Digital PROSPERITY

Understanding the Economic Benefits of the Information Technology Revolution

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ABOUT THE INFORMATION TECHNOLOGY AND INNOVATION FOUNDATION

ITIF is a non-profit, non-partisan public policy think tank committed to articulating and advancing a pro-productivity, pro-innovation and pro-technology public policy agenda internationally, in Washington DC and the states. Recognizing the vital role of technology in ensuring American prosperity, ITIF focuses on innovation, productivity, and digital economy issues.

Technological innovation, particularly in information technology, is at the heart of America's growing economic prosperity. Crafting effective policies that boost innovation and encourage the widespread "digitization" of the economy is critical to ensuring robust economic growth and a higher standard of living. However, as in any new and changing situation, policymakers have varied awareness of what is needed and what will work. In some cases legislators have responded to new and complex technology policy issues with solutions more suited for the old economy. And as the innovation economy has become increasingly important, opposition to it from special interests has grown.

As a result, the mission of the Information Technology and Innovation Foundation is to help policymakers better understand the nature of the new innovation economy and the types of public policies needed to drive innovation, productivity and broad-based prosperity for all Americans.

ITIF publishes policy reports, holds forums and policy debates, advises elected officials and their staff, and is an active resource for the media. It develops new and creative policy proposals to advance innovation, analyzes existing policy issues through the lens of advancing innovation and productivity, and opposes policies that hinder digital transformation and innovation.

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I) Executive Summary

In the new global economy information and communications technology (IT) is the major driver, not just of improved quality of life, but also of economic growth. Moreover, there are strong indications that IT has the potential to continue driving growth for the foreseeable future. Yet, most policymakers do not adequately appreciate this fundamental reality. In fact, after the post-2000 economic dip many concluded incorrectly that the IT economy was smoke and mirrors.

The reality is that while the benefits of new technologies are often exaggerated at first, they often turn out to exceed initial expectations in the moderate-to-long term. This is exactly what has happened with the digital revolution. The digital economy is more than fulfilling its original promise, with digital adoption rates exceeding even the most optimistic forecasts of the late 1990s. The integration of IT into virtually all aspects of the economy and society is creating a digitally-enabled economy that is responsible for generating the lion's share of economic growth and prosperity.

Notwithstanding the centrality of IT to economic growth, there have been surprisingly few attempts to catalogue what is known about IT's impacts on the economy. This report attempts to do just that by collecting, organizing, and surveying studies and examples of IT's impact in five key areas: 1) productivity; 2) employment; 3) more efficient markets; 4) higher quality goods and services; and 5) innovation and new products and services.

In order to better understand IT's role in economic growth it is important to realize that the digital economy is more than an economy conducted on the Internet. Rather, it represents the pervasive use of IT (hardware, software, applications and telecommunications) in all aspects of the economy, including internal operations of organizations (business, government and non-profit); transactions between organizations; and transactions between individuals, acting both as consumers and citizens, and organizations. IT has enabled the creation of a host of tools to create, manipulate, organize, transmit, store and act on information in digital form in new ways and through new organizational forms. And its impact is pervasive as it is being used in virtually every sector from farming to manufacturing to services to government.

Importantly, the "IT engine" does not appear likely to run out of gas anytime soon. The core technologies (memory, processors, storage, sensors, displays, and communication) continue to get better, faster, cheaper, and easier to use, enabling new applications to be introduced on a regular basis. Moreover, the adoption of digital technologies by organizations and individuals continues to grow.

The integration of IT into virtually all aspects of the economy and society is creating a digitally-enabled economy that is responsible for generating the lion's share of economic growth and prosperity.

There is no doubt that the IT revolution has enhanced quality of life, from improving health care, to making it easier for children to get better information and learn more, to giving consumers more convenience in their interactions with business and government and making it easier to measure environmental quality. But while these and other benefits are important, perhaps the most important benefit of the IT revolution is its impact on economic growth. The diffusion of information technology and telecommunications hardware, software, and services turns out to be a powerful driver of growth, having an impact on worker productivity three to five times that of non-IT capital (e.g., buildings and machines). In fact, in the United States IT was responsible for two-thirds of total factor growth in productivity between 1995 and 2002 and virtually all of the growth in labor productivity.

While these productivity impacts from IT are among the highest in the United States, most other nations have benefited from the IT revolution as well. Economists have found significant impacts of IT on the productivity of firms in many other nations, including Australia, Canada, Finland, France, Germany, Korea, Japan, the Netherlands, and

Switzerland. Moreover, while its impact is not as large in most developing nations, IT is making a difference there as well, in part because IT expenditures rose twice as fast in developing nations from 1993 to 2001 compared to the OECD average. For example, IT usage in China was responsible for 38 percent of the increase in total factor productivity growth and 21 percent of GDP growth.

IT boosts productivity in a variety of ways. It lets organizations automate tasks, freeing workers up to create value in other tasks. IT also has widespread complementary effects, including allowing organizations to fundamentally reengineer processes and lets organizations more efficiently use capital and natural resources. IT also has a number of indirect effects, which in turn spur higher productivity, including enabling larger markets and better organizational decision-making.

In addition, IT boosts economic output by enabling more people to work. The IT industry itself creates jobs, on average paying 84 percent more than average jobs. Moreover, IT appears to be playing a key role in reducing the severity of the business cycle, allowing the economy to run at full capacity more of the time. Additionally, IT makes it easier for more people to join the workforce, including disabled people and people who cannot work full-time, but who can work part-time or from home.

Our standard of living is not just a function of higher levels of efficiency, but of the quality of products and services. IT is helping organizations boost quality. IT enables more information about quality to be collected, giving organizations greater opportunity and incentive to boost quality. IT also makes it easier for organizations to design more customized products and services, which by definition are of higher quality because they more closely fit the desires of consumers.

Finally, IT is making it easier to create new products and services. IT gives researchers powerful new tools that make discovery easier. Moreover, IT boosts innovation by giving users more of a role in shaping innovation, in part by making research more collaborative.

In short, IT is the major driver of today's global economy. But just because IT has been the leading engine of growth does not mean that policymakers can afford to be complacent. Ensuring that societies fully benefit from the IT revolution means that policymakers must devote the same, if not higher, level of attention to it than they currently give to more conventional economic policy areas, such as managing the business cycle. While this report does not lay out a detailed IT policy blueprint, it offers five key principles policymakers around the globe should follow if their nations are to fully benefit from the digital revolution.

1) Give the Digital Economy Its Due: Economic policymakers need to view IT issues not just as narrow IT policy, but as the centerpiece of economic policy. This means putting issues of digital transformation at the front and center of economic policy.

2) Actively Encourage Digital Innovation and Transformation of Economic Sectors: The private sector will drive much of digital transformation, but government can play a supportive role. Government should support research in emerging IT areas. IT should also use a wide array of policy levers, including tax, regulatory, and procurement policies, to spur greater IT innovation and transformation, particularly in key sectors like health care, education, transportation, and others influenced by public policy. Moreover, government should lead by example by leveraging their own IT efforts to achieve more effective and productive public sector management and administration.

3) Use the Tax Code to Spur IT Investment: Investment is how IT innovations are diffused throughout the economy. Because IT seems have a much larger impact on productivity, tax policies should focus on spurring additional investment in newer generations of IT.

4) Encourage Universal Digital Literacy and Digital Technology Adoption: Ensuring that societies take full advantage of the IT revolution will require that the large majority of citizens participate in the digital economy. National governments need to work in partnership with the for-profit, non-profit, and state and local government sectors to help citizens use and access technology.

5) Do No Harm: Making digital transformation the center of economic policy means not just supporting IT, just as importantly it means avoiding harming the digital engine of growth. All too often well-intentioned policymakers consider laws and regulations that would slow digital transformation.

While the emerging digital economy has produced enormous benefits, the best is yet to come. The job of policymakers in developed and developing nations alike is to ensure that the policies and programs they put in place spur digital transformation so that all their citizens can fully benefit.

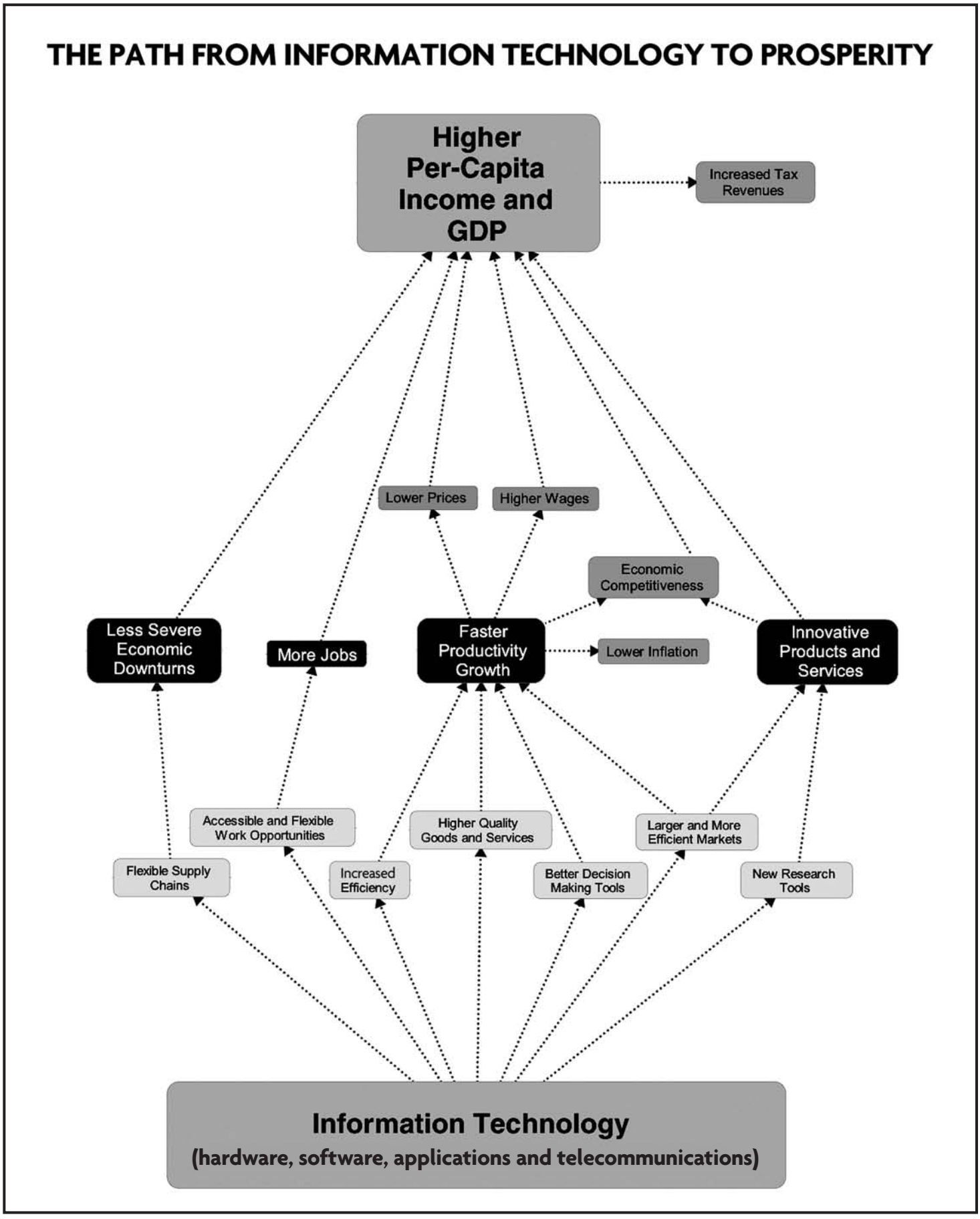
II) Introduction

In the new global economy information and communications technology (IT) is the major driver not just of improved quality of life for people, but also of economic growth. Yet, most policymakers around the world do not adequately appreciate this fundamental reality. There are a number of reasons for this. In earlier years of the IT revolution, many policymakers were looking for a big IT impact and didn't see it. Then in the mid and late 1990s they were told that IT was transforming our world, creating a New Economy, ending the business cycle, and banishing scarcity. But with the "dot-bomb" implosion, the NASDAQ collapse and the recession of 2001 digital exhilaration quickly turned into digital pessimism. Now the pundits tell us that nothing changed and that the "digital revolution" was just the creation of an overly enthusiastic media. When Nicholas Carr (2003, 10) claimed that "IT Doesn't Matter" because, "As for IT-spurred industry transformations, most of the ones that are going to happen have likely already happened or are in the process of happening," many interpreted that to mean that IT doesn't matter for either firms or the economy.[1] As a result, too many policymakers around the world drew exactly the wrong conclusion from this temporary plateau in the IT revolution: that the IT economy was smoke and mirrors.

The reality is that while the benefits of new technologies are often exaggerated at first, they often turn out to exceed initial expectations in the moderate-to-long term. This report argues that this is exactly what has happened with the digital revolution. The digital economy is more than fulfilling its original promise, with digital adoption rates actually exceeding the most optimistic forecasts of the late 1990s. However, this digital revolution has not occurred, as some expected, principally by means of high-flying dot-com startups. Rather, the integration of IT into virtually all aspects of the economy and society is creating the world's first truly digitally-enabled economy that is responsible for generating the lion's share of economic growth and prosperity—more than capital, monetary policy, trade, and even education. Investment in information technology and telecommunications hardware, software applications and services turns out to be a powerful driver of growth, having an impact on productivity three to five times that of non-IT capital (*e.g.*, buildings, machines). In fact, in the United States IT was responsible for two-thirds of total factor productivity growth between 1995 and 2002 (Jorgensen, Ho, and Stiroh 2005), and virtually all of labor productivity growth, and its impact in other nations, including developing nations, was also significant. For most industries and organizations IT is the principal tool they rely on to boost productivity and innovation.

Notwithstanding the centrality of IT to economic growth, there have been surprisingly few attempts to catalogue what is known about IT's impacts on the economy. This report attempts to do just that by collecting, organizing, and surveying studies and examples of IT's impact in five key areas: 1) productivity; 2) employment; 3) more efficient markets; 4) higher quality goods and services; and 5) innovation and new products and services.

The digital economy is more than fulfilling its original promise, with digital adoption rates actually exceeding the most optimistic forecasts of the late 1990s.


