using telephones or pencils, or who worked sitting down.[20] The implication is that the wage differential really reflected the fact that workers using computers, telephones, or pencils, or who work sitting down, receive higher wages because they have higher skills. This research suggests that IT is associated with substantial wage differentials, but does not cause them. Studies for France and Canada find similar wage differentials.[21]

Researchers using French and Canadian micro data also have matched sets of data on employers and workers in those countries, and have two or more years of data. Studies using these matched data all find that substantial cross-section returns to computer use fall sharply when they make use of information about changes in both the worker and employer characteristics. Estimates differ by country and study, but the final differentials are modest, 1 to 4 percent.[22]

These studies also find that the relatively modest wage differential associated with computer use varies markedly across occupations and among workers with different levels of education. For example, a study for Canada finds that more highly educated workers, white-collar workers, and those adopting the computer for scientific applications receive higher than average wage premiums, while other workers do not receive wage premiums when they start using computers on the job. The reasons for such differences remain unresolved. It may be more costly to teach some groups of workers to use computers, or groups may differ in the proportion of computer training costs that they share with the employer (with lower employer shares resulting in higher wages). The researchers find that controlling for training increases the small or zero wage premiums they otherwise find for many low-skilled groups. They speculate that, if appropriate data were available to test for long-run effects, controlling for training and other worker characteristics might show positive wage differentials for most workers using computers.[23]

Some detailed case studies (studies of specific businesses, usually anonymous) suggest another reason for differences in the wage differential associated with using computers at work. One

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[19] M. Handel, "Implications of Information Technology for Employment, Skills, and Wages: A Review of Recent Research," SRI International, SRI Project Number P10168, Final Report (July 2003).

[20] J. DiNardo and J. Pischke, "The Returns to Computer Use Revisited: Have Pencils Changed the Wage Structure Too?" *The Quarterly Journal of Economics*, Vol. 112 No. 1 (February 1997).

[21] H. Entorf, M. Gollac, and F. Kramarz, "New Technologies, Wages, and Worker Selection." *Journal of Labor Economics* (1999), and H. Entorf, and F. Kramarz, "Does Unmeasured Ability Explain the Higher Wages of New Technology Workers?" *European Economic Review*, Vol. 41 (1997); and C. Zoghi and S. Pabilonia, "Which Workers Gain from Computer Use?" Paper presented at NBER Summer Meetings (July 2003).

[22] E.g., Entorf and Kramarz 1997.

[23] C. Zoghi and S. Pabilonia 2003.

case study examined the effect of introducing computers into the operations of a financial organization. For some occupations, the case study found that computers substitute for the routine work that individuals previously performed, reducing the need for such workers. In other occupations, however, computers appear to take on routine tasks and free workers to perform more complex, higher skilled, problem-solving activities.[24] If IT also allows the business to alter the way it works and organize itself more productively, it may raise the skill requirements for all workers in the business, even if they do not directly use computers.

Insights from the International Micro Data Initiative

A wave of new literature in plant- or firm-level research on the effects of IT has been conducted in countries participating in the OECD.[25] (See box 5.1.) As with research using U.S. micro data, the micro data research conducted in other countries also find links between IT and productivity. Where information on computer networks is available, or other measures of how computers are used, the research again suggests that it is not just having IT, but how IT is used that effects economic performance measures such as productivity.

Two kinds of studies are being undertaken. Some studies base their research on new data on IT for a single country. They make use of as much information as they can, and choose empirical techniques best suited to their data. Studies such as these contribute important insights, particularly when one country has information that other countries do not, or researchers are able to use techniques that help ensure that the measured effects indeed are due to IT. However, this strength also makes it hard to compare such estimates across countries.

Studies from individual OECD countries find that IT has an impact on productivity and economic performance. Significant effects of IT on productivity are found in the service sector in Germany.[26] Recent research for France finds that one specific kind of network, the Internet, is associated with productivity gains, but other kinds of networks, which have been in use much longer, are not.[27] Canadian research finds that adopting IT is associated with growth in both productivity and market share.[28] Use of computers in Australia also is associated with productivity growth, with effects that vary across industries and are intertwined with other factors, such as the skill of a business' work force, its organization and re-organization, and its innovativeness.[29]

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[24] D. Autor, F. Levy and R. Murnane, "Upstairs, Downstairs: Computer-Skill Complementarity and Computer-Labor Substitution on Two Floors of a Large Bank," *Industrial & Labor Relations Review* 55(3) (2002).

[25] Research to date is summarized in D. Pilat, *ICT and Economic Growth: Evidence from OECD Countries, Industries, and Firms* (Paris: OECD, 2003).

[26] T. Hempell, "What's Spurious, What's Real? Measuring the Productivity Impacts of ICT at the Firm-Level," Discussion Paper 02-42, Centre for European Economic Research (Zentrum für Europäische Wirtschaftsforschung GmbH; ZEW, 2002), ftp://ftp.zew.de/pub/zew-docs/dp/dp0242.pdf.

[27] B. Crépon, T. Heckel, and N. Riedinger, http://www.nber.org/CRIW/papers/crepon.pdf, Paper presented at "R&D, Education, and Productivity," NBER CRIW conference in honor of Zvi Griliches (Paris: August 2003).

[28] J. Baldwin and D. Sabourin 2001.

[29] G. Gretton, J. Gali, and D. Parham, "Uptake and impacts of ICTs in the Australian economy," paper presented at OECD, Paris, December 2002.

Another group of studies tries to use as many variables and analytical techniques as possible that are similar to those used by researchers in a few other countries.[30] This approach may exclude some variables and some analytical techniques, if researchers in several countries cannot use them. On the other hand, this kind of coordination makes it more likely that similar empirical findings are actually due to IT, and that differences in empirical findings are due to differences in economic conditions and other factors among countries.

An example is a group of researchers conducting parallel analyses for the United States, Denmark, and Japan.[31] Preliminary findings are that IT is positively related to productivity in all three countries, but that the relationship depends on the type of IT used, the sector, and time period. Early results for Denmark show a significant correlation between several measures of the firm's performance and use of the Internet, but not for other uses of IT. For Japan, productivity levels are consistently higher for firms using IT networks. However, growth in labor productivity varies by type of network and how the network is used, and the effect of Internet use is higher for retail trade firms than for manufacturing firms. For U.S. manufacturing plants, there is a strong relationship between use of computer networks and labor productivity.

Better Micro Data Research Requires Better Micro Data

Because the micro data are typically collected for other purposes, such as constructing key economic indicators, we almost always find that they lack some (often, much) of the information needed to address questions such those about the pervasiveness of IT and its effect. These gaps simply do not allow us to draw firm conclusions about the effect of IT. For example, research exploring the micro-level link between IT and economic performance may not always be able to separate the role of IT from other related but unobserved characteristics of the plant. Well-managed plants may use IT as one of many tools to achieve performance goals. If we have information about IT, but not about management practices, the research may attribute performance effects to IT that really are due to good management.

Estimating plant-level relationships among computers, computer networks, and productivity also is hard to do with existing data because many of the most important concepts—what a business produces (output), and all the factors it uses to make its product (such as labor, capital, energy, etc., known as "inputs"), as well as IT itself—are difficult to define, and data based on these concepts are hard to collect.[32] Continuing research on these concepts leads to improve-

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[30] For example, researchers in several countries are using the approach taken by U.S. researchers (Atrostic and Nguyen 2002), and using its findings as the benchmark against which they are comparing research findings using their own countries' data.

[31] B.K. Atrostic, P. Boegh-Nielsen, K. Motohashi, and S. Nguyen, "Information Technology, Productivity, and Growth in Enterprises: Evidence from New International Micro Data," *L'acutalité économique* (forthcoming 2004).

[32] A large literature lays out major data gaps in estimating the impact of information technology on economic performance. For example, conferences conducted by the NBER Conference on Research in Income and Wealth (CRIW) addressing capital and labor measurement over the last 20 years include D. Usher, *The Measurement of Capital* (NBER CRIW Volume 45 (Chicago University Press, 1980)); J. Triplett, *The Measurement of Labor Cost* (NBER CRIW Volume 48 (Chicago University Press, 1983)); and C. Corrado, J. Haltiwanger, and D. Sichel, *Measuring Capital in the New*

ments in what statistical agencies collect, but a dynamic and evolving economy continually presents new challenges.

Even when concepts are well defined, it is costly for statistical agencies to collect data and for respondents to provide the requested information. As a result, some key information needed for analysis may not be collected often or at all. Examples include information such as the number of computers and computer networks that businesses have, how they use them, and how much businesses invest in computers and other IT. The divergent findings in the resulting empirical literature on the effects of IT are likely related to these data gaps, and to differences in the techniques researchers use to try to deal with them.[33]

One way to improve the micro data available for research would be by better integrating aggregate economic indicators and their underlying micro data. It currently is not always easy to reconcile movements in the aggregate statistics with changes observed in the micro data. Aggregate indicators often are constructed from multiple micro data sources, and different sources of data for any concept (such as employment or payroll) may disagree. Collecting more of the data underlying aggregate statistics in ways that enrich their value as micro data, such as using common sampling frames and keeping information that allows linkage of same economic unit over time and across surveys, would improve both the micro data and our ability to understand changes in the aggregate economic indicators.