THE PATH FROM INFORMATION TECHNOLOGY TO PROSPERITY
Higher Per-Capita Income and GDP
Increased Tax Revenues
Lower Prices
Higher Wages
Economic Competitiveness
Less Severe Economic Downturns
More Jobs
Faster Productivity Growth
Lower Inflation
Innovative Products and Services
Accessible and Flexible Work Opportunities
Higher Quality Goods and Services
Larger and More Efficient Markets
Flexible Supply Chains
Increased Efficiency
Better Decision Making Tools
New Research Tools
Information Technology
(hardware, software, applications and telecommunications)

III) Public Policy Principles for Driving Digital Prosperity

IT has been the leading engine of growth, particularly in the United States, but this does not mean that policymakers can be complacent and just sit back, hoping to continue to receive this digital manna from heaven. Ensuring that societies fully benefit from the potential of the IT revolution means that policymakers must devote the same, if not higher, level of attention to it than they currently give to more conventional economic policy areas, such as managing the business cycle. For the digital economy is no magic perpetual motion machine that will inexorably drive growth, with policymakers having the luxury of basking in its reflective growth. Rather, it is a technology system whose economic impacts can be greatly accelerated or retarded by the actions or inactions of policymakers. The right IT public policies might mean the difference between adding 2 percentage points of productivity growth per year to the economy instead of just 1 percentage point. This might not sound like much difference, but it is the difference between incomes doubling in 36 years instead of 70 years. While it is beyond the scope of this report to lay out a detailed IT policy blueprint, there are at are at least five key principles policymakers around the globe must follow if their nations are to fully benefit from the worldwide digital revolution.

Ensuring that societies fully benefit from the potential of the IT revolution means that policymakers must devote the same, if not higher, level of attention to it than they currently give to more conventional economic policy areas.

1) Give the Digital Economy Its Due: Despite the fact that there is widespread agreement among economists that the IT revolution is the key driver of growth, too few policymakers are sufficiently tuned into this reality. Even when policymakers acknowledge the importance of IT, they all too often give short shrift to IT policy in favor of a focus on more "mainstream" macroeconomic fiscal and monetary policy issues that while important in the old economy, are no longer the key enablers of growth. Moreover, even as some policymakers have more recently turned their attention toward microeconomic policies to boost innovation and competitiveness, policies to spur digital transformation have largely been overlooked in favor of efforts to improve education and increase research funding. To be sure these efforts are important. But they are not nearly as important to growth as ensuring continued digital transformation (the ubiquitous use of IT in all industries and applications that can be digitized). Given the importance of IT to growth, it's time that economic policymakers see IT issues not just as a narrow sideline, but rather as the centerpiece of economic policy. This means putting issues of digital transformation at the front and center of economic policy. It also means that other policy areas, such as tax policy, regulatory reform (including patent reform), spending, trade policy, and procurement should be considered with a focus on how they can be used to spur digital transformation.

2) Actively Encourage Digital Innovation and Transformation of Economic Sectors: The private sector will drive much of digital transformation, but government can and should play a supportive role. Economists have long argued that business under-invests in research. Government can play a key role by supporting earlier stage research in emerging IT research areas, either through boosting direct funding or expanding the R&D tax credits. Economists have also documented significant market failures, including network externalities and "chicken-or-egg" issues that slow digital transformation absent smart and supportive public policies. Health care is perhaps the leading example, but it is by no means the only such market failure. Success for any individual health organization that embraces a digital business model depends on other health organizations and patients also embracing the digital model. Such chicken-or-egg and network externality issues exist in a host of industries,

including transportation, real estate, government, and education, as well as in a host of technology industry areas such as high-speed broadband telecommunications, smart cards, radio frequency identification devices (RFID), geographic information systems, mobile commerce, and the new Internet Protocol Version 6.[2] In these cases, government should use a wide array of policy levers, including tax, regulatory, and procurement policies, to spur greater IT innovation and transformation. Moreover, government officials at all levels can and should lead by example by leveraging their own IT efforts to achieve more effective and productive public sector management and administration. Among other things, this means governments should not only actively promote e-government but should also look to how IT can be used help solve a wide array of pressing public challenges. In this regard IT can now be a key public policy tool, alongside tax, procurement and regulation.

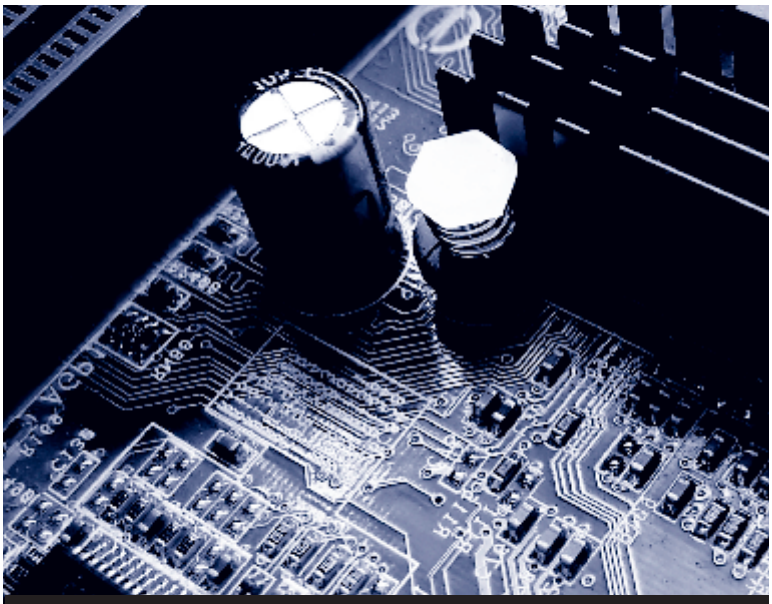
3) Use the Tax Code to Spur IT Investment: While IT innovation is important, it is only through investment in IT (hardware, services, software, applications and telecommunications) that IT innovations are diffused throughout the economy. Research has conclusively shown that organizational investment in IT powers growth. In fact, IT appears to be "super capital" that has a much larger impact on productivity than other capital. As a result, public policies should focus on spurring additional investment in newer generations of IT. Policymakers should avoid taxing IT investments, particularly broadband telecommunications. They should also avoid placing tariffs on IT imports as tariffs reduce IT investment. They should also allow companies to more rapidly depreciate IT investments for tax purposes. Some economists might question such policies, arguing that such tax incentives should only go to investments in areas like R&D where companies seldom capture all the benefits. However, there is emerging evidence that because IT transforms organizations and leads to innovations within other organizations, it operates in the same way as research and knowledge, with high spillovers that may be taken advantage of by other organizations. In such an environment, the socially optimal amount of investment will lag behind actual investment. In these cases it makes sense for the tax code to spur additional IT investment, or at least to avoid having the tax code penalize IT investment.

4) Encourage Universal Digital Literacy and Digital Technology Adoption: The benefits and promise of the digital revolution are immense. Moreover, as consumers become digital "prosumers" (consumers who also use IT to become producers by doing things like paying bills online), ensuring that we fully take advantage of the IT revolution will require that a large majority of citizens participate in the digital economy. Yet, in 2005 only between 65 and 75 percent of American households had an Internet-connected computer at home.[3] There are multiple reasons why the rate is not higher, including in some cases affordability, particularly for broadband telecommunications.[4] But perhaps the most important factor is lack of digital literacy. To succeed in today's economy people need basic familiarity and understanding of computer and Web skills. Some companies, like Microsoft,[5] have taken significant steps to help build digital literacy. Some organizations, like One Economy, have taken steps to encourage digital adoption. And some states, like North Carolina, have stepped up efforts to expand digital literacy and IT and broadband takeup, especially in rural areas.[6] But national governments need to do more in partnership with the for-profit, nonprofit, and state and local government sectors to spur digital literacy and take-up.

5) Do No Harm: Putting digital transformation at the center of economic policy means not just supporting it, but just as importantly avoiding harm to the digital engine of growth. Notwithstanding the progress that IT enables, all too often well-intentioned policymakers are willing to consider laws and regulations that would slow digital transformation. Efforts to regulate or ban RFID technology under the guise of privacy protection is but one notable case (Atkinson, May 2006). But there are many other policy proposals, such as over-regulating Internet telephony (Voice-over-Internet protocol) or regulating Internet video content, that could have deleterious effects. In other cases, policymakers continue to preserve, and in some cases erect, laws and regulations protecting powerful off-line incumbents (*e.g.*, banks, car dealers, optometrists, realtors) against competition from emerging on-line competitors, thus thwarting competition, slowing productivity growth and hurting consumers (Atkinson, July 2006). While still protecting consumer safety, policymakers should ensure that markets are as open as possible to entry and online competition.

IV) What is the Digital Economy?

For most people the digital economy refers to the economy conducted on the Internet, but the digital economy is much broader than this. The digital economy represents the pervasive use of IT (hardware, software, applications and telecommunications) in all aspects of the economy, including internal operations of organizations (business, government and non-profit); transactions between organizations; and transactions between individuals, acting both as consumers and citizens, and organizations. Just as 100 years ago the development of cheap, hardened steel enabled a host of tools to be made that drove economic growth, today information technology enables the creation of a host of tools to create, manipulate, organize, transmit, store and act on information in digital form in new ways and through new organizational forms (Cohen, Delong, Weber, and Zysman 2001).



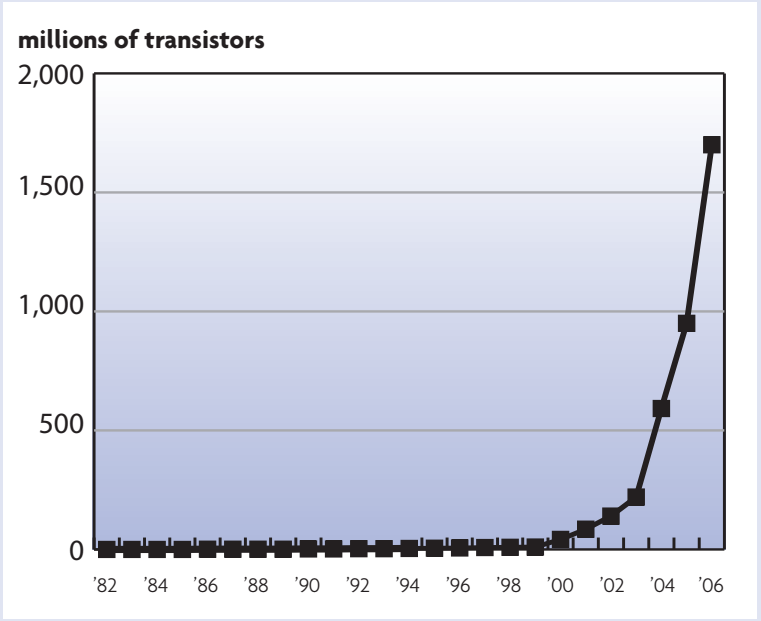
Moore's Law has created a microelectronics revolution dramatically driving down costs and increasing performance.

The technologies underlying the digital economy also go far beyond the Internet and personal computers. IT is embedded in a vast array of products, and not just technology products like cell phones, GPS units, PDAs, MP3 players, and digital cameras. IT is in everyday consumer products like washing machines, cars, and credit cards, and industrial products like computer numerically-controlled machine tools, lasers, and robots. Indeed, in 2006, 70 percent of microprocessors did not go into computers but rather went into cars, planes, HDTVs, etc., enabling their digital functionality and connectivity. Connecting these IT tools is a robust and growing wireless and wireline telecommunications network. Moreover, the technology is anything but static. As it continues getting cheaper, faster, better, and easier to use, organizations continuously find new and expanded uses for IT every day, as the recent emergence of YouTube illustrates. As some keen observers of the digital economy point out, "At each point in the last 40 years the critical step in the transformation of technological potential into economic productivity has been the discovery by IT users of how to employ their ever greater and ever cheaper computing power to do the previously impossible." (Cohen, Delong, Weber, and Zysman 2001) Cataloging even one-tenth of the new applications being created today in a wide array of application areas and sectors would be a monumental task.

Why has IT become so ubiquitous and so central to growth and innovation? Certainly, a number of economic, social and political factors played critical roles, but the short answer is that IT prices have plummeted, performance has exploded, and usability has vastly improved. If just one of these had happened, the digital revolution would have been stillborn. If prices had fallen without performance improvements, the result would be cheap but

The digital economy represents the pervasive use of IT (hardware, software, applications and telecommunications) in all aspects of the economy.

Figure 1: TRANSISTOR GROWTH IN INTEL COMPUTER PROCESSOR CHIPS[7]



not very effective technologies. If performance had improved without price declines, IT would have proven too expensive to put into everyday devices and applications. If both happened but the technology remained hard to use, adoption rates would be significantly lower. Luckily, all three happened.

In 1965, Intel co-founder Gordon Moore observed that as transistors got smaller, the number of transistors that fit onto an integrated circuit grew exponentially. He "challenged" the semiconductor industry to continue this exponential growth, a challenge which the industry has risen to time and again. Each doubling requires innovation, capital expenditure, and risk. In practical terms, the result has been that the computing power of a chip doubles every 18 months. This prediction has held true for over 40 years. In 1978, the price of Intel's 086 processor was $480 per million instructions per second (MIPS). By 1985, the cost of the 386 processor had fallen to $50 per MIPS. Ten years later the Pentium Pro cost just $4 per MIPS. In 2003 the Itanium 2 processor cost half that, at $2 per MIPS.[8] We can see this trend by examining the growth in the number of transistors on Intel processors **(See Figure 1)**.

This exponential progress is continuing across many core IT technologies (memory, processors, storage, sensors, displays, and communication) **(See Table 1)**. The real price of servers fell approximately 30 percent per year between 1996 and 2001 (Van Reenen 2005). Hard drive storage capacity has doubled every 19 months while the cost of a stored megabyte of data has fallen 50 percent per year. As a result, the cost of storing one megabyte of information fell from $5,257 in 1975 to 17¢ in 1999 to half a cent in 2002 to less than 1/10th of a cent today. That is why sales of a whole array of devices based on stored data, from portable MP3 video players to digital television recorders, are taking off. This is why Hewlett-Packard can sell its Media Vault that stores 300 gigabytes of data—enough to store 150 movies—for around $380. It's why Web companies like Google, Yahoo, and Microsoft are providing consumers with large amounts of free Web-based storage for their e-mail, photos, and other files. For example, Google provides around 2.7 gigabytes (2,700 megabytes) of free storage for users of their Gmail e-mail service. If Google were to provide this service today using the technology of 1975 (in 2006 prices), it would cost them over $50 million per user! But because memory is now so cheap, Google and other companies can afford to give vast amounts of it away for free, paying for it through unobtrusive advertisements.

While much of the growth has been driven by improvements in hardware, software has also improved. One study estimates that software productivity (the writing of code) has more than quadrupled since 1970.[9] Moreover, an increasing number of software firms are offering more comprehensive, rather than specialized, packages for businesses, which allows for lower-cost implementation and easier use. The use of Web-based applications also helps reduce costs, especially in associated consulting and support.

Not only has technology gotten cheaper and more powerful, it has become much easier to use. Through the mid-1970s, computers were considered complex devices that could only be operated by trained professionals. Operating a computer was often compared to flying a commercial jet –one needed years of training and a license. And anyone who took a close look at hardware and software prior to 1970 would have to conclude as much. Beginning in the early to mid 70s and accelerating with the introduction of Apple's first Macintosh computer with a graphical user interface, the world dramatically changed. Computers and their software were now designed for ease of use, which has

made it possible for non-highly-trained people to exploit the benefits of IT. The trend toward more user friendliness has continued and accelerated to this day, and is moving in the direction of intuitive devices that will not even require familiarity with a mouse or a keyboard, only the ability to speak.