Conclusion

Micro data research conducted in the United States and in OECD countries shows that IT is related to economic performance and productivity. Careful research also shows that the relationships are complex. IT emerges as a multifaceted factor. The kind of IT that is used and how it is used appear to matter in many (but not all) settings, including the ownership structure of trucking markets, the relative dynamism of retailing, and the relative risk taking and innovativeness of manufacturing sectors across countries. At the same time, the use of IT alone does not appear to be enough to affect economic performance. When researchers have information about the characteristics of businesses, workers, jobs, and markets, they find that IT appears to work instead in tandem with those factors.

Economy (NBER CRIW Volume 65 (Chicago University Press, forthcoming)). A series of meetings of international experts, known as the "Canberra Group," addressed capital measurement issues during the late 1990s (http://unstats.un.org/unsd/methods/citygroup/capitalstock.htm). An excellent manual describing how to calculate productivity devoted considerable text to issues in measuring capital can be found in P. Schreyer, *Measuring Productivity: Measurement of Aggregate and Industry-Level Productivity Growth—OECD Manual* (Paris: OECD 2001). Measuring intangible capital, potentially important in both IT and non-IT capital, received much attention recently (see for example B. Lev, *Intangibles: Management, Measurement, and Reporting* (Brookings Institution Press: 2001)).

[33] See, for example, Dedrick *et al.* (2003); D. Pilat, 2003; B.K. Atrostic, J. Gates, and R. Jarmin, 2000, "Measuring the Electronic Economy: Current Status and Next Steps," Working Paper CES-WP-00-10, Center for Economic Studies, U.S. Bureau of the Census, Washington DC; and J. Haltiwanger, and R. Jarmin (2000), "Measuring the Digital Economy," in E. Byrnjolfsson and B. Kahin (eds.), *Understanding the Digital Economy* (MIT Press 2000).

Separating out the effect of IT remains difficult because the analysis requires detailed information, and requires it for multiple periods. However, such detailed and repeated information is rare. Most business micro data contain only the information needed to calculate important economic indicators. The micro data are most sparse for the sectors outside manufacturing—the most IT-intensive sectors. More definitive research on the impact of IT requires that producing micro data sets becomes a statistical agency priority.

Appendix 5.A. Conducting Micro Data Research on the Impact of IT

THE CENTER FOR ECONOMIC STUDIES, U.S. CENSUS BUREAU

The Center for Economic Studies (CES) is a research unit of the Office of the Chief Economist, U.S. Bureau of the Census, established to encourage and support the analytic needs of researchers and decision makers throughout government, academia, and business. CES currently operates eight Research Data Centers (RDCs) throughout the United States. RDCs offer qualified researchers restricted access to confidential economic data collected by the Census Bureau in its surveys and censuses. CES and the RDCs conduct, facilitate, and support research using micro data to increase the utility and quality of Census Bureau data products.

The best way for the Census Bureau to assess the quality of the data it collects, edits, and tabulates is for knowledgeable researchers to use micro records in rigorous analyses. Each micro record results from dozens of decisions about definitions, classifications, coding procedures, processing rules, editing rules, disclosure rules, and so on. Analyses test the validity of all these decisions and uncover the data's strengths and weaknesses.

Research projects at CES and its RDCs are examining how facets of the electronic economy affect productivity, growth, business organization, and other aspects of business performance using both new data collected specifically to provide new information about IT, and existing data. Projects using existing Census Bureau micro data on businesses include McGuckin *et al*. 1998; Dunne, Foster, Haltiwanger and Troske, 2000; Stolarick 1999; and Doms, Jarmin, and Klimek, 2002). Research making use of the new 1999 supplement to the Annual Survey of Manufactures linked to existing Census Bureau micro data include Atrostic and Gates 2001; Atrostic and Nguyen 2002; Haltiwanger, Jarmin, and Schank 2002; and Bartelsman *et al.* 2002. Research findings from many of these projects are discussed in this chapter. The research also helps the Census Bureau assess what current data collections can say about the electronic economy so that we can more efficiently allocate resources to any new measurement activities. More information about CES, RDCs, requirements for access to data, and examples of research produced at the RDCs is at http://www.ces.census.gov/ces.php/home.

DATA SOURCES AT CES

Researchers at CES and the RDCs built, and use, a longitudinal data set linking manufacturing plants over time. The data are based on surveys and economic censuses, and contain detailed data on shipments and factors used to produce them, such as materials and labor, as well as characteristics of the plant, such as whether it exports.

Recent CES research broadens the range of available micro data beyond manufacturing. A new micro data set, the Longitudinal Business Database, currently contains the universe of all U.S. business establishments with paid employees from 1976 to present. It allows researchers to examine entry and exit, gross job flows, and changes in the structure of the U.S. economy. The LBD can be used alone or in conjunction with other Census Bureau surveys at the establishment and firm level. In addition, micro data from surveys and censuses of the retail, wholesale, and some service sectors is now becoming available.

The National Employer Survey, conducted by the Census Bureau for the National Center on the Educational Quality of the Workforce, collects detailed information about work practices, worker training, and the use of computers. Restricted access to confidential data from the survey is available to qualified researchers through the RDCs. Information about the National Employer Survey can be found at http://www.census.gov/econ/overview/mu2400.html.

PUBLIC-USE DATA

This chapter also refers to research conducted using two other sets of micro data collected by the Census Bureau. The Current Population Survey (CPS) is a survey of households that is collected by the Census Bureau for the Bureau of Labor Statistics. The CPS periodically collects information about people's use of computers at work and at home. More information can be found at http://www.census.gov/population/www/socdemo/computer.html. The Truck Inventory and Use Surveys collect information about on-board trip computers and electronic vehicle management systems as part of the Census of Transportation. Information about the Census of Transportation can be found at http://www.census.gov/econ/www/tasmenu.html.

CHAPTER VI:

INFORMATION TECHNOLOGY'S ROLE IN LIFE SCIENCES RESEARCH & DEVELOPMENT

By Cassandra Ingram and Gurmukh Gill*

Information technology (IT) has dramatically reduced the costs, increased the speed, and improved the productivity of life sciences research and development (R&D). Life sciences R&D, in turn, has opened up new challenges and opportunities for IT applications. This virtuous cycle has contributed to a whole new frontier for knowledge generation. For example, the confluence of IT and biological advances made possible the mapping of the entire human genome and genomes of many other organisms in just over a decade. These discoveries, along with current efforts to determine gene and protein functions, have improved our ability to understand the root causes of human, animal and plant diseases and find new cures. Furthermore, many future IT innovations will likely be spurred by the data and analysis demands of the life sciences.

This chapter describes the relationship between IT and life sciences R&D. We provide information on the life sciences market for IT goods and services. While currently the life sciences market comprises only a small part of the total IT market, it is a vibrant market and growing rapidly. Job opportunities that combine the skills of life and computer scientists are also expected to expand.

Bioinformatics Is Vital for Advances in the Life Sciences

In recent years, innovations where IT and the life sciences converge have created vast quantities of data. The development of automated DNA sequencing and other innovative methods have reduced the costs and time needed to discover the genetic makeup of various organisms.