In short, IT has consistently gotten "faster, better, cheaper, and easier." And the prices are expected to keep falling even as performance continues its increase. While the digital revolution couldn't have occurred without price declines, quality improvements, and increased usability, these were not the only factors. The advances had to be in a technology that had widespread use and economic implications. If lighting, for example, were subject to Moore's law, and the cost of electric lighting fell to almost nothing, businesses and consumers would enjoy lower electric bills, but this wouldn't drive an economic revolution.

Moore's law created a revolution because IT is what economists call a "general purpose technology." General purpose technologies have three characteristics (Bresnahan and Trajtenberg 1995). First, they are pervasive in that they end up being used by most sectors. Second, their performance and price improve over time, sometimes quite dramatically. And third, they make it easier to invent and produce new products, processes and business models. Technologies like the steam engine, railroads, electricity and the internal combustion engine are all examples of general purpose technologies that drove economic transformation and growth in the past.[10]

For all intents and purposes, IT is the only general purpose technology today that is driving growth. This is not to say that other technologies—such as chemical processing, electric lighting, and polymer sciences—are not important supporting technologies. But unlike IT, they are not acting as locomotives of growth. Nor is it to say that other technologies—most likely nano-technology—could not play that role in the future. But for now, these technologies are not mature enough to drive the growth of the global economy.

IT has all three characteristics of a general purpose technology. IT is pervasive, being in virtually every sector from farming to manufacturing to services to government. IT price declines and performance improvements have been unlike any other technology in history and show no signs of letting up. And IT has dramatically enhanced the ability to develop new business models (*e.g.*, outsourced business processes, e-businesses, new logistics systems, etc.); new products and services (*e.g.*, smart phones, the iPod and digital media services); new processes (*e.g.*, self check-in at airports); and fundamental new inventions (*e.g.*, mapping of the genome years faster than most predicted).

Because it is the powerful general purpose technology of our time, IT hasn't just led to some business processes being automated or to consumers getting a few more conveniences. IT has transformed the economy, not just through higher productivity, but in a multitude of different ways.

Just as importantly, it appears likely that the "IT engine" is not likely to run out of gas any time soon. The core technologies (memory, processors, storage, sensors, displays, and communication) continue to get better, faster, cheaper, and easier to use, enabling new applications to be introduced on a regular basis. For example, Apple's decision to roll out its new video iPod was a decision that was largely enabled by the rapid fall in price and expansion in capacity of digital storage. The tiny iPod can now hold 80 gb of data, enough for around 100 hours of video. As technology continues to improve it will enable improvements in a wide array of areas, such as better voice, handwriting and optical recognition; more intelligent agents that routinely filter and retrieve information based on user preferences; and expert systems software to help make decisions in medicine, engineering, finance, and other fields. Moreover, new software applications such as service-oriented architecture and Web services allow organizational functions to be broken down into standard, re-usable components, significantly improving efficiency.

The adoption of digital technologies continues to grow. There are over 11.5 billion Web pages publicly available

Table 1: IT DOUBLING (OR HALVING) TIMES[11]

	years
Total bits shipped	1.1
Microprocessor Cost per Transistor Cycle	1.1
Magnetic Data Storage	1.3
Dynamic Random Access Memory (RAM) (bits per dollar)	1.5
Average Transistor Price	1.6
Processor Performance in MIPS	1.8
Transistors in Intel Microprocessors	2.0
Microprocessor Clock Speed	2.7

(Jones and Potter, 2006, 47). The number of U.S. households subscribing to broadband increased from 35.3 million in 2004 to 52.2 million in 2006, and is projected to increase to 90 million by 2010, or 71 percent of households online.[12] In addition, online use of applications like bill payment, purchasing, and other practices continues to grow. When any individual nation gets to 75 percent high-speed broadband penetration and 50 percent usage of key applications (such as electronic bill payment), a critical inflection point is likely to occur. At that point the cyber world will begin to dominate, whereas now both cyber business and traditional business exist in parallel worlds.

Finally, while IT has helped transform some sectors and activities, such as retail and financial services, its impact in other sectors is more nascent. Sectors like health care, education, transportation, government, real estate, and others are at the early stages of digital transformation and as they transform, productivity will continue to grow. At some point in the near to moderate term future, particularly with the support of the right public policies, IT will be applied to most things we want to do, with every organization and economic function that can employ digital technologies doing so.

IT has been the key factor responsible for reversing the 20-year productivity slowdown from the mid-1970s to the mid-1990s and in driving today's robust productivity growth.

Many of the widely appreciated benefits of the IT revolution are in areas of improving quality of life: improving the quality of health care; making it easier for children to get information and thereby learn more; giving consumers more convenience in their interactions with business and government; making it easier to measure environmental quality, and a host of other beneficial applications. But while these and related benefits are important, perhaps the most important benefit of the IT revolution is its impact on the economy, particularly on productivity and overall economic output. IT has been the key factor responsible for reversing the 20-year productivity slowdown from the mid-1970s to the mid-1990s and in driving today's robust productivity growth.

Networks and advanced telecommunications link together the new economy.

V) IT Drives Productivity Growth

Productivity growth—the increase in the amount of output produced by workers per a given unit of effort—is the most important measure and determinant of economic performance. The United States enjoys one of the highest standards of living because in the 20th century economic output per person grew eight-fold.[13] If productivity grows one percent faster each year for the next 40 years than it did in the 1980s, and if that growth is distributed relatively evenly, the average American will earn $41,000 more per year than he or she would have otherwise. With this increased income Americans could afford better housing, universal high-quality health care, more college education and many other benefits. Moreover, the increased output would generate more tax revenues making it significantly easier for the federal government to cope with the fiscal impact of the impending retirement of the baby boom generation. This is because every 0.1 percentage point increase in annual productivity growth adds $50 billion annually to the federal budget after 10 years have passed (CBO 2001). In short, productivity growth is the key to prosperity and solving future economic challenges **(See Box 1)**. Continued digital transformation is the major driver of productivity, especially in an era of globalization where nations confront competing and disruptive business models on a greater scale.

In the heyday of the old economy from 1948 to 1973, labor productivity grew on average 3.2 percent per year. As a result, real wages for virtually all Americans increased significantly. However, from 1974 to 1995 labor productivity growth fell to about 1.5 percent per year **(See Figure 2)**. As productivity slowed through the 1980s, many economists thought that the beginning of the "micro-computer" age might create a productivity rebound. However, initial studies found little connection between IT investment and productivity, giving rise to the so-called "productivity paradox" of increased investments in IT and little measured productivity boost **(See Box 2)**.

There were two reasons why these early studies failed to find a connection between IT investment and productivity. First, the studies were flawed in both the methodologies and the data sets employed (Dedrick, Gurbaxani and Kraemer 2003). Second, and more importantly, the IT system of the 1980s, while impressive to someone used to 8-track music players and pocket calculators from the early 1970s, was just too nascent to have a measurable impact. Even by 1990, IT expenditures remained less than 10 percent of total capital expenditures **(See Figure 3)**. IT performance was quite limited, and few devices were networked together.

However, the mid-1990s were a turning point that marked the move from the sluggish U.S. economy of the

Figure 2: ANNUAL LABOR PRODUCTIVITY GROWTH[14]

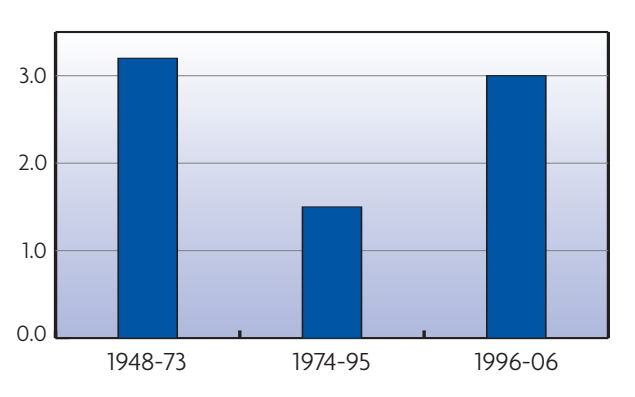
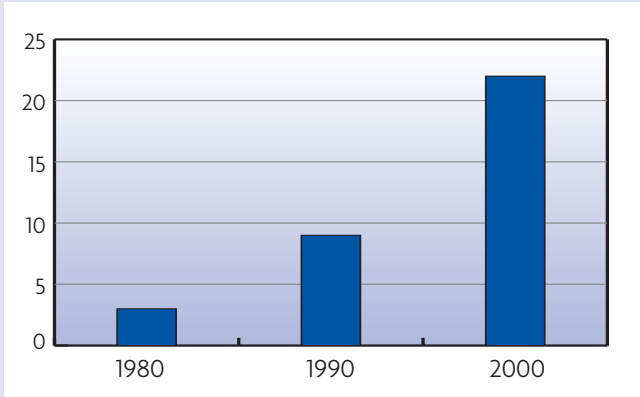


Figure 3: IT INVESTMENT AS A SHARE OF TOTAL CAPITAL INVESTMENT[15]



1970s, 1980s, and early 1990s to the dynamo of the last decade. In the fourth quarter of 1995, labor productivity jumped from an average of 1.46 percent annual growth over the previous 22 years to 3.4 percent and never looked back.[16] As economists Jorgenson, Stiroh, and Ho (2006) declared, "While the post-1995 period includes the boom of the late 1990s, it also includes the NASDAQ collapse in 2000, the 2001 recession, the 9/11 terrorist attacks, an investment bust, corporate accounting scandals, the war in Iraq, and rising oil prices. The strength of productivity growth through this period is nothing short of phenomenal!" That such growth could take place despite the upheavals of the period show the strength of the new IT system. The new contemporary digital tools of productivity finally became integrated and used in fundamental economic and business processes.

As productivity rebounded when the Internet boomed and cheap powerful computing took off, many economists began to suspect that IT was finally delivering the productivity gains they had long expected[17] **(See Figure 4)**. As productivity growth kept up through the early 2000s and even increased, evidence mounted that IT was behind this unanticipated economic boom. IT products had finally become small enough, cheap enough, and powerful enough to be part of virtually all sectors of the economy and to drive a $13 trillion economy.[18]

Box 1: PRODUCTIVITY: THE KEY DRIVER OF PROSPERITY

WHILE PRODUCTIVITY may not get as much attention among policymakers as the quarterly changes in GDP, the unemployment rate, and inflation, most economists argue that productivity is the single most-important economic statistic and measure of economic performance.

There are two main measures of productivity. The first, labor productivity, refers to the amount of output a worker achieves given a particular unit of work. For example, if a UPS driver using wireless technology can deliver more packages a day than a driver without, the labor productivity of the former driver is higher than the latter. But in this case, the former worker is using more technology, which UPS must pay for. To assess productivity controlling for changes in inputs, such as more physical capital (*e.g.*, wireless technology) or more human capital (*e.g.*, more training for the driver), economists measure total factor productivity. Higher total factor productivity is an indication of greater efficiency in the economy because of better technology or economic organization, as opposed to simply more capital. IT has boosted both labor productivity and total factor productivity.

Higher productivity is important in ensuring robust economic growth. For example, the speed-up in productivity growth of the mid to late 1990s means that the economy now produces $1.9 trillion more in output every year (*Business Week* 2002, 56).[20] The higher productivity growth also kept down inflation and enabled the economy to weather the shocks of 2000 and 2001 and experience a mild instead of severe

Box 1, Figure 1: ECONOMIC GROWTH FROM DIFFERENT PRODUCTIVITY RATES[19]

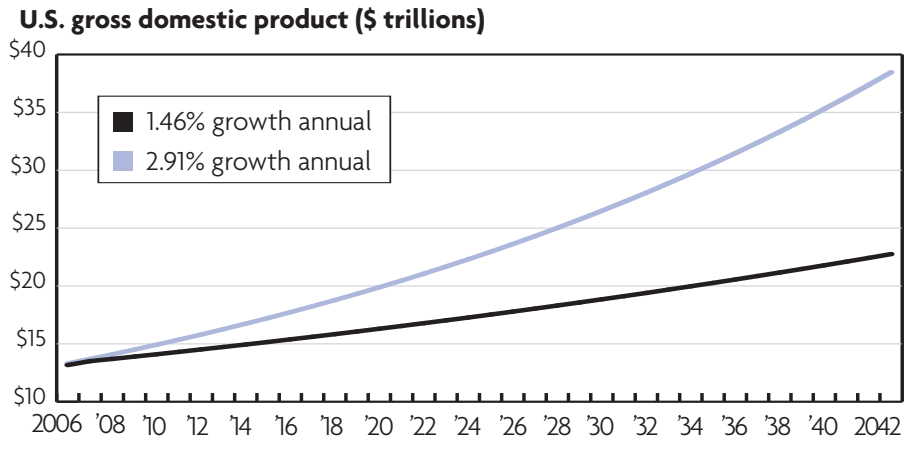
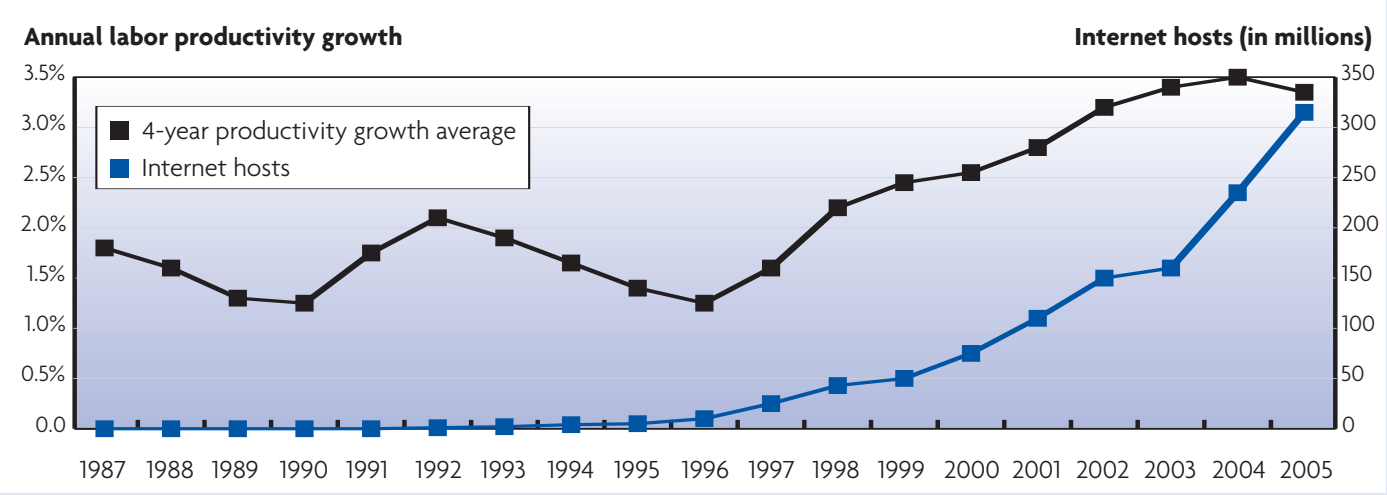


Figure 4: THE GROWTH OF PRODUCTIVITY AND THE INTERNET[21]



recession. And unlike traditional measures of economic growth, such as GDP, that can be boosted solely because more people are working longer hours, productivity growth is more closely linked to higher standards of living through higher wages and the ability to produce better and more plentiful consumer goods and services. Finally, higher productivity is an important driver of economic competitiveness. One way that the U.S. can successfully compete with lower wage nations is to boost productivity in traded sectors so that our higher wages are offset by our much higher productivity.