* Ms. Ingram (cassandra.ingram@esa.doc.gov) is an economist and Mr. Gill (gurmukh.gill@esa.doc.gov) is senior executive for economic research in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

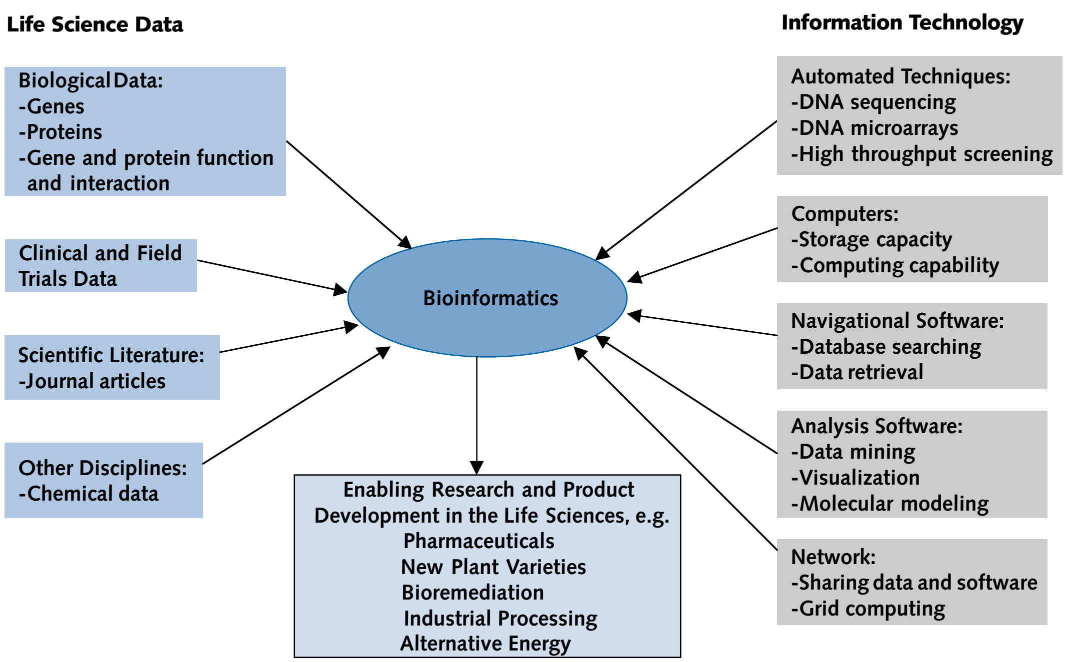
Additionally, innovations such as high-throughput screening and microarrays are enabling studies of gene and protein functions (i.e., genomics and proteomics).

The expanding complexity and diversity of information also pose new challenges. For example, data produced from studies of protein and gene function and interaction can require the consolidation of information in various formats and from diverse sources. Additionally, data may not be in a standard or readily usable format, particularly if they are not available electronically or are text-based information from scientific literature, patents and clinical trials. Critical biological information also is found throughout various scientific disciplines, such as the chemical sciences.[1] The ability of researchers to manage and analyze these diverse and extensive data is critical to the future success of life sciences R&D.

THE NEED FOR DATA MANAGEMENT AND ANALYTIC IT TOOLS

The needs described above have spawned the research field "bioinformatics,"[2] which focuses on the use of IT to collect, organize, store, interpret, share, and analyze biological data. Developments in bioinformatics will be critical for facilitating R&D in areas such as human and animal health, agriculture, industrial processing, natural resource recovery, and environmental remediation. Figure 6.1 illustrates the IT and life sciences components of bioinformatics.

Figure 6.1. Bioinformatics Uses Information Technology to Manage and Analyze Information Generated by the Life Sciences



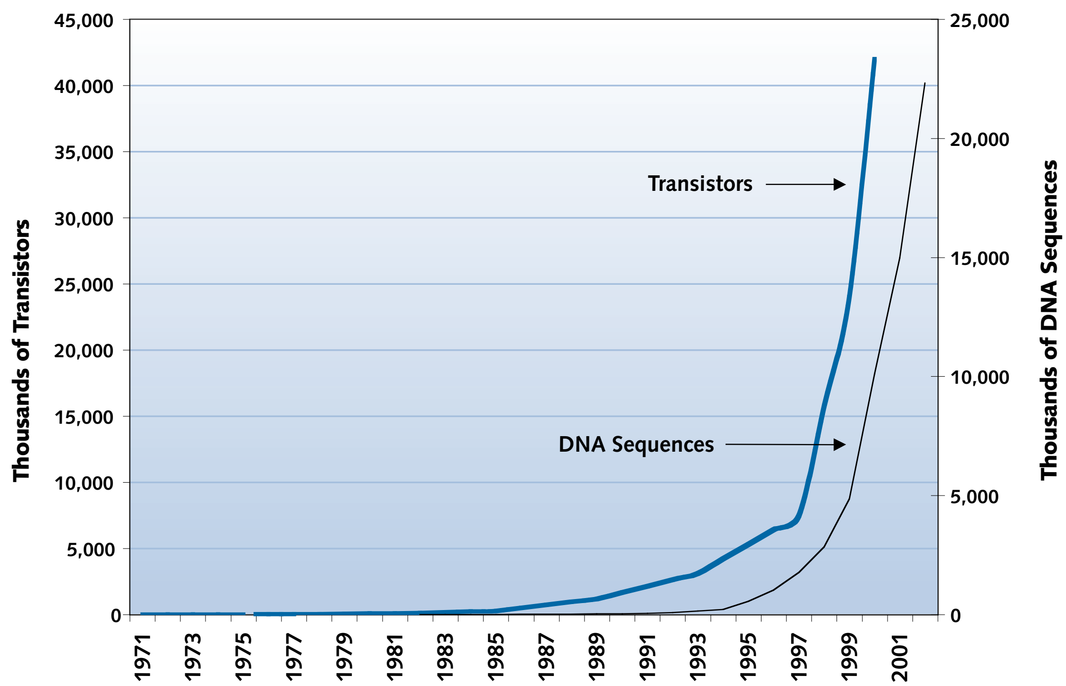
[1] For example, patient response to chemically-formulated pharmaceuticals.

[2] Computational biology research is the more traditional discipline that relates to bioinformatics, and consists of data analysis and interpretation and the development of new algorithms and statistics in the biological sciences.

Computing Power and Networks

Data storage, management, and analysis requirements in the life sciences are outpacing current computing capabilities, even though computing power continues to increase. Computing power has expanded at roughly the same rate as public DNA sequences located at the National Institutes of Health (NIH)—both have been doubling every 18 to 24 months for several years (Figure 6.2).[3] In 1971, only 2,250 transistors were on an integrated circuit; by 2002 there were 42 million. Similarly, only 606 DNA sequences were housed at NIH's Genbank in 1982. The number of sequences climbed to 22.3 million in just 20 years.

Figure 6.2. Number of Transistors per Integrated Circuit vs. DNA Sequences in Genbank



Source: Data on computing power, or the number of transistors per integrated circuit, is from Intel at http://www.intel.com/research/silicon/mooreslaw.htm. Data for the number of public DNA sequences of several organisms in Genbank is from the National Center for Biotechnology Information, National Institutes of Health at http://www.ncbi.nlm.nih.gov/Genbank/genbankstats.html.

Researchers are exploring strategies to increase computing capabilities for diverse life sciences purposes, such as computer-based drug design. One strategy is to expand the potential of supercomputers. Another is to unify computing resources through development of global, or grid, computing networks. These networks link the power of individual PCs or supercomputers.[4] Researchers have achieved teraflop speeds (a trillion floating point operations per second) using

[3] Mark S. Boguski, "Bioinformatics—A New Era," *Trends Guide to Bioinformatics* (Elsevier Science, 1998).

[4] See http://www.cs.mu.oz.au/~raj/papers/TheGrid.pdf (accessed Sept., 2003).

these grid networks. In the future they hope to achieve petaflop speeds (a thousand trillion floating point operations per second).[5]

The Internet is a particularly valuable tool for life sciences researchers, especially for those with limited resources. It enables researchers to tap into data, software, and computing power.

New software developments also promise life sciences researchers' the ability to acquire, format, search, and analyze disparate data sources and types. Data mining and visualization software[6] are improving scientists' ability to screen data and identify important relationships. One software analysis tool, 3-D molecular modeling, facilitates studies of the function and relationships between biological molecules. These analysis tools are enabling scientists to conduct some research at the computer instead of at the lab bench, reducing the time and costs of life sciences R&D.

Standardization enables researchers to link different databases and software programs, thereby making the discovery process more efficient. Standardizing scientific nomenclature, databases and software helps researchers exchange and analyze information more easily.[7] Researchers also benefit from the development of technical and computational standards for hardware and software.

Given the diversity of and rapid developments in life sciences databases and software, standardization is too difficult and costly for any organization to undertake alone. To overcome this obstacle, the Interoperable Informatics Infrastructure Consortium (I3C)[8] was founded in 2001 to collectively address some standardization problems. I3C is an international consortium that includes life science and IT participants from private industry, government institutions, academia and other research organizations. They develop and promote "global, vendor-neutral informatics solutions that improve data quality and accelerate the development of life science products." I3C's accomplishments include standards developed to identify and access biologically significant data and a method that simplifies data retrieval from multiple databases.

BIOINFORMATICS ASSISTS DRUG DISCOVERY AND DEVELOPMENT

Bioinformatics is improving the R&D process in drug discovery and development. IT tools have become important for managing and screening genetics data and for modeling outcomes in drug development. New developments in bioinformatics and genetics, such as pharmacogenetics (i.e., the study of the relationships between diseases, genes, proteins, and pharmaceuticals), will

[5] See whatis?com at http://whatis.techtarget.com/definition/0,,sid9_gci212778,00.html (accessed Sept., 2003).

[6] *Instrument Business Outlook.* Vol. 11, i12 (Sept 30, 2002) 3(1).

[7] *Bioinformatics Workshop.* A report produced for the Research and Resources Infrastructure Working Group, Subcommittee on Biotechnology, National Science and Technology Council, White House Office of Science and Technology Policy, and prepared by Tracor Systems Technologies, Inc. under contract with Krasnow Institute of Advanced Studies and George Mason University. (February, 1998).

[8] Information on I3C can be found on their website at http://www.i3c.org/ and http://www.i3c.org/demos/bio2002/i3cdatasheet.pdf (accessed Aug., 2003).

enable researchers to identify quickly a patient's genetic predisposition to contract certain diseases as well as their potential drug response.

Costs of drug discovery have been escalating, nearly tripling since 1991.[9] It now costs $900 million and takes 15 years on average to develop a new drug.[10] Clinical trials constitute most of these costs. Additionally, about 75 percent of drug development costs can be attributed to failures. Analysts anticipate that advances in IT and the biological sciences—such as the computer-enabled ability to quickly screen drug candidates and predict drug responses—could lower failure rates substantially, reducing costs by as much as one-third and time by as much as two years.

BIOINFORMATICS IS A KEY LIFE SCIENCES R&D ACTIVITY

IT tools and bioinformatics R&D are key to remaining competitive for biotechnology and pharmaceutical companies. These companies are expanding IT capabilities by developing in-house R&D programs in bioinformatics, acquiring bioinformatics companies, and partnering with IT companies, bioinformatics firms, and the public sector (e.g., the federal government and universities).

Survey of Firms Engaged in Biotechnology Activities

Results from a survey on the use of biotechnology in U.S. industry[11] demonstrate the importance of bioinformatics to life sciences firms. Table 6.1 displays some of the biotechnology activities of survey participants. About 30 percent of survey respondents indicated that bioinformatics was one of their biotechnology R&D activities. While 29 percent conducted bioinformatics research, only 3 percent reported having bioinformatics products or processes that were marketed or in production. Firms were also substantially engaged in activities highly dependent on bioinformatics such as genomics, DNA sequencing and synthesis, drug design and delivery, synthesis and sequencing of proteins and peptides, and combinatorial chemistry and 3-D molecular modeling.

Table 6.2 presents information on bioinformatics activities by application. Firms focusing on human health applications constituted the greatest number of survey respondents. Therefore, it is not surprising that 81 percent of the respondents (i.e., 247 out of 304) that conduct bioinformatics research were addressing human health problems. Within any application, between 19 to 45 percent of firms indicated that they conducted bioinformatics research.

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[9] The Boston Consulting Group, *A Revolution in R&D: How Genomics and Genetics Are Transforming the BioPharmaceutical Industry*, (2001) at http://www.bcg.com and http://www.bcg.com/publications/files/eng_genomicsgenetics_rep_11_01.pdf (accessed Oct., 2003).

[10] Tufts Center for the Study of Drug Development at http://csdd.tufts.edu/ and http://csdd.tufts.edu/NewsEvents/RecentNews.asp?newsid=29 (accessed Oct., 2003).

[11] Survey data from *Critical Technology Assessment of Biotechnology in U.S. Industry*, U.S. Department of Commerce, Technology Administration and Bureau of Industry and Security (August 2002).

Table 6.1. Percent of Survey Respondents by Biotechnology Activity, 2002

	Conduct research on/in	Approved, marketed, or in production		Total
		Product(s)	Process(es)	
DNA-based				
Bioinformatics	29	2	1	30
Genomics, pharmacogenetics	29	3	2	30
DNA sequencing/synthesis/ amplification, genetic engineering	39	5	3	43
Biochemistry/Immunology				
Drug design & delivery	33	4	2	38
Synthesis/sequencing of proteins and peptides	27	3	1	30
Combinatorial chemistry, 3-D molecular modeling	18	1	0	19

Note: The total number of responses to the biotechnology activity question was 1021. Percents do not add up to 100 percent because firms can have more than one activity.

Source: Survey data from *Critical Technology Assessment of Biotechnology in U.S. Industry*, U.S. Department of Commerce, Technology Administration and Bureau of Industry and Security, August 2002.

Table 6.2. Number of Survey Respondents Indicating Bioinformatics Research Activities by Application, 2002

Application	Number of firms in application	Conduct bioinformatics research
Human Health	780	247
Animal Health	144	37
Agricultural & Aquacultural/Marine	128	41
Marine & Terrestrial Microbial	41	19
Industrial and Agricultural-Derived Processing	132	45
Environmental Remediation and Natural Resource Recovery	41	12
Other	160	30

Note: The total number of firms that responded to the biotechnology survey was 1,031, and 304 of these firms indicated that they had some activity in bioinformatics. The number of firms by biotechnology application does not add up to the total number of firms that responded to the survey because firms were classified in an application if they indicated it as either a "primary" or "secondary" focus.

Source: Survey data from *Critical Technology Assessment of Biotechnology in U.S. Industry*, U.S. Department of Commerce, Technology Administration and Bureau of Industry and Security, August 2002.

PUBLIC INSTITUTIONS SUPPORT BIOINFORMATICS R&D

Public institutions have made significant investments in research areas where the life sciences and IT converge. They supported and organized endeavors to map the genomes of several organisms, created databases, developed data retrieval and analysis software, conducted IT and other bioinformatics-related R&D, and funded bioinformatics training programs. These activities help drive the demand for IT goods and services in the life sciences.

The National Institutes of Health (NIH) represents a majority of Federal spending for life sciences R&D, which is focused on human health. A five-year campaign to double NIH R&D funding to $27.3 billion was completed in 2003.

Several NIH programs and initiatives that are closely linked with bioinformatics R&D, such as the Human Genome Project,[12] will get funding boosts in 2004.[13] Also in 2004, NIH plans to devote $35 million for developing new life science approaches and technologies, such as bioinformatics. The National Institute of Allergy and Infectious Diseases, which is the lead institute in bioterrorism research, will receive increased funding. Bioinformatics is a key element in developing drug and vaccine candidates as countermeasures to potential bioterrorism pathogens. NIH also makes sizable investments in IT R&D. In 2003, NIH allocated $336 million for information technology R&D, representing about 1.3 percent of their $23.6 billion R&D budget.

Other federal agencies, such as the National Science Foundation (NSF) and the Department of Energy (DOE), also support life sciences and IT R&D, especially in disciplines other than human health (e.g., environmental biology, the plant sciences and alternative energy sources).[14] A little over 10 percent of NSF's $5 billion budget and 2 percent of DOE's $22 billion budget are devoted to biological R&D. NSF's biological sciences R&D budget in 2004 shows a 20 percent increase (to $82 million) in emerging frontiers research, which includes bioinformatics. Of this, information technology research for the biological sciences would rise 10.3 percent to $7.5 million. DOE is a major supporter of advanced scientific computing research. R&D spending for this program is expected to increase 4.2 percent, to $173.5 million.

IT Market and Job Opportunities in the Life Sciences

The life sciences are opening up a new frontier for profitable IT innovations and applications. Although the life sciences represent only a small fraction of the entire IT market, that portion is growing at a substantial rate. A number of market research reports describe the life science market for IT in the United States and globally as dynamic with vast growth potential.[15] Global

[12] The Human Genome Project funding will increase 2.8 percent, from $465 million in 2003 to $478 million in 2004.

[13] See "Summary of the FY2004 President' Budget" for NIH at http://www.nih.gov/news/budgetfy2004/fy2004presidentsbudget.pdf (accessed Sept., 2003) and NIH budget highlights from the American Association for the Advancement of Science at http://www.aaas.org/spp/rd/nih04p.pdf.

[14] See NSF's FY 2004 budget request at http://www.nsf.gov/bfa/bud/fy2004/toc.htm and budget request for the biological sciences http://www.nsf.gov/bio/bio_bdg04/bionarr04.htm (accessed Sept., 2003). See DOE's FY 2004 budget request at http://www.mbe.doe.gov/budget/04budget/content/highlite/highlite.pdf (accessed Oct., 2003). DOE also has contributed to Human Genome research and has a new Genomes to Life program, which is focused on the "function and control of molecular machines for energy and environmental applications."

[15] The four primary market research firms that estimate the bioinformatics market are the International Data Corporation (http://www.idc.com/getdoc.jhtml?containerId=TEA001604), Frost & Sullivan (http://www.frost.com/prod/servlet/frost-home.pag), Strategic Directions International (http://www.strategic-directions.com/), and Front Line Strategic Consulting (http://www.frontlinesmc.com/).

bioinformatics market estimates vary widely, ranging from $0.8 billion to $14.6 billion in 2002.[16]

The life sciences market for IT is small relative to the whole IT market. The most optimistic estimate of the U.S. life science market for IT was $7.4 billion[17] in 2002. This was less than 0.9 percent of the value added of the IT-producing industries (which was $829 billion in 2002).[18]

However, the life sciences market segment appears to have strong growth potential. During the economic downturn of 2001, growth in value added of IT producing industries declined by 5.6 percent (see chapter 1). Market research firms reported that during this same period growth rates in the IT life science market were high overall. They also expect growth rates to continue to rise, ranging from 19 to 25 percent annually[19] until at least 2006.