To see how important productivity is, consider the fact that if labor productivity were to grow over the next 25 years at its 1973-1995 average of 1.46 percent per year, output per capita would increase by roughly 44 percent. However, if we can sustain the rate of productivity growth enjoyed over the last ten years (2.91 percent) output per capita over the next 44 years would more than double (105 percent). According to Glen Hubbard (2002, 24), former Chairman of the Council of Economic Advisors, an increase of just "two-tenths of a percentage point in structural productivity growth every decade is about $1,000 for every man, woman and child in the country." The Congressional Budget Office (CBO 2005) projected that an increase in the productivity growth rate of just one-tenth of a percentage point would add $200 billion to GDP after ten years. Another study (Varian, Litan, Elder, and Shutter 2002, 11) found that this one-tenth of a percentage point increase in productivity growth would result in $50 billion more federal revenue after ten years, or would let federal taxes be cut by $50 billion with no loss in revenues.

This is not to say that productivity growth alone is enough to ensure growing widespread prosperity, but without it, growing widespread prosperity is not possible. In spite of the importance of productivity, some argue that because of the increase in income inequality, that productivity shouldn't be the focus of policy. Yet, this view ignores the fact that even when income growth is unbalanced, lower income Americans still usually benefit from growth. For example, in a comprehensive study, Dew-Becker and Gordon (2005) found that from 1987 to 2001 two-thirds of the increase in productivity went to the 20 percent of households earning the most. Yet while the bottom 80 percent did not benefit as much as they should, they still did benefit from productivity growth, getting one-third of the benefits or an additional $535 billion in earned labor income than they would not have without productivity growth. Moreover, it's important to remember that approximately 40 percent of the productivity-enabled increase in labor income of the top 20 percent went back to society in the form of federal and state income taxes. This is not to say that policy efforts to ensure more opportunity and less skewed income growth are not important. But it is to say that a policy focused just on redistribution and ignoring productivity growth is one that is doomed to failure since the pie will not be growing as fast as it could.

As a result, there is a now a strong consensus among economists that the IT revolution was and continues to be responsible for the lion's share of the post '95 rebound in productivity growth. In a conclusive review of over 50 scholarly studies published between 1987 and 2002 on IT and productivity, Dedrick, Gurbaxani and Kraemer (2003, 1) found that "the productivity paradox as first formulated has been effectively refuted. At both the firm and the country level, greater investment in IT is associated with greater productivity growth." In fact, nearly all scholarly studies since the mid-1990s have found positive and significant effects of IT on productivity (Dedrick, Gurbaxani and Kraemer 2003, 12). As Harvard economist Dale Jorgenson (2001, 1) writes, "Despite differences in methodology and data sources, a consensus is building that the remarkable behavior of IT prices provides the key to the surge in economic growth." Economists have studied the impacts of IT on the productivity of firms, industries and economies. In all three cases, they have found that IT has been the major driver of increased productivity.

IT is helping to transform manufacturing.

PRODUCTIVITY IN FIRMS

Studies have found that the more firms invest in IT the higher their productivity. In a study of over 1,167 large U.S. firms MIT economist Eric Brynjolfsson (2003) found that firms with the highest levels of IT investment per worker also had the highest levels of productivity. Black and Lynch (2000) found a positive and significant relationship between the proportion of non-managers using computers and the productivity of manufacturing establishments. Atrostic and Nguyen (2005) found that the use of computer networks raises productivity in manufacturing plants by roughly 7.5 percent. Moreover, productivity is significantly higher in plants running sophisticated software to integrate multiple business processes, such as inventory and production (Atrostic and Nguyen 2006). Caselli and Paterno (2004) found that IT investment in manufacturing had a bigger impact on productivity growth in the second half of the 1990s than in the period 1973-1995. Clayton and Goodridge (2004, 47) found that "computer networks in firms have a positive impact on Total Factor Productivity." Bartel, Ichniowski and Shaw (2005) found that greater use of IT (including computer-controlled machine tools) in the valve production industry was associated with higher firm productivity.

Looking at the adoption of Internet-based business practices, one study (Varian, Litan, Elder, and Shutter, 2002) found that between 1998 and 2001 firms in the United States saved $155 billion, and by 2010 are expected to cumulatively save $528 billion. It estimated that the net impact of these cumulative cost savings is expected to account for 0.43 percentage points of the future increase in productivity growth, roughly half of the expected faster growth in productivity compared to the slower growth of the 1974-1995 period. A study of IT use in the UK found that an additional 10 percent of workers using computers resulted in a 2.2 percent gain in productivity in older firms and 4.4 percent in new firms. Internet usage had an even bigger impact, with a 10 percent increase in Internet usage resulting in a 2.9 percent gain for older firms (Farooqui 2005). Another UK study found that the use of computer networks by firms increases total factor productivity by 5 percent (Criscuolo and Waldron 2003, 53). For every 10 percent of employees using personal computers, that firm's productivity increased 2.2 percent, while Internet-enabled computers boosted productivity 2.9 percent (Clayton 2005). Firms that also heavily used telecommunications had even higher productivity gains, particularly in retail

and wholesale sectors. Firms engaged in e-procurement enjoyed 7 percent higher value-added than firms that did not, while firms engaged in e-selling had 4 percent lower prices (Criscuolo and Waldron 2003).

The views of business executives are consistent with the results of these studies. A survey of 300 U.S. business executives conducted in 2003 (Violino) found that, "About 91% of the executives said workers tally the same hours but get more done because of technology." European executives are also positive about the impacts of IT. Most thought IT had a beneficial impact, not just on productivity (55 percent), but on work organization (61 percent), product quality (38

Box 2: ROBERT SOLOW'S PRODUCTIVITY PARADOX

WHILE INFORMATION TECHNOLOGY was in wide use in the late 1980s, productivity growth still slumped. Most economists were puzzled that this powerful new technology was not budging the productivity needle. Indeed, economist Robert Solow famously quipped, "We see the computer age everywhere except in the productivity statistics." (Gordon 2003, 256) The fact that productivity measures did not seem to show any impact from new technologies was labeled "the productivity paradox."

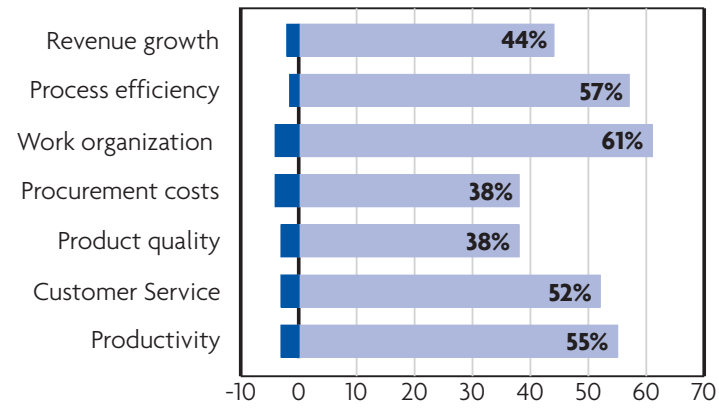
Some economists looked at the data and concluded that IT really wasn't all that important. But the real reason we were not seeing IT in the productivity statistics was that the IT system was too embryonic to move a $6 trillion economy. It turns out that IT was boosting productivity, but only in particular sectors that invested heavily in IT. Studies examining particular industry sectors found significant positive relationships between IT investment and productivity. For example, from the 1970s to the 1990s productivity grew 1.1 percent per year for sectors investing heavily in computers and approximately 0.35 percent for sectors investing less.

Even if IT helped particular sectors, why was it not showing up in the overall productivity statistics? Comparing the adoption of computers to the electric motor, Historian Paul David (1990) suggested that in both cases it took a long time for companies to figure out how best to use these technologies and reorganize their production systems.

While David's "learning" hypothesis seems reasonable, and in fact remains widely cited to this day, it suffers from two key drawbacks. First, there is little evidence that these technologies are hard to learn. In fact, with "Windows'" functionality, off-the-shelf software, and the easy to use World Wide Web, information technologies are relatively easy for companies to adopt and use. Second, David assumes that electric motors came onto the scene fully formed and that it took 30 or 40 years for recalcitrant companies to finally adopt them. In fact, electric motor technology took over 25 years to increase power output, functionality, versatility and ease of use to get to the point where they were widely used and had a big impact (Atkinson 2004).

Like the electric motor then, it is not that it took a long time for organizations to learn how to use IT, but that in the 1980s and early 1990s the technologies were still rudimentary. Compared to today, PC technology of even the early 1990s seems antiquated, not to mention expensive. As late as 1994, virtually no personal computers were networked to the Internet, and for the few that were, they lacked an easy to use Web browser. The first popular Microsoft Windows platform (3.0) was not shipped until 1990 and even this was not nearly as easy to use as Windows95 or later versions. "Pentium" computer chips were not introduced until 1993 and were slow compared to today's chip speeds. The average disk drive storage was 2 gigabits compared to 80 gigabits today. Few machines came with CD-ROMS, speakers, or graphics cards. Most importantly, without a World Wide Web to connect to, many computing devices acted as nothing more than glorified typewriters. In short, until the mid-1990s most Americans were working on Ford Model Ts, not Ford Explorers. Compared to the original Apple 2 computer with no hard drive and 560 KB of memory, the machines of the early 1990s looked pretty impressive and economists expected them to have a big economic impact. Yet, compared to today's machines, they are simply not useable. As a result, even if companies have to reorganize to fully utilize the technology, unless the technology is ready, reorganization is not possible or feasible.

Figure 5: PERCEIVED IT IMPACT ON EUROPEAN BUSINESSES[22]



percent), and customer service (52 percent) **(See Figure 5)**.

Yes, IT boosts individual firm productivity, but what is its impact on financial performance? Because so many product and service markets are highly competitive, most of the benefits of IT usually flow through to consumers in the form of lower prices, higher quality products, and better service. This process is what Nicholas Carr was referring to when he claimed that IT doesn't matter. Carr acknowledged that IT mattered a great deal to the economy, but argued that since all firms have to use IT (not using it consigns them to a significant competitive disadvantage); it fails to give firms a distinctive advantage that they can use to achieve higher returns. However, there is evidence that IT matters not just to the entire economy, but to individual firms as well. For example, Brynjolfsson finds that for every dollar invested in computer capital, market valuation of the firm rises over $10 (Brynjolfsson, Hitt, and Yang 2002, 5-6). Individual firm managers report the same thing. For example, in 2005, 44 percent of EU firms surveyed reported that IT investments boosted revenue growth.[23] Thus, while the benefits from increases in firm productivity normally are passed on to consumers in the form of higher productivity and lower prices, these also boost market share, which helps increase profits.[24]

This is not to say that all IT implementations are a success, clearly they are not. The transition to a digital economy has been characterized not only by successes, but also by some high-profile IT failures. Proper management of IT systems is important, and success is not always assured. However, even taking into account failures and sub-optimal systems, the evidence suggests that IT has helped firms overall.

PRODUCTIVITY IN INDUSTRIES

When economists move their analysis up a level to the study of entire industrial sectors they get similar results. For example, Dumagan, Gill and Ingram (2003, 48) found that between 1989 and 2001, productivity growth averaged 3.03 percent per year in sectors that invested more in IT, compared to only 0.42 percent per year in sectors that invested less. The Conference Board found that industries that used IT more intensively contributed 1.4 percentage points to U.S. productivity growth between 1995 and 1998, significantly more than non-IT-intensive sectors. The President's Council of Economic Advisors (2001) found that from 1995 to 1999, productivity was four times greater (4.18 percent vs. 1.05 percent) in industries with high levels of IT investment than in those with less investment. Daveri (2003) found that over 70 percent of the total acceleration in productivity in the second half of the 1990s occurred in sectors that used IT at above average rates.

PRODUCTIVITY IN ECONOMIES

Finally, when economists have used growth accounting models to examine IT's impact on entire economies, both in the United States and a host of other nations, they also find that IT is the major driver of growth. Daveri (2003) found that 78 percent of the increase in productivity in the United States was due to IT. Other studies have found that IT is responsible for all of the growth in labor productivity, even as other factors (such as declining labor quality) have led to productivity declines. For example, Federal Reserve Bank economists Oliner and Sichel (2002) found that the use of computers and the production of computers were responsible for 0.92 percentage points of the 0.89 percentage point increase in labor productivity growth rates between 1996-2001 and 1991-1995.[25] The OECD (2004, 96) found that IT (production and use) was responsible for 109 percent of the growth in labor productivity from 1996 to 2002.

The impact of IT on total factor productivity (the productivity of all factors, not just labor) has been less, but is still quite significant. Jorgensen, Ho, and Stiroh (2005) found that IT contributed 0.47 percentage points to the growth in total factor productivity from 1995 to 2002, compared to

just 0.24 percentage points for all other factors **(See Figure 6)**. Moreover, the importance of IT to the growth rate of total factor productivity growth has grown consistently over the last 50 years.

Economists have found significant impacts of IT on productivity of firms in many other nations, including Australia (Simon and Wardrop 2002), France (Greenan, Mairesse, and Topiol-Bensaid 2001), Germany (Hempell), Korea (Seo and Lee 2006), Japan (Motohashi 2003), and Switzerland (Simon and Wardrop 2002). Maliranta and Rouvinen (2003) found similar effects of IT in business in Finland, including finding that IT has higher productivity impacts than other kinds of capital. Van Leeuwen and van der Wiel (2004) found that firms in the Netherlands that invested more in IT not only enjoyed faster productivity growth but also produced more innovations. Baldwin, Sabourin and Smith (2004) found that IT use in Canada is associated with higher labor productivity in industries that adopt it.

Finally, cross-national comparisons have found similar results. Schreyer (1999) found that IT made a positive contribution to productivity and economic growth in all G7 nations from 1990 to 1996. Gust and Marquez (2002) found that nations whose IT expenditures rose sharply in the 1990s (including the United States), experienced a pickup in productivity growth. In contrast, countries where spending on IT fell or only grew marginally saw no productivity acceleration. Daveri (2003) found that while productivity did not pick up as fast in Europe as it did in the United States, that IT accounted for virtually all of the increase in nations like France, Germany, Italy and UK.