JOB OPPORTUNITIES IN BIOINFORMATICS

Increasingly companies and research organizations are seeking workers with more formalized training that have the skills of both computer and life scientists. The high starting salaries of bioinformaticians, $65,000 to $90,000 per year, reflect the strong demand for bioinformatics employees.[20]

Computer specialists[21] in the life sciences are among the high-technology employment categories currently experiencing job growth. Occupational projections by the Bureau of Labor Statistics[22] (BLS) suggest that employment of computer specialists in the Drug and Research &

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[16] The large discrepancy in market and growth estimates mostly depends on market segment covered and organizations included, the years spanned, and assumptions made related to future market projections.

[17] The International Data Corporation estimated that the IT life science market was about $14.6 billion worldwide and that the U.S. market represented 51 percent of this total.

[18] The estimate of 0.9 percent is based on total revenue and is not value added; i.e., where purchased inputs and labor costs from outside the firm are excluded. See chapter 1 on information technology producing industries.

[19] Growth rates presented in the market research reports were compound annual growth rates.

[20] Stephan, Paula E. and Grant Black, "Bioinformatics: Emerging Opportunities and Emerging Gaps," *Capitalizing on New Needs and New Opportunities in Biotechnology and Information Technologies: Government-Industry Partnerships in Biotechnology and Information Technologies*, ed. Charles W. Wessner., Board on Science, Technology and Economic Policy, National Research Council (Washington, DC: National Academy Press, 2001).

[21] The occupations included in the BLS aggregate "Computer Specialists" are computer programmers, computer and information scientists (research), computer systems analysts, computer software engineers (applications), computer software engineers (systems software), computer support specialists, database administrators, network and computer systems administrators, network systems and data communications analysts, and all other computer specialists.

[22] See the following BLS websites for data and analysis http://www.bls.gov/oco/cg/cgs009.htm, http://ftp://ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/ind_pdf/i808730.pdf, and http://ftp://ftp.bls.gov/pub/special.requests/ep/ind-occ.matrix/ind_pdf/i422830.pdf (accessed Sept., 2003).

Testing Services industries[23] will continue to grow rapidly for several years. BLS estimates that Drug industries will increase computer specialist jobs by 60 percent, from 5,545 in 2000 to 8,859 in 2010. BLS expects computer specialist jobs in Research & Testing Services industries to increase 68 percent, from 42,567 in 2000 to 71,549 in 2010.

A survey of biotechnology use in U.S. industries further demonstrates the demand for computer specialists in the life sciences.[24] While computer specialists only accounted for 6.2 percent of the respondents' biotechnology R&D workforce, growth in this occupational category was the fastest among the biotechnology R&D job categories. Between 2000 and 2002, responding companies added 1,236 computer specialist jobs, a 20 percent increase.

Conclusion

Researchers have become increasingly reliant on IT tools to reduce the costs and boost the productivity of life sciences R&D. At the moment, the life sciences market for IT goods and services is small. However, the life sciences market for IT remained strong even during the 2001 recession and is expected to grow rapidly. Bioinformatics employment opportunities also have been expanding.

[23] While the Drug and Research & Testing industries are not entirely composed of life sciences industries, a study entitled *Critical Technology Assessment of Biotechnology in U.S. Industry*, U.S. Department of Commerce, Technology Administration and Bureau of Industry and Security (October 2003), (http://www.technology.gov/reports/Biotechnology/CD120a_0310.pdf) found that firms engaged in biotechnology activities mostly were classified under one of two industries, either Drugs or Research & Testing Services, using the Standard Industrialized Codes. These two industries were used in this analysis as the most representative of the life sciences industries.

[24] U.S. Department of Commerce, Technology Administration and Bureau of Industry and Security, *Critical Technology Assessment of Biotechnology in U.S. Industry* (October 2003), (http://www.technology.gov/reports/Biotechnology/CD120a_0310.pdf).

CHAPTER VII:

DIGITAL TRANSFORMATION: INFORMATION, INTERACTION, AND IDENTITY

By Patricia Buckley*

Just as the Industrial Revolution led to changes in existing laws, regulations, management practices, and patterns of social interactions, so too is the Information Age reshaping today's economic and social environment. Narrowly viewed, the Industrial Revolution resulted from manufacturers applying newly available power systems to their production processes that, in turn, enabled the emergence of mass production. This innovation increased productivity and led to the production of completely new products at relatively low costs. However, the Industrial Revolution also drove change in the economic, social, and legal landscapes: towns grew, workers began to organize and, in time, concerns about issues such as plant safety and air quality arose. Similarly, the information technology (IT) that underlies the digital revolution is creating new economic, social, and legal challenges, even as it increases productivity.

One of the most obvious shifts resulting from the digital revolution is the change in our relationship to information itself. We now expect that any information we need is easily and almost instantaneously accessible. However, that expectation is based on the assumption that information has been stored so it can be easily found and retrieved. Further, it requires that new, updated information continues to be produced and made available.

Digital capabilities are also reshaping interactions among individuals and organizations. Communication devices and channels continue to proliferate, expanding opportunities for interaction. The power inherent in new IT applications is being harnessed to improve the performance of organizations of all types by automating key interaction points. Effective management in this digital environment presents special challenges—from dealing with "interaction overload" (from unwanted telephone calls and email) to a loss of control (due to the complexity introduced by IT).

* Ms. Buckley (patricia.buckley@esa.doc.gov) is a Senior Policy Advisor in the Office of Policy Development, Office of the Chief Economist, Economics and Statistics Administration.

However, it is the issue of identity that may prove to be one of the most fundamental challenges we encounter in the shift to a digital economy. Challenges to the security of identity come in many forms. They range from identity theft to unauthorized access to a network (hacking) or a facility. One important area of IT research and development is in the evolution of reliable identity verification technologies. Such technologies are needed in both the physical and virtual worlds. Although such security tools are a necessity, they must be designed and implemented so that they do not ignite privacy concerns.

This chapter considers some of the changes and challenges posed by the shifts that have occurred in the environments surrounding information, interaction, and identity during this period of digital transformation.

Information

Improvements in technology continue to increase our ability to capture, store, manipulate, and display information. Declining costs and shrinking component size have accompanied these technological improvements. The combination of these trends has led to a sharp increase in the information component of many everyday devices—from disposable telephone cards that track message units to pocket-sized telephones that have contact databases and games. Businesses also benefit as IT enables the development of manufacturing equipment that not only produces the product, but also reports production-run quality and tracks its own maintenance schedule. Even the authors of this report have benefited from the improved functionality of our computers. Using sophisticated statistical software, we can now manipulate large datasets that, until recently, exceeded the storage capacity of most desktop computers.

The Internet has become key in information expansion, by providing a common protocol for communication among devices. Although increased information content and functionality is beneficial for any single device, when devices are joined together in a network their potential expands dramatically. Using the Internet, people can locate everything from the mundane (looking up a pasta salad recipe, checking a bank account balance, verifying the movie schedule) to the important (finding information on evacuation routes following a disaster, or deodorizing a child who mistook a skunk for her puppy). The Internet also makes available information that was formerly beyond easy reach, such as: a list of ongoing clinical trials from the National Institutes of Health, the English language version of Al Jazeera, or historical photographs of the Wright brothers. In addition to providing benefits to private individuals, the Internet has also become an integral part of the landscape in which government, business, and organizations function.

As individuals and organizations continue to weave the Internet into their activities and infrastructures, resolving issues of search, archiving, and protection of intellectual property rights is critical to realizing the full potential of this network of networks.

SEARCH

Internet users depend on their Web browser's search engine, on navigational guides or portals (e.g., Yahoo!), or on stand-alone search engines (e.g., Google, Altavista, and NorthernLight) to locate information. Since search engines use different algorithms—algorithms that may or may not have advertising expenditures as a variable—to locate items on the Internet, results can vary substantially. For example, Table 7.1 shows the top three results obtained when searching for the phrase “digital economy,” using several search engines.

Table 7.1. Top Three Search Results for “Digital Economy”

Microsoft Explorer	Google	Altavista	Yahoo!
Information Highway Advisory Council	Department of Commerce Home Page	Walmart.com: Understanding the Digital Economy by Erik Brynjolfsson	Understanding the Digital Economy Conference
Barnes & Noble.com—Cyberbranding Hardcover	Amazon.com: Books: The Digital Economy: Promise and Peril In The ...	Wired 2.03: The Economy of Ideas	Amazon.com: Books: The Digital Economy: Promise and Peril In The ...
Information Technology for Management, Hardcover—Amazon.com	Department of Commerce Home Page	Understanding the Digital Economy	U.S. Government Electronic Commerce Policy

Source: Internet search on October 27, 2003.

Nor is any search engine capable of searching everything. Two of the most prominent limiting factors are related to language and file format. During a recent Online Information conference (December 2002, London) it was noted that “the most obvious access problem is that ‘all the world’s information’ will be provided in documented form in most of the world’s languages, and while Google and other search engines have interfaces in the major languages, the information that is retrieved will not necessarily be in the language of the interface.”[1] Speakers at the conference went on to note that while there are almost 600 file formats according to one count (with at least half of these found on the Internet), search engines index only a small portion of these. [2]

ARCHIVING

Organizations charged with maintaining information collections, such as libraries, face significant opportunities and challenges in a digital environment. The opportunities arise because digital information is easy to replicate and transmit with no loss of quality, which makes sharing articles, books, movies, pictures, and audio recordings easy. The procession of improvements in information storage—from microfiche and microfilm to the Internet, CDs, and DVDs—has substantially increased the opportunities for information collection, storage, and sharing. This increase has many benefits. For example, teachers can bring historical photo-

[1] Laurel A. Clyde, “Search Engines are Improving but They Still Can’t Find Everything,” *Teacher Librarian,* June 2003.

[2] *Ibid.*

graphs from the Library of Congress collections directly to their classrooms, and voters can easily review statements made by candidates for office.

However, from an archiving standpoint, content created digitally is of particular concern. Some historic documents that once would have circulated on paper may now only be circulated electronically—for example, an e-mailed note to a member of the President's staff containing comments on a proposed treaty.

Solving the problems of digital archiving requires both a strategy and improved IT tools. The National Archives and Records Administration (NARA), given its mission of preserving the "essential evidence that documents the rights of American citizens, the actions of federal officials, and the national experience," faces a particular challenge with regard to the growing volume of e-mail communications. Recognizing that its "current systems for archival preservation of electronic records are limited in capability and ad hoc in nature…NARA launched the Electronic Records Archives (ERA) initiative," with the San Diego Supercomputer Center to improve its capabilities.[3]

On a broader level, the National Digital Information Infrastructure and Preservation Program charges the Library of Congress to work with NARA, the Commerce Department, the White House Office of Science and Technology Policy, the National Library of Medicine, the National Agricultural Library, the National Institute of Standards and Technology and "other federal, research and private libraries and institutions with expertise in telecommunications technology and electronic commerce policy" with developing the "protocols and strategies for the long-term preservation of such materials, including the technological infrastructure required at the Library of Congress."[4]

Archiving is not only a concern for organizations, such as the National Archives, but also for other government entities, businesses, and individuals that collect, archive, and preserve digital communications and documents. Every individual and organization that deals with information must devise a system to organize what they want to, or must, keep—whether paper, disk, or e-mail attachment. Organizing and storing information that may be needed in the future is a growing challenge.

CONTROL

It has always been difficult for creators of intellectual property to maintain control of their output and information technology has a long history of increasing that difficulty. Making copies of written text—whether the original was carved in stone or written on paper—has always been possible. However, technology continues to make it increasingly easier and cheap. The advent of the photocopier allowed any individual to make copies cheaply without regard to

[3] The National Academy of Sciences, "Building an Electronic Records Archie at the National Archives and Record Administration: Recommendations for Initial Development," 2003 Pre-publication copy—subject to further editorial correction.

[4] The Library of Congress, http://www.loc.gov/today/pr/2003/03-022.html

the wishes of the copyright owner and the spread of facsimile (fax) machines allowed for quick dissemination of written documents. Similarly, the creation of relatively low-cost audio and video recording devices presented challenges to those who owned music and film publishing rights.

Maintaining control of intellectual property became significantly more difficult in the digital environment. Not only can one create copies and disseminate them at virtually no cost, digital copies are equal in quality to the original.

The audio recording industry is one interesting example of an industry trying to find its equilibrium in the digital world. Napster challenged the recording industry's business model by enabling Internet users to bypass its distribution systems. In doing so, Napster also made it more difficult for the industry to control, and thereby profit from, its intellectual property (the rights to music owned by record companies and recording artists).

Although the recording industry succeeded in shutting down the free version of Napster in 2001, other services (ones that are more truly peer-to-peer and therefore more difficult to shut down) such as Morpheus and Kazaa have emerged. According to one estimate, Kazaa users number almost a quarter billion worldwide—triple the number of users that Napster had prior to its shutdown.[5] The ability of users of these online music-sharing services to swap music over the Internet called into question the market for shrink-wrapped compact discs, as well as the licensing arrangements between recording artists and their publishers. Response to this continued challenge has been twofold—litigation and the development of legitimate online markets, such as iTunes.

Interactions

IT is also transforming information exchange. Not only do people and devices have the opportunity to interact over a growing number of channels, the differing attributes of these channels are altering the activities in which people engage. From high-profile shifts, such as the proliferation of e-mail and e-commerce sites, to more behind-the-scenes shifts in activities, such as supply chain management, these new options are having a profound effect on the economic environment. The increased potential for interaction brings benefits, but also raises the specter of interaction overload.

COMMUNICATION AND COMMERCE

Innovations in IT have resulted in a proliferation of communication devices operating over a variety of channels. These devices and channels are more than simple substitutes for each other. Their underlying technologies give them unique attributes that are redefining the terms under which communications and commerce occur.

[5] "Music Industry's Aggressive Tactics Tune Out Fans on Net," *USA Today*, May 6, 2003.

Communications

As anyone who has recently filled out a school form can attest, the number of communications channels available to the members of an average household is large—home telephone number(s), and home e-mail address(es), work telephone number(s), work e-mail address(es), mobile telephone number(s), beeper number(s), etc.

Communication devices and channels proliferate because each device or channel has a different set of attributes. With communication using basic landline telephony, you make a call to a specific physical location, and someone at the location does (or does not) answer. Landline telephony is extremely robust (system outages are rare, and dropped calls are not a problem) and relatively cheap. With more sophisticated telephone systems, people can forward calls, identify callers, and store messages. Mobile telephones bring another dimension to telephony by associating the telephone number with an individual, not a location. Channels based on Internet technologies enable the ability to send anything that can be stored in a digital form to multiple select recipients or to post it for the world-at-large. Text messaging, whether over a telephone or a personal digital assistant, is another new communications type.[6]

The variety of interactions conducted widens considerably as individuals and organizations use these communications tools to redefine how they conduct many common activities. One attribute of some of the channels listed above is to diminish the importance of a user's location. The development of landline telephony meant that the parties to a conversation could be located at great distances from each other, but at stationary locations. Mobile telephony means that, within certain geographic limits, one need not know where a person is physically to communicate with him. E-mails are also non-location dependent because one can send and receive messages anywhere in the world to any account accessible over the Internet. Furthermore, Internet access is increasingly becoming a mobile communications channel due to the spread of broadband wireless Internet access (e.g., Wi-Fi).[7]

A barrage of unwanted messages—some legitimate marketing messages and other potentially fraudulent or dangerous—have accompanied this expansion in communications channels. Anyone with an e-mail account has experienced spam—unsolicited notifications spanning the range from sexual aids to illegal international money laundering schemes. Many individuals feel overwhelmed by the constant barrage. The volume of illegitimate messages also makes it more difficult for legitimate businesses to communicate with potential customers who would be interested in their offers. Attempts to provide appropriate remedies have had mixed success. Specific regulations are in place to protect children online, but, in general, individuals and organizations must rely on filtering protocols that are less than perfect. Efforts to reduce the number of telephone solicitations through the use of the "Do Not Call" list being administered

[6] This list of communication channels is not exhaustive, nor could any complete list be compiled because of the lines dividing the various channels are becoming increasingly blurred. Documents can be sent from a computer to a fax machine, telephone calls can be made using Internet, etc.

[7] See for example, Douglas Heingartner, "Roving the Globe, Laptops Alight on Wireless Hot Spots," *The New York Times*, June 5, 2003, p. G4.

by the Federal Trade Commission are currently under court challenge, even as anti-spam legislation was passed by Congress.

E-Commerce

A specific type of interaction that has received considerable attention over the past few years is electronic commerce—that is, buying and selling online. The evolution of online transactions has been both "less" and "more" than many analysts originally estimated. During the second quarter of 2003, the U.S. Bureau of the Census reported that retail e-commerce sales were $12.5 billion.[8] Although this represents only 1.5 percent of total retail sales—far from replacing in-store sales as some proponents promised—it does represent a 28 percent increase over the second quarter of 2002. E-commerce growth in the business-to-business space, has also fallen short of early expectations. Between 2000 and 2001 (the latest data available), manufacturing e-commerce (whether over the Internet or proprietary systems) increased from 18.0 to 18.3 percent of total shipments, and merchant wholesale e-commerce increased from 8.8 to 10.0 percent.[9]

However, if one considers only the dollar value of online transactions, the importance of e-commerce to the economy is underestimated. Even when the transaction does not take place online, the terms and conditions of the commercial interaction are altered by the availability of e-commerce options. A car buyer can go to the nearest dealership armed with detailed research obtained online. The local bookstore must now consider the pricing and service policies of online competitors.