Even though IT has driven productivity growth in Europe and Canada, their growth has been less than that of the United States. One of the main reasons for this is that firms in Europe and Canada, particularly service firms, invested less in IT than their counterparts in the U.S. (van Ark, Inklaar, and McGuckin 2003). For example, one study (CSLS 2005, 8) found that the major reason for Canada's lagging productivity growth is its lagging IT spending per worker, less than half of U.S. levels. Indeed, the U.S. leads other nations in IT investment. Among 19 OECD nations, the U.S. led all nations in investment in IT (hardware, software, and telecommunications) as a share of fixed capital investment, with rates 50 percent or more above other nations (other than Finland) (OECD 2005). Moreover, U.S. investment in IT grew faster than in other large OECD nations (Canada, France, Germany, Italy, Japan and the UK). And in terms of computers per white collar worker, the U.S. ranked second out of 28 nations, behind Australia.

The impact of IT on productivity has been largest in developed nations, in part because it makes more economic sense in higher wage nations to use IT to substitute for labor. Nevertheless, IT has still had an impact in some developing nations, and its impact is likely to grow as they get wealthier and as their economies become more IT-intensive, which appears to be happening. For example, IT expenditures rose twice as fast in developing nations from 1993 to 2001 compared to the OECD average (Qiang and Pitt 2004). Virtually all the nations with the fastest rate of growth in IT investment were developing nations **(See Figure 7)**. The IT industry itself has also provided a growing number of higher paid jobs. India, which has added millions of relatively high paying IT jobs, particularly in software and IT enabled services, is a case in point.

Several studies have found that the impacts from the use of IT, as opposed to impacts of the IT industry itself, to be less in developing nations. Yet, some nations, such as Malaysia and Thailand, have shown significant IT-induced productivity growth. Moreover, Heshmati and Yang (2006) argue that one reason studies have not found larger impacts is the lack of high quality data on IT use in developing nations. For example, in many nations software usage is much higher than sales figures would suggest because so much of it is pirated. When they controlled for these factors, Heshmati and

Figure 6: SOURCES OF TOTAL FACTOR PRODUCTIVITY GROWTH[26]

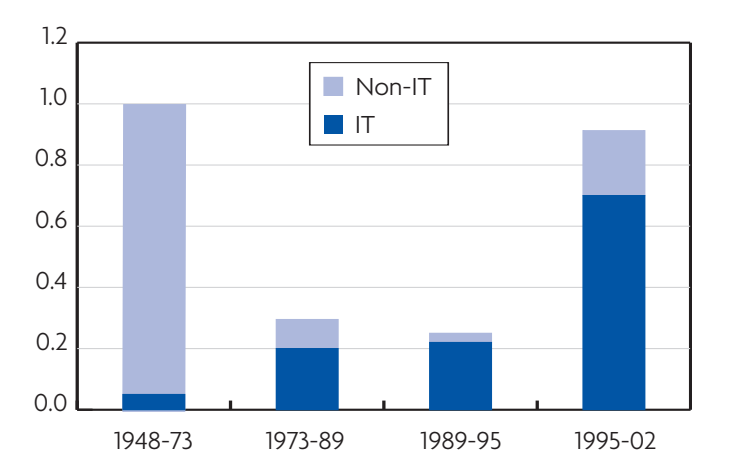
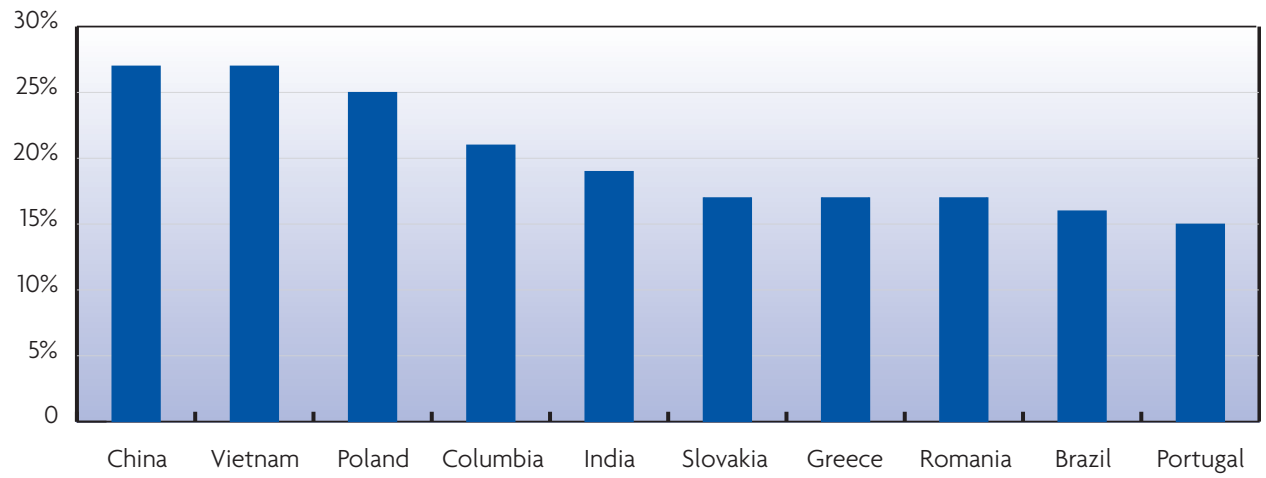


Figure 7: ANNUAL GROWTH RATE OF IT INVESTMENT, 1993-2001[27]



IT is bringing new opportunities for growth to the developing world.

Yang (2006) found that IT usage in China has actually played a critical role in growth, accounting for 38 percent of the increase in total factor productivity growth and 21 percent of GDP growth. Given the impact on growth from increases in the labor force and from reallocation of labor from agriculture to industry, the role of IT in boosting Chinese growth is quite significant. Another study (Lio and Liu 2006) found that while IT adoption has twice the impact on agricultural productivity in developed nations than developing ones, its impact in developing nations is still significant. Sridhar and Sridhar (n.d.) found that telecommunications infrastructure, particularly cellular telephone penetration, was a contributor to growth in developing nations. Likewise, a study of 42 developing nations (Jacobsen 2003, 13) found a significant positive correlation between cellular telephone adoption and economic growth. Indeed, one reason why IT can help developing nations is that unlike technologies from the old economy that required massive investment in fixed plant capacity and high levels of technical skills, IT capital equipment is relatively cheap and easy to use (Steinmueller 2001). For example, instruction manuals, user guides, and other assistance on IT products and services are usually available online for anyone to access.

Another reason why the benefits from IT have been less in some developing nations is that many, in an attempt to grow their own IT industries, not only imposed high tariffs on imported IT products, but did relatively little to promote IT adoption. However, not only did these policies usually not

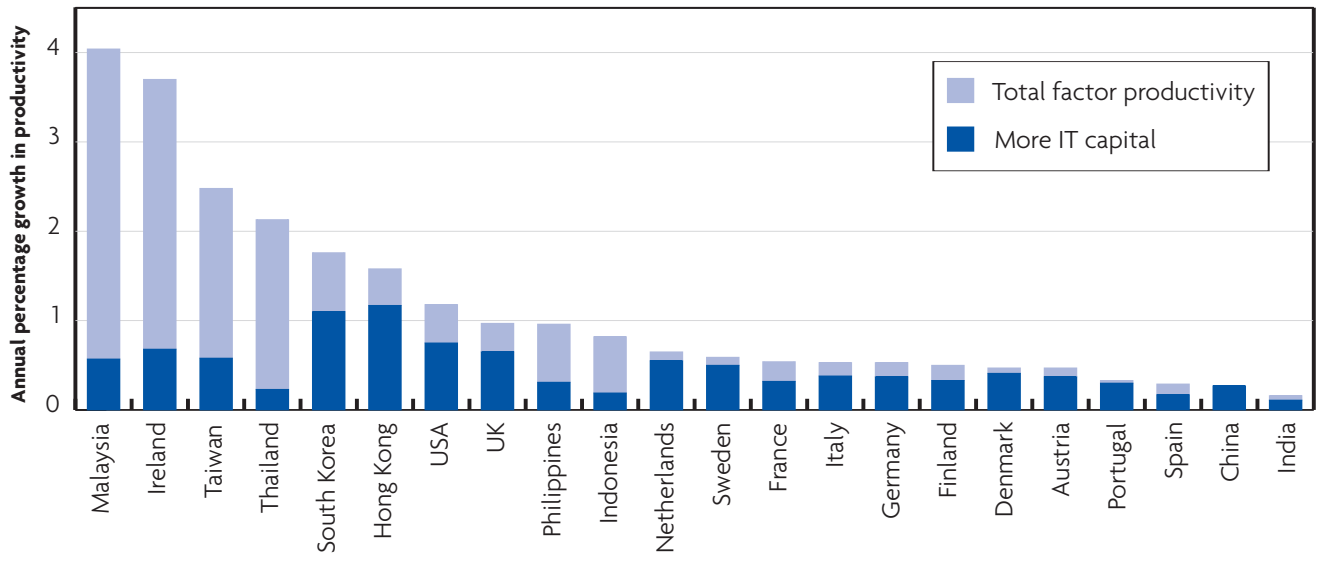
spur the creation of a domestic IT industry, they reduced IT adoption among existing industries. As Kaushik and Singh (2004, 594) state in reference to their study of IT adoption in India, "High tariffs did not create a competitive domestic [hardware] industry, and [they] limited adoption [of IT by users in India] by keeping prices high." This, combined with other factors, such as mistrust of e-commerce transactions and artificially high Internet access costs, may be one reason why, according to one study, Asian nations had lower than expected IT adoption levels given their level of economic development.[28] A recent World Bank (Qiang and Pitt 2004, 12) study urges nations to adopt more balanced policies regarding IT adoption and use, arguing that doing so could lead to stronger economic growth **(See Figure 8)**.

By the late 1990s there was a general consensus among economists around the world that more and better use of IT is the major driver of productivity growth. However, initially, economists disagreed over whether that growth was confined to the IT industry itself (*e.g.*, to the computer industry) or was coming from the many sectors that used it to become productive. Economist Robert Gordon (2000), an initial skeptic regarding the effect of IT on productivity, was a leading voice claiming that most of the productivity uptick came from higher productivity in the IT industry itself (2004). It is true that IT-producing sectors have experienced the greatest gains in productivity growth. But Gordon underestimated just how broad the productivity gains were among IT-using industries. Most studies find that the IT industry itself was responsible for no more than one-quarter of the productivity pick-up. Jorgenson, Ho, and Stiroh (2005, 10) found that the four IT-producing industries that account for 2.9 percent of the U.S. GDP were responsible for a quarter of the U.S. resurgence. Fernald and Ramnath (2004) estimated their contribution at about 20 percent of the pick-up in productivity growth, while the OECD estimated their share at just 16 percent.

Other research also shows that the productivity effects of IT were not concentrated just in the IT producing sector. Stiroh (Dec. 2002) found that the productivity boom was broad-based with two-thirds of industrial sectors experiencing an acceleration of productivity after the mid-1990s. Bosworth and Triplett (2003) also found widespread productivity acceleration in the service sector due to IT. In another study (2004, 5), they found that, "IT in services industries accounted for 80 percent of the total IT contribution to the U.S. labor productivity growth between 1995 and 2001." McKinsey Global Consulting (2005) found that productivity growth in the computer hardware sector accounted for around 15 percent of the increase in U.S. productivity growth rates during the period 2000 to 2003.

Even Gordon (2004) modified his view after his later research found acceleration in productivity outside IT producing sectors, noting that "After fifty years of catching up to the U.S. level of productivity, since 1995 Europe has been

Figure 8: CONTRIBUTIONS OF IT TO LABOR PRODUCTIVITY (1995-2000)[29]



falling behind…Studies of industrial sectors suggest that the main difference between Europe and the U.S. is in ICT-using industries like wholesale and retail."

Even though IT investment has increased, it is still less than 25 percent of the total capital investment. Why then has it had such a large impact on productivity? One reason is that IT seems to be "super capital" that has much larger impacts on productivity than other forms of capital equipment. For example, Gilchrist, Gurbaxani and Town (2001) found that accelerated investment in IT generated increases in productivity over three times greater than would be the case if it were other kinds of capital investment. Plice and Kraemer (2001) found that in developed nations IT capital showed 5 to 8 times higher return on investment than non-IT capital. A similar study in Australia (Poon and Davis, 2003) found that IT investments were four to five times more productive than other types of capital. There is some evidence that IT has similar effects in developing nations. For example, Malaysia's return on IT investments is three times higher than non-IT investments (Qiang and Pitt, 2). In essence, by increasing the share of capital stock that was IT-based, nations were getting more productive.

TWO KINDS OF PRODUCTIVITY EFFECTS FROM TECHNOLOGY

In order to understand why IT has such disproportionate impacts on productivity, it is important to distinguish between two kinds of productivity effects from technology: capital deepening and higher total factor productivity (TFP). Capital deepening refers to the fact that as workers get more capital they are generally more productive. Increases in TFP occur when the same amount of capital is used more effectively.

While most economists agree that IT-producing sectors have seen productivity gains from both capital deepening (more capital) and from total factor productivity increases (more efficient use of capital), they don't agree whether IT-using sectors are enjoying greater TFP growth than they would without IT (Dedrick, Gurbaxani, and Kraemer 2003, 16). Greater TFP growth in IT-using industries would signify that IT is having secondary effects beyond simple capital deepening and deserves recognition for a larger role in the U.S. resurgence. For example, Stiroh (Dec. 2002) finds that although IT generates productivity gains from the production and use of IT, there is little evidence of IT improving TFP in IT-using industries. Yet a number of other studies find impacts from IT on TFP. Brynjolfsson and Hitt (2003, 6) find that over the short run, computers contribute as much to the economy as they cost. However, over the longer term they contribute more than their costs, partially explaining a burst in productivity not attributable to IT after the initial investment. Likewise, Wilson (2004, 13) finds that of all types of capital, only computers, communications equipment and software are positively associated with multi-factor productivity.

There are at least three possible reasons why IT boosts multi-factor productivity and has stronger effects on productivity than other capital. First, because IT capital equipment innovations are new, they are able to pick off the "low hanging fruit" of relatively easy to improve efficiencies. This is particularly true in the service sector where before the IT revolution it was difficult to use existing capital equipment (largely electro-mechanical machines) to boost productivity. In an economy increasingly focused on sharing and processing information, including transactions, (in the United States service industries make up over three-quarters of GDP and employ more than 80 percent of the workforce) it is not surprising that a technology system that lets companies better utilize and process information should allow them to reap such huge rewards. In virtually every organization there are opportunities for digital automation and in many cases organizations can easily take advantage of them once they learn of the opportunities and solutions.

Second, IT doesn't just automate tasks, it also has widespread complementary effects, including allowing companies to fundamentally reengineer processes. As early as 1999 a quarter of companies reported that they had made organizational changes to respond to the changes wrought by IT (OECD 2000, 13). For example, laser scanners not only boost checkout clerk productivity, they also allow retailers to re-reengineer their entire supply chain. When IT is combined with organizational changes, such as business process reengineering, its impact on productivity is much greater (Dewan and Kramer 2000). Bartel, Ichniowski and Shaw (2005, 32) note that, "Once a business invests in new IT-based production machinery and installs the equipment on the factory floor, it will be changing the fundamental nature of what it does and how it does it." Bresnahan, Brynjolfsson and Hitt (2000) found that firms that embrace "new economy" management practices (*e.g.*, decentralized decision-making) and at the same time invest significantly in IT, outperform other firms. As they note, "Firms do not simply plug in computers or telecommunications equipment and achieve service quality or efficiency gains. Instead they go through a process of organizational redesign and make substantial changes to their service or output mix." (2000, 4). Likewise,

the OECD (2000, 13) found that IT "seems to offer the greatest benefit when ICT [IT] investment is combined with other organizational assets." This is perhaps one reason why a study found that U.S. multinational enterprise subsidiaries in the UK achieve larger productivity gains from use of computers than do UK firms. Over 80 percent of this advantage in productivity for U.S. owned subsidiaries is explained by better use of IT (Clayton 2005). Business executives agree, as 97 percent believed technology alone would not raise productivity in their firm to the highest level achievable unless it was accompanied by organizational changes (Violino 2004). These secondary effects end up letting firms make more significant productivity gains than they would achieve simply by using it to make an individual process more efficient.

IT is enabling the widespread use of self-service kiosks, in this case, to let guests check into hotels.

Third, IT has what economists call "network externalities," which are the "spillovers" from adding additional users to a network. Simply put, increasing the user size of a network makes all current users better off. For example, the first e-mail applications were not terribly practical because so few people had e-mail. But as more organizations provided their workers with e-mail and connected to the Internet, e-mail became valuable, even essential. When a firm provided e-mail to its employees it not only let them communicate more effectively, it allowed employees of other companies to more effectively and efficiently communicate with the firm's employees. Studies confirm these spillovers. Mun and Nadiri (2002) find that computerization of a firm's customers and suppliers reduces the firm's costs. This is because it is easier for a company to employ IT to make its interactions with customers and suppliers more efficient if the suppliers and customers also make complementary investments. So when firms or individuals invest in IT hardware and software, they not only make their own processes more efficient and valuable, they add value throughout the entire network. Likewise, a study of accounting firm audit functions found that firms with better IT systems had lower audit costs (Banker, Chang, and Kao 2002). These network externalities are one reason why large firms, like Wal-Mart and automakers, require their suppliers to invest in interoperable IT systems.

Economists have long understood that companies normally do not capture all the benefits of investments in research and development. This is the major rationale behind the R&D tax credit, which tries to equalize firm and societal returns. While investments in IT are in some ways similar to investments in traditional physical capital, in other ways they are similar to investments in research. As Dedrick, Gurbaxani, and Kraemer wrote, "Clearly IT capital has aspects of both forms of capital." (2003, 21). In its role as production capital—simply boosting efficiencies inside the firm—IT is similar to physical capital where spillovers and externalities are limited. But in its role as transformational capital—IT transforms organizations and leads to new innovations and efficiencies in other organizations—IT is similar to investments in research, with high spillovers that can be taken advantage of by other organizations. Competing firms quickly copy IT investments made at innovative firms. For example, other retail firms copied investments by Wal-Mart to transform its supply-chain through IT. Because of these spillovers and externalities, information technology innovators cannot capture exclusively all the benefits of their investments, and as a society there will be sub-optimal investment levels in IT.

So how exactly does IT boost productivity and economic growth? IT has a number of effects, both direct and indirect. Direct effects include making workers more productive and enabling more efficient use of capital and natural resources. IT also has a number of indirect effects, which in turn spur higher productivity, including enabling larger markets and better organizational decision-making.

MORE PRODUCTIVE WORKERS

The principal way IT boosts productivity is by making workers more productive, and thereby allowing the same number of workers to produce more products and provide more services. In some cases more or better IT tools help workers produce more. For example, give workers faster and more reli-

able hardware, software, and an Internet connection, and they will be able to accomplish more with better speed and fewer complications than if they use paper, pencils and typewriters. In other cases, IT substitutes for a worker, allowing that worker to perform other tasks and add additional value to the economy. Airline ticket kiosks, for example, allow consumers to check in at an airline without having to use the services of a ticket agent. How exactly does IT boost worker productivity? The mechanism surely differs by firm and occupation.

IT lets workers do more things at the same time (*e.g.*, reading e-mail while sitting in on a conference call). In a study of executive recruiters (i.e., head-hunters) Brynjolfsson and Van Alstyne (2005) found that IT let head-hunters "multi-task," thereby letting them get more done in the same period of time. Likewise, IT allows people to work where and when they previously could not, such as talking by cell phone while traveling on a train or checking e-mail in the airport. Indeed, a 2006 Pew Survey (Rainie and Keeter 2006) found that 41 percent of cell phone owners use free time during travel or while waiting to place calls. While multi-tasking can sometimes result in lower quality output if the person isn't doing either function well, in many cases it means more output and the same or higher quality.

IT lets workers focus more exclusively on valuable work and avoid the less productive distractions that are part of many jobs. For example, by relying on IT (*e.g.*, broadband, mobile e-mail and voice, etc.) the retailer Best Buy was able to give a large share of its corporate headquarters employees the option of more flexible working hours, including working at home. As a result, output increased by 35 percent. While some of this increase may have resulted from some individuals working more hours (due to a more flexible schedule), some was due to workers becoming more efficient. Indeed, the evidence suggests that telecommuting boosts productivity (Potter 2003). And with the deployment of widespread high-speed broadband, it will become increasingly easy for a growing share of the workforce to work from home, at least part of the time (Balaker 2005, 338). More and more employees are "going Bedouin," with 40 percent of all employees not in the office on any given day (Conlin 2006). Indeed, telecommuting growth is much faster than the growth of the workforce.[30]

IT allows routine tasks to be automated, thereby increasing economic output. Between WWII and the 1980s, automation (the replacement of a human with a machine to perform a function) was largely confined to the factory. Indeed, this is one reason why productivity was so much higher in manufacturing than in services. Companies could automate many manufacturing functions with electro-mechanical technologies, but there were few technologies to automate service functions. IT changes that. IT is being used in all sectors to automate work, including work that is difficult, monotonous, or hazardous. The Chilean mining firm Codelco created underground local area networks that link miners to the world above, wired trucks that indicate to operators when they require maintenance, and provided wireless equipment that allows miners to work kilometers away in safe office conditions (Carless 2004). As a result output doubled and worker safety and conditions improved. Likewise, Union Pacific railroad used IT-based systems to remotely control locomotives. Automated voice recognition software has the potential to reduce medical transcription costs in the United States by $1.9 billion per year (Girosi, Meli, and Scoville 2005, 22).

IT enables organizations to dramatically improve the efficiency of internal operations. Organizations are using IT to shift their internal transactions, such as travel reimbursements, changes of address, pension fund modifications and an array of other functions, to more efficient Intranet systems. For example, the software company Oracle recently implemented a system to process employee expense reports online, cutting the cost from $25 per report to $10 and saving over $6 million annually. Cisco saves $360 million per year through using the Internet for e-business.[31] St Luke's Episcopal Hospital in Houston uses wireless networks and has equipped doctors and nurses with laptops on which to enter treatment information. It cut data-entry time by 30 percent and allowed the respiratory therapy group to cut staff by 20 percent, saving $1.5 million per year. Aramark, the snack supply company, has given its drivers wireless handhelds to download information about what vending machine products have been purchased. Driver productivity went up more than 40 percent during a two-year pilot program. By switching to electronic medical records, U.S. hospitals and doctors' offices could cut expenditures on medical records personnel by two thirds, saving $1.7 billion per year (Girosi, Meli, and Scoville 2005, 23).

IT helps government streamline routine and often costly transactions. The benefits of IT are not consigned to business. Government can use IT to cut costs. The Bush administration's IRS Free File system—a single point of access for

Wireless handhelds are giving frontline workers powerful tools to do their jobs more effectively and efficiently.

free online prep and tax filing services by industry partners—has saved the Internal Revenue Service more than $32 million in processing costs for the 15 million tax returns that have been filed electronically through Free File since the program's inception in 2003. Estimates show that for each tax return filed electronically instead of on paper, the IRS saved $2.15 per return, while the error rate declined from 20 percent for paper returns to under 1 percent for electronic returns (OMB 2006, 23). Likewise, the General Services Administration's "GSA Advantage!" program, an online purchasing and acquisition system, provides savings of $90 to $240 in administrative costs per transaction compared to manual purchase orders (OMB 2005). E-government can also provide significant savings to state and local governments and users of their services. For example, renewing a driver's license online costs governments around $1, compared to about $8 for in-person renewal. U.S. states are also experimenting with new ways to direct citizens to lower cost (and more convenient) online channels. For example, some states have begun to outsource mailing functions such as car registration renewals to private firms. As a result of such public-private partnerships, several states have seen significant increases in Internet registrations and decreases in field office visits.[32] Developed nations are not the only ones that can use IT to transform government. In fact, e-government can have important beneficial impacts on developing nations as well (Heeks 2001).

IT lets firms restructure their supply chains. It used to be that only well stocked inventories could assure that production would not be held up by lack of inputs, but this is a costly form of insurance. Today IT enables just-in-time (JIT) production in which businesses gather better information from suppliers in order to track moment-by-moment changes in the supply chain. The ability to track shipments online allows firms to time production and anticipate bottlenecks in supplies, while up-to-the-minute information about inventories tells suppliers when fresh deliveries are needed. An example of an integrated and informed supply chain is Cisco Systems. Using remote monitoring of production lines, Cisco can detect a problem and adjust production at an assembly line or distribution center immediately in factories across the globe, often not even owned by Cisco, all from its headquarters in San Jose, California (*The Economist* 2006).[33] IBM, with over $91 billion dollars in annual revenue, was able to save $6 billion dollars in 2005 by reengineering its supply chain processes, which included the automation of some processes through Web-based applications in addition to other process changes and consolidation of functions. For example, IBM established an e-procurement system which substantially improved efficiencies, reducing the average contract cycle time from 6-12 months to less than 30 days. IBM also established an Internet based tool for booking employee travel in 2004 that posted average monthly savings of $2.5 million. IT is even allowing firms to move to just-in-sequence systems where parts arrive not only on time but in sequence, so that the parts for a particular car (*e.g.* red interior, with special tires and a DVD player) arrive at the right time and in proper order.

An emerging technology that could continue to boost productivity in the supply chain is radio frequency identification devices (RFID). The Defense Department has added RFID tags to its shipment containers that store information about the container's location, route and contents. When a container passes through a port its tag wirelessly senses it, updates its whereabouts, and alerts the next nodes in the Defense Department's supply chain. If such a system had been in place during the first Gulf War, DOD would have saved $2 billion by better tracking inventory (Arthur 2003). RFID is being introduced across a wide array of sectors. For

example, Ballantine Produce, a California-based fruit grower, uses RFID technology to more closely track its shipments to retailers. In the future, the company hopes to monitor the temperature of its fruit at all points along the supply chain and tailor its instructions for retailers accordingly, having them sell the ripest boxes of fruit first. Wal-Mart, which uses Ballantine as a fruit supplier, has achieved a 16 percent drop in out-of-stock merchandise in RFID-equipped stores (Overfelt 2006).

IT lets bits to be substituted for atoms. Processing paper, plastic and other physical forms of information media is quite expensive compared to processing digital bits. Processing a check costs banks approximately $1.40 compared to just 8 cents for processing an electronic bill payment. Shipping plastic movie reels to movie theaters across the world is significantly more expensive than transmitting digital movie files to theaters through broadband connections. Selling music in stores on CDs is much more expensive than selling it online.[34] Taking pictures with film and processing each print is more expensive than using digital cameras. Putting classified ads in newspapers is more costly than placing them on Web sites like Craigslist.org.

IT enables more productive self-service. Self-service gas pumps save consumers millions of dollars a year. Bank ATM machines allow customers to conduct banking transactions on their own time. IT-enabled kiosks are spreading rapidly. Hyatt Hotels is installing self-service kiosks in its hotels, allowing guests to check-in and obtain room keys in under a minute (Levinson 2005). Likewise, many retail stores, including grocery and home supply stores, use kiosks to speed checkout and lower costs. For example, more than 800 Home Depot stores are equipped with self-checkout kiosks and 32 percent of their customers use them (Nardelli, Sellers, and Schlosser 2004)**(See Box 3)**.

One of the major applications for self-service is the Internet. Instead of consumers contacting customer service representatives, they can go online and do the work themselves in the same time or less. For example, customers can check online the progress of packages shipped by most major shipping companies. Companies like ABF Freight System have designed their IT systems so that customers can integrate with the ABF back-end, essentially using ABF infrastructure to make shipments as if they were their own (Dragoon 2005). By using Web technologies to standardize piecemeal print jobs, Vistaprint is able to cut the cost of custom print jobs by 80 percent or more. Clients use the Web to design print jobs, and IT-enabled printers print and cut custom orders. Likewise, much of e-government allows citizens to interact with government through the Web, saving taxpayers money and often improving service. For example, Kansas Online Crash Logs streamlined the Kansas Highway Patrol's process of recording and distributing crash information by reducing the amount of paperwork dispatchers complete, as well as dramatically reducing phone calls from the public and media. Now the media and public can check crash logs often and view the most cur-

Figure 9: E-COMMERCE RETAIL SALES AS A PERCENT OF TOTAL SALES[35]

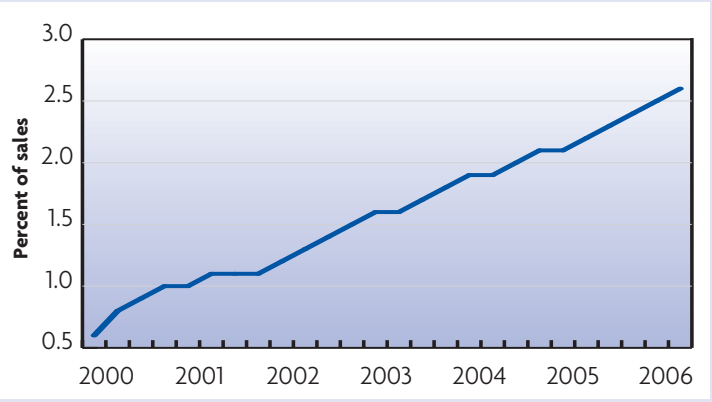
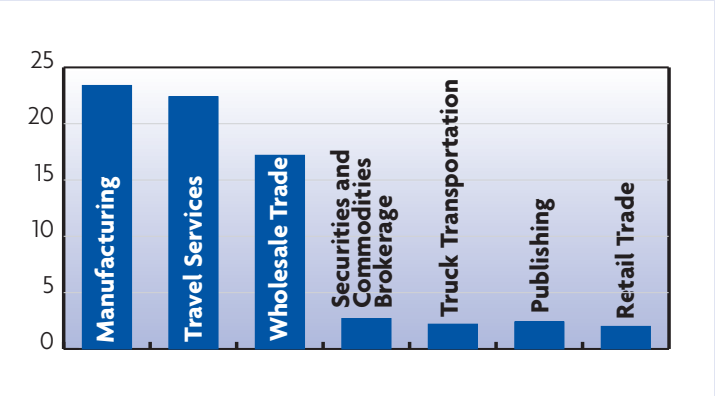
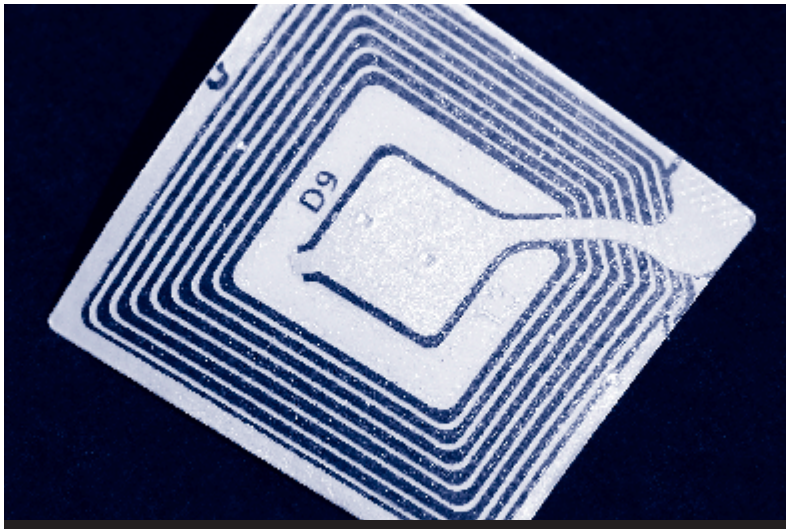


Figure 10: SHARE OF PURCHASES BY SECTOR CONDUCTED ELECTRONICALLY[36]





Tiny RFID tags promise great benefits including higher productivity.

rent, accurate crash information without impacting the daily operations of the dispatchers. In Ohio, the state put in place an e-tax reporting system that lets business taxpayers enter information common to all municipalities once, and then automatically distributes the information to all appropriate entities. Previously, businesses had to understand and comply with a patchwork of requirements and processes across the range of municipalities in which they conduct business.