E-Business Process

The availability of IT products and services also impacts the processes that underlie the interactions. The term "e-business processes" refers to business activities that use information and communications technologies. E-commerce is a specific type of e-business process, as are human resource information systems, and enterprise resources planning systems.

One particularly interesting area of e-business applications is that of supply chain management. Use of IT products and services has enabled interactions between contract participants that closely rival (if not match) the quality of interaction that occurs within a firm. This gives businesses considerable leeway in determining which functions to conduct in-house and which to outsource.

While the ability to automate interactions has been available to large organizations for some time, the development of low cost, "off-the-shelf" tools has greatly expanded the use of e-business applications among smaller organizations. IT-driven changes in the ways that businesses are managing their supply chains has been so great that the statistical agencies have had to reexamine their data collection in a number of areas. (See Box 7.1.)

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[8] US Department of Commerce, Bureau of the Census News Release, August 22, 2003. http://www.census.gov/mrts/www/current.html

[9] US Department of Commerce, Bureau of the Census, E-Stats, March 19, 2003. http://www.census.gov/estats.

Box 7.1. Challenges for Economic Data Collection: Changes in the Supply Chain

The supply chain is one area of business process where IT is providing the means for businesses to streamline and reduce costs. While new supply chain efficiencies benefit the companies undertaking such investments, the new business structures pose challenges for economic data collection.

Existing statistical programs classify business locations into industries based on their underlying production function—businesses doing similar activities are grouped together. This classification system assumes that manufacturers, wholesalers, retailers, and service businesses each perform a distinct set of functions that fit neatly into separate boxes.

As electronic information management changes the way businesses interact with each other, boundaries between these formerly distinct sectors are blurring. Manufacturers, wholesalers, and retailers all may be selling "services." Service firms in transportation and logistics may be leveraging their expertise to take on new functions such as inventory management, or other functions that traditionally have been associated with manufacturers and distributors.

The Bureau of the Census is taking steps to ensure that the data collected adequately reflects these changes in the economy. These steps include adding questions on the supply chain to the 2002 Economic Census survey forms for many industries, which were mailed to 5 million American business locations in December 2002. The questions asked were customized for particular industries. For example, in manufacturing, respondents were asked if various supply chain activities were performed by the individual location, by another establishment within the company, by another company, or not at all. Activities included product design and a series of activities related to order fulfillment (bundling or kitting, pick and pack, warehousing, breaking bulk, local delivery, long distance delivery, and processing of returned merchandise). Census also added several questions on inventory management practices and contract manufacturing practices.*

*Source: US Department of Commerce, Bureau of the Census.

MANAGEMENT

> "When a resource becomes essential to competition but inconsequential to strategy, the risks it creates become more important than the advantages it provides."[10]

Increasingly, IT is a prerequisite rather than an option for governments, businesses, volunteer groups, and households. Possessing information technology may not put you ahead, it may just keep you from falling behind. In such an environment, effective management of IT resources is critical.

The economic research cited earlier in this report indicated that the link between investments in IT and increased productivity at the firm level is often most apparent when IT investment is accompanied by organizational change. However, as the jumble of wires that inhabits the walls, ceiling, and floors of our homes and workspaces attests, adoption of IT in most enterprises has occurred in a piecemeal fashion that simply automated existing processes. Systems are justified and expanded on the basis of how well they address a specific existing need (e.g., human

[10] Nicholas G. Carr, "IT Doesn't Matter," Harvard Business Review, May 2003, p. 42.

resources, acquisition, production, etc.). Often, little thought is given as to whether the process itself needs to be changed or as to how these new systems will interact with existing systems. The new is simply overlaid on the old.

Enterprise Architecture

An unstructured approach to IT investment can cause management problems. The actual interactions occurring between people, processes, data, and the technology become obscured under a wild tangle. Many organizations facing this problem have turned to broad-scale approaches, such as enterprise architecture (EA), to gain an understanding of how the organization is operating and, therefore, how it can be improved. Further, since IT increases the amount of information available to every member of the organization, decision-makers in these organizations are thinking about how technology can be used to empower and enable each individual involved.

An enterprise's leaders must have an accurate understanding of how the enterprise operates to manage it effectively. As an enterprise's complexity increases, this task becomes more difficult. One technique for accomplishing this goal is to construct a systematic description of the enterprise—an enterprise architecture—that relates the outcome of the enterprise's activities to the contributions of its people, business processes, data, and technology. An EA provides the holistic, "outside looking in," view that enables decision makers to understand where incompatibilities, redundancies, and overlaps exist within the enterprise. It also provides insight into the extent to which individual activities are contributing to (or detracting from) the enterprise's mission.

An enterprise's EA typically reveals a very different organization than the enterprise's organizational chart, and it forces enterprise management to confront how it actually conducts business. When all the points of interaction are described, management then has the information needed to begin a review of the effectiveness of these interactions in supporting the mission and goals of the enterprise.

Collaborative Tools

IT offers opportunities for communities of interest to form, share information, and work toward common goals. Some of these collaborative spaces are casual, such as online chat rooms. Others are formal, such as a team working on a design project. Businesses, for example, are increasingly using collaborative software programs to facilitate group discussion and decision-making. Such software allows participants to interact in dedicated online spaces, engage in discussions, and share and track information. Collaborative software, like most IT tools, cannot create efficiency in a vacuum. Organizers and participants must establish rules for interaction (i.e., who can participate, how action items are distinguished from extended conversations, who is in charge of deleting obsolete items, etc.).

Box 7.2. E-Gov Initiatives Improving Government through IT: Geospatial One Stop

The E-Government Act of 2002, signed into law by the President on December 17, 2002, provides explicit legislative recognition of the transformative potential of IT. This Act, together with the E-Gov initiatives currently under development, are part of the Administration's effort to bring the activities of the Federal government into line with the reality of the current digital environment.

As an integral part of the President's Management Agenda, the cross-agency E-Gov initiatives will make it easier for citizens and businesses to interact with the government, save taxpayer dollars, and streamline citizen-to-government transactions. Geospatial One-Stop, one of 24 initiatives, illustrates how cross-agency teams are working to improve the efficiency and effectiveness of government IT spending. The information below as well as information on the other E-Gov initiatives can be found at www.egov.gov

> Geospatial data identifies the geographic location and characteristics of natural or constructed features and boundaries on the Earth. Although a wealth of geospatial information exists, it is often difficult to locate, access, share, and integrate in a timely and efficient manner. Myriad government organizations collect geospatial data in different formats and standards to serve specific missions. This results in wasteful spending on information assets, and impedes the ability of federal, state, and local government to perform critical intergovernmental operations, such as homeland security.
>
> The Geospatial One-Stop initiative will promote coordination and alignment of geospatial data collection and maintenance among all levels of government. Initiative goals include:
>
> - Developing a portal for seamless access to geospatial information
> - Providing standards and models for geospatial data
> - Creating an interactive index to geospatial data holdings at federal and non-federal levels
> - Encouraging greater coordination among federal, state, and local agencies about existing and planned geospatial data collections

Source: http://www.egov.gov

Identity

Ten years ago Peter Steiner succinctly captured one of the key issues in Internet interaction in a New Yorker cartoon showing one dog sitting at a computer talking to another dog with the caption "On the Internet, nobody knows you're a dog."[11] And the identity issue remains one of critical importance today. The shift online of many work and personal activities requires that users have some level of assurance about the identity of the people or businesses from whom they receive information or with whom they conduct business. Effective use of networks also requires that participants are confident that information and transactions are not altered during transmission or storage. They must also be confident that access to sensitive or proprietary information is limited to users entitled to access that information. Without adequate safeguards,

[11] *New Yorker Magazine*, July 1993.

businesses and individuals will bear the brunt of increased cost due to fraud and theft and, as a society, we will not fully realize the potential benefits of online activity.

Obviously, identity concerns exist beyond the online environment. The need to verify identity is of critical importance in many contexts. Port security requires that seafarers entering a harbor on a cargo ship are correctly identified and adequately screened. Financial market stability requires that investors are confident that their financial transactions occurred in the manner requested and that no one has tampered with their account balances. Residents living near a chemical or power plant need assurance that only actual employees can access the plant's control facilities.

Challenges to the security of identity include such disparate activities as identity theft, unauthorized access to a network (hacking), and unauthorized access to a facility. One important area of IT research and development is the development of technologies capable of verifying identity with a high degree of certainty. However, the use of such security tools can ignite privacy concerns.