IT also empowers consumers to do for themselves what they used to have to pay professionals to do for

Box 3: PRODUCTIVITY AND SELF-SERVICE

MUCH OF THE EXCITEMENT and interest in the new digital economy has focused on companies like Google, Yahoo, and the Internet generally. What has been missed by most observers is the power and potential of an IT-driven self-service economy. New digital tools are enabling consumers to become, in the words of futurist Alvin Toffler, prosumers—acting at the same time as both consumer and producer. Thirty years ago, futurist Alvin Toffler (1980) predicted the rise of 'prosumers' (consumers who also produce). But it took the rise of the digital economy for his prediction to come true. Today, prosumers are an important part of the economy.

Whether it's using a self-serve checkout line at a grocery store, filling out and submitting a form online, entering a transit system using a smart card, using an airport kiosk to print a boarding pass, paying a toll with E-ZPass, or paying bills online (Fox and Beier 2006), self-service is a growing share of the U.S. economy, helping to facilitate increased productivity and consumer convenience. As a result, in the future productivity growth may depend as much on what goes on the living room floor as on the shop floor. Just as companies invest in capital equipment, so too do prosumers invest in their own capital equipment: computers, broadband, wireless networks, displays, smart cards, etc. Indeed, with the service sector now accounting for over 80 percent of employment, self-service will have to play a much larger role if we are to continue boosting incomes and economic growth.

Self-service isn't new. After all, people push buttons on elevators to signal their floor, self-dial telephones, use vending machines, and drive cars. But the potential of self-service was vastly limited in the pre-digital economy. In today's digital economy, consumers equipped with digital tools from cell phones to smart cards to digital movie cameras to broadband-enabled computers are playing a growing role in the economy.

Unfortunately, self-service sometimes gets a bad rap. The media routinely portrays the efforts of companies to implement self-service options as creating work for the consumer solely for the benefit of the company. In reality, most self-serve applications don't cost the consumer more time, they just involve one person (the consumer) doing the work, not two (the consumer and the employee). Granted while some self-service applications (e.g., "press 2 if you are interested in opening an account") can be maddening and cost consumers more time, overall self-service technologies usually cut overall labor time (for both the worker and consumer). And in some cases, they can save consumers time and add convenience. Even where personal service provides consumers with more value (a chauffeur-driven car is seen as a luxury), it usually costs more (which is why usually why only wealthy people have chauffeurs). Other kinds of personal service are the same. They cost more money to provide than does self-service. However, in the type of competitive markets more companies are facing, savings from self-service are passed back to consumers through lower prices, at least over the moderate to long term. As a result, standards of living go up.

them. In particular, software and the Web are enabling consumers to do a host of costly professional and semi-professional functions. For example, Intuit's Turbotax software revolutionized the tax preparation business by offering a CD-ROM with as much tax expertise as a tax accountant, but at a considerably lower price. Online legal services for drawing up a will, lease, or other simple contract can be 75 to 80 percent cheaper than using a lawyer (Atkinson, Jun. 2006). Online sites like Travelocity or Orbitz let consumers bypass travel agents, allowing airlines to charge lower prices. The cost of processing a traditional airline ticket is $8; compared to just over $1 for an e-ticket purchased on the Web.

No discussion of the effect of IT on productivity would be complete without a focus on e-retailing. E-commerce retail sales continue to grow approximately six times faster than total retail sales and provide significant savings **(See Figure 9)**. For example, buying contact lenses over the Internet enables consumers to save between 10 and 40 percent of the cost of buying from an optometrist (Atkinson, Jul. 2006). Online retail will continue to grow in part because the longer people are online the more likely they are to make online purchases.[37] E-retail is still a modest share of the economy, but in some sectors it is emerging as a sizeable share of transactions **(See Figure 10)**. For example, over 20 percent of travel reservations (*e.g.* airline tickets) are ordered online. Other sectors show less take-up, but are growing.

MORE EFFICIENT USE OF CAPITAL AND NATURAL RESOURCES

IT doesn't just enable workers to be more productive, it also lets organizations use capital equipment and natural resources more efficiently.

In any organization capital is a scare resource, and its more efficient use frees up that capital for more effective uses elsewhere in the organization or in the economy as a whole. But capital equipment only contributes to output if it is used, and in many organizations equipment is underutilized. By helping to match demand and supply, IT can play a key role in enabling organizations to increase utilization rates of capital equipment.

Because of difficulty in predicting demand, transportation equipment is often underutilized. For example, trucks might be fully loaded for delivery, but might make the return trip partially or completely empty. Indeed, about one-fifth of trucks at any one time are "transporting air" (Murphy and Hoffman 2001, 7). With global positioning systems (GPS), cell phones, and wirelessly connected computers, truck drivers and dispatchers can now more easily find loads to pick up for return deliveries (Nagarajan, Canessa, Mitchell, and White 2000). For example, by using IT to coordinate schedules, two companies, Fort James Paper and General Mills, were able to give their scheduled runs to a single carrier that dedicated trucks to the business, leading to savings of $731,000 a year (Murphy and Hoffman 2001, 7). The Web enables this kind of demand aggregation. Sites like *Getloaded.com* act as a matching service, preventing excess capacity from going to waste by connecting trailers that would otherwise be traveling empty with loads that need to go to the same destination.[38] One study found on-board-computers that allow managers to better coordinate trucks and loads boosted capacity utilization 3.3 percent and saved $16 billion annually in the $500 billion trucking industry (Hubbard 2003, 2).

IT is being used to boost rail, shipping, and aviation productivity. For example, Union Pacific uses GPS to track locomotives from a central dispatch center. The dispatch center informs trains of the fastest possible path between two stations, and can monitor the performance and maintenance conditions of its locomotives, further improving efficiency. Likewise, Europe is now testing an inexpensive and satellite-based command and control system to better allocate traffic along low-density rail lines (Morris 2005). Valero Energy uses real-time data on the movement of tanker ships to cut down time spent in ports, where they are charged for overtime. By reducing dock time by 30 minutes per vessel, Valero saves $7.5 million annually in fees (Chabrow 2006). Airlines use IT to better schedule flights and to raise seat utilization, allowing them to fly fewer flights, saving fuel and money. This is particularly important in ensuring that scheduled departures are as full as possible. Airlines receive no revenue from empty seats and the increased weight of each additional passenger means little in terms of fuel use. Now airlines can advertise and sell e-fares online one or two weeks before a flight departs, filling up otherwise underbooked flights with customers willing to fly with flexible schedules and pay lower prices.

Global positioning systems (GPS) boost the productivity of the transportation sector and give travelers needed information.

Box 4: IT ENABLES ENERGY EFFICIENCY

BECAUSE INFORMATION TECHNOLOGY boosts productivity and economic output, it indirectly leads to more natural resource and energy use. However, there is considerable evidence that in its direct impacts it allows resources, including energy, be used more efficiently. Although the United States is using more energy than twenty years ago, we would be using even more without the efficiencies that IT enables. For example, from 1996 through 1999, the United States experienced an unprecedented 3.2 percent annual reduction in energy intensity (energy used per unit of GDP), four times the rate of the previous 10 years (Romm 2001). While several factors may account for this, including the shift in the U.S. economy toward less energy-intensive sectors, the incorporation of IT into business practices appears to be a key source of this improvement (Romm 2001).

One reason for this is that IT is making organizations more energy efficient (Romm 2001, 131). For example, despite increased transportation costs, new business practices like Amazon.com's central warehousing are less damaging to the environment than traditional bricks-and-mortar retail operations (Hendrickson and Matthews 2003). Using the DOD as a case study, Hendrickson and Matthews (2003) found that centralizing warehouses reduces the environmental impact greatly, and in the case of spare parts, centralizing all 286 warehouses into 19 major warehouses would render a net benefit economically and environmentally even if twice as much trucking and shipping was used. One reason this may be true in the retail environment is that most shoppers get in their car and drive to the store, using considerable amounts of energy. Likewise, IT can substitute for energy-intensive transportation in a number of areas, including telecommuting. For example, an analysis of substitution and environmental effects in Sweden for telework, teleconferencing, and telemedicine (Arnfalk 2002) found that if these three substitutes were used to their utmost potential, transportation in Sweden could be reduced by a third. New advanced teleconferencing technologies that enable "telepresence" (enabling eye contact between participants, life size images, and no jerky video images) will likely spur even more substitution of travel. IT is at the heart of more efficient gas-electric hybrid cars. Compared to reading a newspaper, receiving the news on a PDA wirelessly results in the release of 32 to 140 times less CO2, and several orders of magnitude less Nox and Sox (Horvath and Toffel 2004). The energy involved in selling $100 of books for a traditional superstore vs. an online bookseller is 14 times more (Romm 2001). Romm (2001) documents how a 20 mile round trip to the mall to purchase two 5 pound products consumes about 1 gallon of gasoline. Shipping the packages 1000 miles by truck consumes 0.1 gallon of gasoline.

Some earlier reports (Huber and Mills, 1999, 70-72) suggested computers and the Internet were responsible for a significant share of electricity use, as much as eight percent. However, scientists at Lawrence Berkeley National Laboratory (Romm 2001, 146) examined the study in detail and found that it overstated by a factor of eight, and that computers and all office equipment consume at most three percent of electricity. Moreover, the next generation of computers and servers promise to be significantly more energy efficient. For example, Dell Computer recently announced that its new line of desktop computers would use significantly less energy.

It's true that because IT boosts growth that there will be more environmental impacts. But IT enables that growth to be less energy intensive than it otherwise would be. LBNL also found that the IT economy could reduce the growth in carbon emissions by 67 percent over what they would otherwise be between 2000 and 2010 (Laitner 2003). Moreover, by raising incomes, society can more easily afford investments to cut energy use (*e.g.*, such as buying more expensive hybrid cars).

IT also allows more efficient use of physical space. One area that is ripe for savings is health care. Software-based scheduling algorithms allow hospitals to more efficiently utilize expensive and scarce operating room space. Telecare and related assistive technologies can enable older and disabled people to remain in their own homes—rather than in hospitals or residential care—saving money and reducing demand for residential care space (Curry, Trejo, and Wardle 2002). One study (Litan 2005) estimates that faster roll out of residential broadband technologies would save $15 billion a year by 2020 in reduced usage of long-term care facilities by senior citizens. For example, broadband could enable individuals to more easily check on their aged relatives. Another study found that better use of health IT systems could save as much as $37 billion per year in reduced patient stay lengths in U.S. hospitals, with total savings of all kinds at $81 billion per year (Girosi, Meli, and Scoville 2005, 36).

The digital economy is as important to the farm as it is to the office.

Within manufacturing companies, computer-controlled machines let companies reallocate production, getting more production out of less physical space. Within the distribution sector, RFID technologies allow firms to cut 7.5 percent in warehouse costs (SAIS 2005). Within the office sector, "hotelling"—assigning flexible office space to workers only when they need it—has allowed industries like consulting, accounting and IT services to reduce the amount of office space they use. Likewise, telework can cut expenditures on office space (AT&T 2004). For example, Sun Microsystems was able to cut its office space use by 30 percent after implementing its "iWork" program.

IT also lets individuals better utilize their own physical capital. For example, the company Zipcar allows consumers to use the Internet to easily rent locally-located cars at a moment's notice. By giving urban dwellers cheap access to cars, people are more likely to give up owning a car that they may seldom use. Such a sharing concept would be impossible without the Internet to locate and coordinate these substitutes for personally owned cars (and without IT-enabled car locks that let only the user drive the car). Likewise, house matching sites like *CouchSurfing.com* facilitate matching between travelers and residents willing to spare a bedroom or a couch, or just have a chat with travelers passing through.[39] Other online sites let travelers exchange places to stay. A person visiting Paris can stay in the house of a person there who is on vacation, as long as they let someone stay in their home. Such systems expand the output of the lodging "industry" without requiring any new hotel rooms.

IT not only allows capital to be used more efficiently, it boosts natural resource productivity (Urstadt 2006). Energy companies are employing new technologies to better pinpoint underground oil reserves. Computer modeling lets geologists see much more accurately what is underground, which means more accurate decisions on where to drill. Similarly, without IT, it is highly doubtful deep sea drilling would be possible, let alone successful in one out of four drilling attempts, a big improvement from the recent past when nine out of ten drilling attempts on land were unsuccessful (Urstadt 2006).

Other companies are using IT to boost the efficiency of natural resource production. Glacial Lakes Energy has increased ethanol production at its South Dakota plant with more effective computer monitoring of variables throughout the complex ethanol production process. Since implementing predictive control software, the company has increased production by as much as 10 percent while cutting its natural gas usage by up to 3 percent (Patton 2006) **(See Box 4)**. IT also lets farmers harvest more crops from the same amount of land. Precision agriculture using sensors and GPS enables farmers to cut crop input costs (*e.g.*, amount of seeds and fertilizer) while boosting yields (Meister Media Worldwide 2006).