SECURITY

Identity is a characteristic of an individual or enterprise. It is made up of a variety of attributes, such as name, social security number, fingerprint, or corporate logo. Both the identity owners and those who rely on the assurance of correct identity can suffer damage when identity is misappropriated or identity controls are bypassed.[12] Efforts such as e-authentication, biometrics, and firewalls can help increase security around various aspects of identity.

Identity Theft

Identity theft is a growing problem for both individuals and organizations. Over the last five years, the FTC reports that 27.3 million Americans were victims of identity theft, including 9.9 million during the last year alone. They report further that "identity theft losses to businesses and financial institutions totaled nearly $48 billion and consumer victims reported $5 billion in out-of-pocket expenses."[13] Sixty-seven percent of the identity theft victims reported that existing credit card accounts were misused and 19 percent reported illegal activity in their checking or savings accounts.[14]

There are many ways in which a criminal can gain enough personal information (credit card number, social security number, blank checks, etc.) to steal the identity of someone else. Some methods are decidedly low tech, such as dumpster diving, stealing a purse or wallet, or using phony telephone solicitations. However, hacked computers are a growing source for personal information that the thief will either use directly or sell to a third party.

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[12] See for example, Judith S. Donath, "Identity and Deception in the Virtual Community," prepared for *Communities in Cyberspace*, P. Kollock and M. Smith, editors (final draft). http://smg.media.mit.edu./people/judith/Identity/IdentityDeception.html

[13] "FTC Releases Survey of Identity Theft in U.S. 27.3 Million Victims in Past 5 Years, Billion in Losses for Businesses and Consumers," News Release, September 3, 2003 www.ftc.gov.

[14] *Ibid*.

It is not only individual criminals who are using the Internet to steal and sell information, there is a growing trend toward larger scale criminal organizations. Until recently, the Internet sales of stolen credit card information were primarily conducted by individuals. There was little organization or automation. However, the Honeynet Project and Alliance, which tracks certain illegal online activities, has found an increase in the degree of organization involved in the exchange of stolen credit card information. Hundreds of sellers of stolen credit card numbers might be linked over networks that provide “far greater automation of a number of illicit activities contributing to credit card fraud and identity theft, including: compromising merchant sites, validating and verifying stolen credit card information, and the sale or exchange of stolen information.”[15]

Computer Crime

Identity theft is only one of a wide variety of crimes that can be committed using the Internet. According to the Department of Justice, online crimes cover the range from multimillion-dollar swindles, online auction scams, and business-opportunity frauds to piracy of software and other copyrighted material. Some progress is being made, however, in catching criminals who use the Internet. For example, under a coordinated initiative called Operation E-Con, the Justice Department recently reported the arrest of over 130 individuals and the seizure of more than $17 million.[16]

Another threat comes from those who—with or without malicious intent—illegally access computer systems. Symantec, an Internet security provider, conducts statistical analysis of current trends in cyber security threats by tracking real-time cyber attack activities detected by a sample set of more than 400 companies.[17] They categorize attacks into three groups: malicious code trends (worms and blended threat activity[18]), other cyber attack trends, and vulnerability trends. Symantec reports that “[b]ased on vulnerabilities that surfaced in 2002, a number of high-risk future threats have emerged, which attackers and malicious code writers are only beginning to leverage.”[19]

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[15] The Honeynet Project is an all volunteer organization of security professionals dedicated to researching cyber threats. See “Know Your Enemy—A Profile,” Assessment Date: June 6, 2003. http://www.honeynet.org/papers/profiles/cc-fraud.pdf

[16] Operation E-Con is being coordinated by 43 United States Attorney’s Offices nationwide, the Federal Bureau of Investment, the Federal Trade Commission, the Postal Inspection Service, Secret Service, and the Bureau of Immigration and Customs Enforcement, in addition to other state, local, and foreign law enforcement agencies. US Department of Justice, “Justice Department Announces Dozens of Arrests in Nationwide Internet Fraud Takedown, Operation E-Con,” Press Release, May 16, 2003. http://www.justice.gov.

[17] According to Symantec, they maintain “one of the world’s largest and most detailed repositories of cyber attack data … collected from thousands of firewalls and intrusion detection systems throughout the world.”

[18] Symantec defines blended threats as attacks that combine the characteristics of viruses, worms, Trojan horses, and malicious code with server and Internet vulnerabilities to initiate, transmits and spread an attack. By utilizing multiple methods and techniques, blended threats often spread rapidly and cause widespread damage.

[19] Mark Higgins, Ed., “Symantec Internet Security Threat Report: Attack Trends for Q3 and Q4 2002,” Volume 3, February 2003.

Authentication

One way to decrease the occurrence of identity theft and other types of computer crime is to increase the level of identity certainty—that is, better authentication. For strictly online communications or transactions, demand continues to grow for an electronic equivalent for signatures and contracts as online communications and transactions increase. For situations where an individual is physically present, biometric tools are being developed.

Even though electronic credentialing or authentication techniques continue to increase in sophistication, they must be continually improved to stay ahead of hackers. Further, establishing and maintaining authentication systems can be costly and complicated. For example, to reduce the proliferation of duplicative systems at the federal level, the Administration's E-Authentication initiative launched an interim gateway in 2002 as a pilot project to support the 24 government-wide E-Government initiatives. Although the gateway was successful in the interim phase, participants determined that this solution would not scale sufficiently for the gateway to handle the authentication of credentials for all of the federal agencies. Therefore, the Administration is shifting to the federated approach used by industry.[20]

IT is also playing a role in authenticating identity in situations where an individual is physically present—via technologies, such as biometrics. According to the International Biometric Industry Association, biometric authentication "is the automatic identification or identity verification of an individual based on physiological or behavioral characteristics. Such authentication is accomplished by using computer technology in a noninvasive way to match patterns of live individuals in real time against enrolled records. Examples of biometric-based technologies include products that recognize faces, hands, fingers, signatures, irises, voices, and fingerprints."[21]

Use of these technologies is likely to become more common. For example, as part of the effort to increase the security of U.S. borders, the Enhanced Border Security and Visa Entry Reform Act of 2002 mandates that all visas issued for entry into the United States incorporate biometrics by 2006. The Act does not specify what type of biometric should be used, but among the requirements that might be considered are whether the biometrics can be checked against criminal watch lists when the user enrolls, whether they guard against dual enrollment (i.e., maintaining multiple identities), and whether they verify identity at ports of entry.[22]

PRIVACY

Even as users demand assurance of the correct identity and security of websites they visit, most want to maintain their rights to privacy. For example, visitors to a web site that claims to be maintained by the National Institutes of Health (NIH) want safeguards in place that guarantee

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[20] Jason Miller, "New Authentication Plan Takes Shape," *Government Computer News*, Nov 10, 2003 http://www.gcn.com/22-32/news/24101-1.html.

[21] http://www.idia.org/faqs.htm.

[22] Michael Geruso, "Looking Visa-Holders in the Eye," *Mechanical Engineering*, September 2002, pg. 26.

that the information provided on the site is indeed the unaltered information supplied by NIH. However, the same visitors do not necessarily want NIH to maintain a record of who they are and what pages they visited.

All federal government websites and almost all other reputable private websites will have a privacy policy statement linked to their website homepage. These statements disclose what information is captured when you visit or request a download, whether tracking agents such as cookies are used, how long data are kept, and whether information gathered is ever provided to third parties. Most sites that do maintain arrangements to sell or trade data offer the opportunity for a user to opt-out of the data sharing arrangement.

Statutory and regulatory safeguards to personal information privacy continue to be developed, though in a sector-specific manner. For example, the Federal Trade Commission (FTC), as part of its consumer protection mission, supports the privacy protections provided under several pieces of legislation. "Under the FTC Act, the Commission guards against unfairness and deception by enforcing companies' privacy promises about how they collect, use and secure consumers' personal information. Under the Gramm-Leach-Bliley Act, the Commission has implemented rules concerning financial privacy notices and the administrative, technical and physical safeguarding of personal information, and it aggressively enforces against pretexting. The Commission also protects consumer privacy under the Fair Credit Reporting Act and the Children's Online Privacy Protection Act."[23]

Similarly, the Department of Health and Human Services (HHS) is responsible for the regulation that enables the federal privacy protections for individually identifiable health information provided for under the Health Insurance Portability and Accountability Act (HIPAA) of 1996. Under the Privacy Rule (published December 2000), covered entities had to have standards in place to protect and guard against the misuse of individually identifiable health information by April 1, 2003 (April 14, 2004 is the deadline for small health plans).[24]

Conclusion

While adjusting to the realities of the current digital environment is far from costless, recognizing where the challenges lie and addressing them directly will help smooth the transition.

[23] Federal Trade Commission, Privacy Initiatives http://www.ftc.gov/privacy/index.html

[24] Department of Health and Human Services, "General Overview of Standards for Privacy of Individually Identifiable Health Information," Revised April 3, 2003. http://www.hhs.gov/ocr/hipaa/guidelines/overview.pdf