VI) IT Boosts Growth Indirectly

IT has had such a major impact on growth because as a general purpose technology, it not only has direct effects on productivity it also has a number of indirect effects which in turn make organizations more efficient. IT not only enables the creation of larger markets, it allows companies to achieve greater economies of scale and exerts greater competitive pressure on firms to boost performance. In addition, IT also gives managers better tools by which to make decisions, thereby improving firm performance.

LARGER MARKETS

The IT revolution has been instrumental in enabling the emergence of more globalized markets in both manufacturing and services. Indeed, it is hard to imagine how today's globally dispersed production systems would work without IT to knit them together, whether it is computer-based logistics systems that allow companies to weave together multinational supply-chains; e-mail and cheap telecommunications systems that let managers easily communicate across the globe;[40] or software, Internet and digital telecommunications capabilities that enable an increasing share of offshore information-based services.[41]

By improving supply chains and information on potential economic opportunities and reducing communication costs, IT is allowing businesses to rearrange inputs, labor, and capital as never before. These new globalized production chains allow businesses to specialize in what they are good at, contract out what they are not, and reach scales that minimize costs (Innocenti and Labory 2004). IT is expanding and merging markets to the point that we now have a truly global market for most intermediate and many final goods. Moreover, with the much larger markets globalization enables, it is now easier for niche businesses and new innovations to find their market, which may not necessarily be in the local area. Without IT, the scale and scope of globalization would be greatly reduced and the economic benefits that stem from more competitive and larger mar-

IT has transformed and streamlined the logistics system.

IT enables better decision-making by allowing decision makers to mine data to find patterns and predict outcomes.

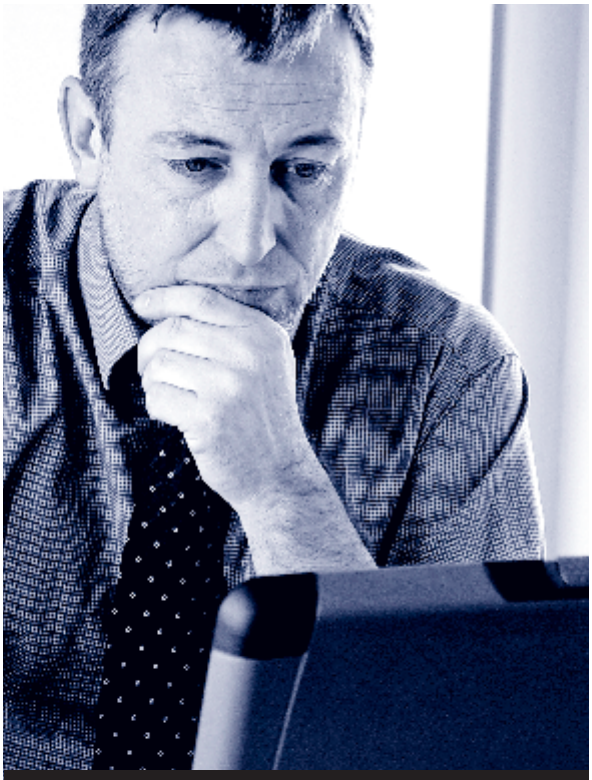
kets would be significantly less.

This is not to say that there are no costs from globalization or that global integration could not work better. Particular workers, firms, industries and regions can be hurt by globalization, even though it generally benefits everyone. Moreover, the global trading system could work much better if nations, particularly those running oversized trade surpluses stopped engaging in mercantilist policies (like currency manipulation, closed markets and standards manipulation) that distort global markets. But the answers are not to reduce the scope of globalization, but rather to do more to help those hurt by globalization and to reduce mercantilist trade distortions.[42]

BETTER DECISION-MAKING

IT is also a productivity multiplier because it enables organizations not only to make processes more efficient, but also to make better and faster decisions. Shorter product cycles, rapidly changing economic environments and a multitude of new competitors means that decision makers must make decisions faster and with more accuracy than in the past in order to stay in the game.

IT is giving organizations a greater capability to make better decisions and to move toward becoming a "real-time enterprise" able to react nearly instantaneously to changes in business. For example, IT has enabled the creation of what are sometimes referred to as "digital dashboards," or software for executives that bring minute-by-minute updates of market conditions and firm vital signs right to the executive's computer (*The Economist*, Jan. 2002). A small but growing share of corporations are setting up "digital nervous systems" that connect virtually everything involved in the company's business and let managers track changes in real time. For example, most of General Electric's senior managers have computer access to a constantly updated view of their enterprise. The dashboard compares how certain measurements, such as response times, sales, or margins, perform against goals, and alerts managers if the deviation becomes large enough for them to have to take action. Likewise, Eastman Chemical Company launched its Lighthammer Collaborative Manufacturing Suite to facilitate the development of a variety of applications used to aggregate and analyze data across the company. Improved use of data is expected to help Eastman save more than $10 million annually through better decision-making and improved productivity (Greenemeier 2005). Wells Fargo put in place a net settlement system that allows it to clear and settle checks and accounts throughout the day instead of at the end, enabling it to engage in what it calls "near real time" decision-making (Hildebrand 2005). In addition to allowing the company to comply with capital adequacy and pursue better risk management, the net settlement system paves the way for eventual paperless banking (Hildebrand 2005). Continental Airlines uses a data warehouse program based on seconds-old flight operations and reservations data that allows its employees to make decisions on purchasing for aircraft parts, fraud detection, and crew payroll-management, allowing it to save millions and expand revenues (Whiting 2003).



IT is giving decision-makers powerful new tools.

But these aren't just tools for large companies. Such systems have gotten cheap enough for small companies to use. For example, by using such dashboards restaurant managers can now track not only inventories and order times for multiple establishments, but real-time monitoring of work-

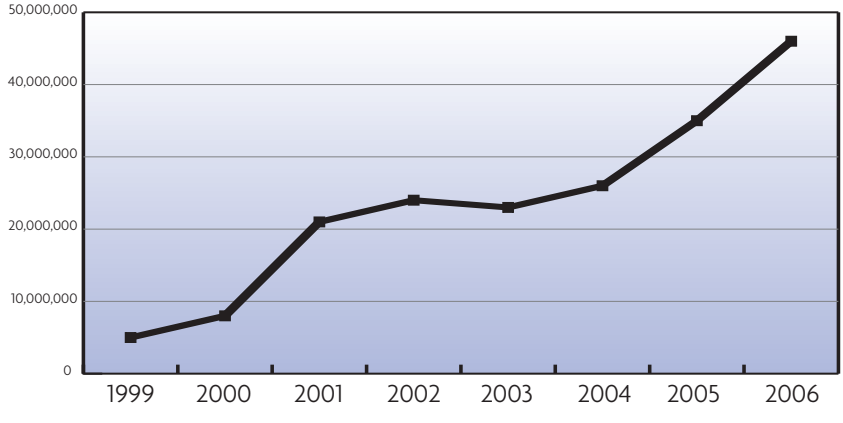
Box 5: WHAT INFORMATION TECHNOLOGY BUST?

TO LISTEN TO THE NAYSAYERS, one would think that the IT revolution was stillborn, with the dot-com implosion and the crash of the NASDAQ representing the justified culmination of the New Economy fad. Of course reality was bound to disappoint given the sky-high expectations. Kevin Kelly, editor of *Wired Magazine*, opined that "The network economy will unleash opportunities on a scale never seen before on Earth." (1999) One enthusiast marveled, "The Internet should be as important as the invention of cities ... The arrival of the network economy, the gurus say, should be like the transition from an agricultural economy to an industrial one." (Maney 1998) Even business leaders succumbed to the hype. General Electric CEO Jack Welch proclaimed that, "commerce in the next decade will change more than it's changed in the last hundred years."[43] Any company not embracing the Internet was, according to popular wisdom, doomed to extinction.

When epochal transformation is the bar, reality is bound to fall short. Yet while today's digital economy may not have lived up to the most extreme hype, it's actually closer to the hype than the gloom. To the surprise of many, the IT revolution has exceeded even the heady expectations of the late 1990s. In 1997 IT forecasting firm Forrester Research estimated that by 2001 business-to-business (B2B) e-commerce would total $186 billion. In fact, it was $715 billion. In 1999 *Business 2.0* projected that B2B e-commerce would grow from $131 billion to $842 billion in 2003, while business to consumer (B2C) was estimated to reach $97 billion (Atkinson 2004, 8-9). In fact, B2B e-commerce was worth $1.8 trillion and B2C $143 billion. By early 2004, two-thirds of Internet users had purchased a product online (Pew 2004). In 2005 there were over 20,000 computer networks and close to a billion users around the world (OECD 2006). Even the take-up of broadband telecommunications has been a more optimistic story than the pessimists would have us believe. In 1998 it was projected that 9 million American homes would subscribe to broadband in 2003, in fact 20 to 25 million households had subscribed.

Such an interruption in economic revolutions is actually the norm. As technology-historian Carlota Perez (2002, 36) documented, technology revolutions start with what she calls the "installation phase" when "new technologies erupt in a maturing economy and advance like a bulldozer disrupting the established fabric and articulating new industrial networks... At the beginning of that period, the revolution is a small fact and a big promise; at the end, the new paradigm is a significant force... ready to serve as a propeller of widespread growth." She goes on to argue that the second half of these technological revolutions, the "deployment period", is when the fabric of the economy is rewoven and reshaped by the new technology and system and when the technology becomes normal best practice. However, the turning point between the two phases is usually a critical crossroads, often resulting in an economic downturn. This is exactly what we have seen in the last 15 to 20 years. As the installation period ended in 2000, it did indeed represent a crossroads, when it became clear that some business models would thrive and others die. However, now, during the deployment period, IT is well on its way to reshaping the economy and driving growth. In short, while the IT revolution may not have lived up to the most extreme hype of the late 1990s, at least in terms of its penetration into the economy and society, it has more than fulfilled its promise. And the next decade promises as much progress, if not more, as the last.

Box 5, Figure 1: GROWTH IN .COM DOMAIN NAMES[44]



ers and the ability to adjust menus, all remotely (Friedman 2006). Such technologies are even being used by small enterprises in developing nations. For example, AgriIDS is an IT-powered plan to disseminate agricultural information throughout India in order to increase yield and make every farmer an expert (Reddy 2004).

Such systems are developing into expert system programs that combine large amounts of knowledge and allow users to make inquires. For example, the United States National Library of Medicine's PubMed free search engine and MEDLINE database is an online medical knowledge system that provides doctors with answers to clinical questions, relying on the best and latest information.[45] Retail intelligence systems give stores much better information about purchases, allowing them to make better decisions about the types of products to sell and in which stores, and when to mark down products.

IT also enables better decision-making by allowing decision makers to mine data to find patterns and predict outcomes. By combing through data to find patterns between inputs and outputs, organizations can make better decisions. Perhaps the most interesting example of this comes from major league baseball. As author Michael Lewis (2003) notes in his book about the Oakland Athletics, by using sophisticated data mining technologies, Oakland A's management was able to outperform other teams in the draft as well as in the selection of strategies employed during games. Lewis documents that where hundreds if not thousands of data points are involved (*e.g.*, should a player bunt with one out and a man on first), decisions based on data mining (examining the outcomes when players bunted vs. swung away) usually outperformed those based on conventional wisdom of managers.[46]

IT is also improving the speed of decision-making, and is reducing the number of decisions needed by automating those that require rapid action based upon easily accessible digital data and structured decision-making criteria. For example, in some regions during the summer of 2003, automated decision-making systems quickly dealt with power surges by redirecting the excess voltage to neighboring networks with spare capacity. Automated decision-making systems also play a key role in some emergency response plans by quickly deploying and organizing emergency staff and resources. By making these split-second decisions, automated systems can save resources and even lives, while freeing up humans to make the more nuanced judgments.

VII) IT Ensures that the Economy Runs at Full Capacity

While productivity is the most important factor in determining our standard of living, output and work hours are also important. To the extent that individuals who would like to work cannot, the GDP is less. IT affects jobs and output in three key ways. First, the IT industry itself creates jobs, as people are employed developing, producing, implementing and managing IT systems **(See Box 6)**. Second, IT appears to have dampened the severity of the business cycle, allowing the economy to run at full capacity more of the time. Third, IT appears to make it easier for more people to join the workforce, including disabled people and people who cannot work full-time, but who can work part-time **(See Box 7)**.

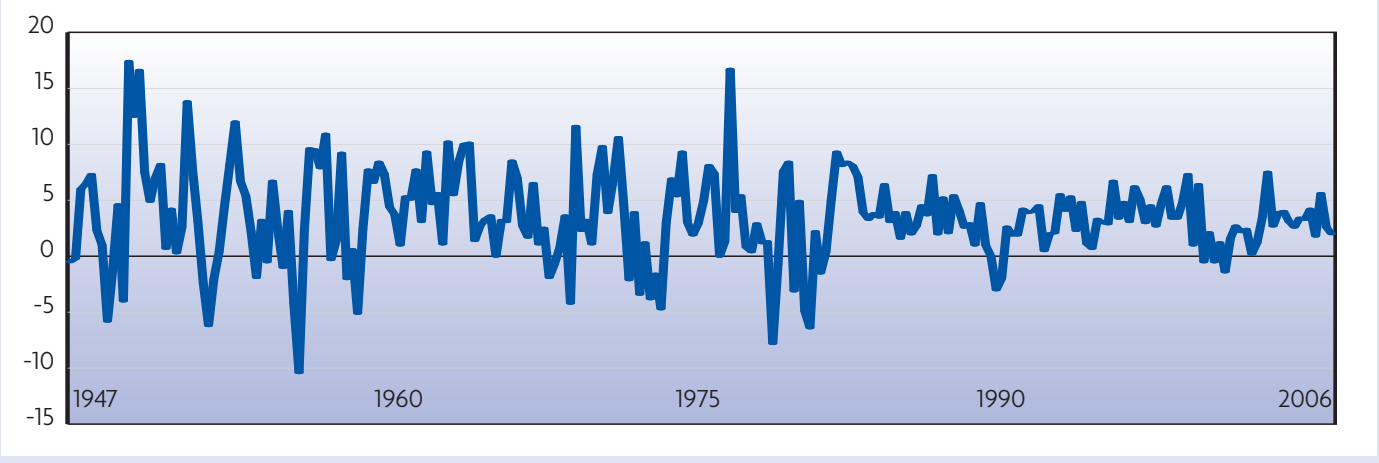
IT REDUCES ECONOMIC DOWNTURNS AND DAMPENS BUSINESS CYCLES

Perhaps the most discredited claim of New Economy proponents was that the business cycle was dead. No sooner had they made this claim than the economy went into recession in 2001. But it turns out that those hopes weren't so far-fetched after all. Since the mid-1980s the economy has been unusually stable (Dynan, Elmendorf, and Sichel 2006, 124). Throughout much of our history, recessions were severe, frequent, and long-lasting. Indeed, from 1853-1953 the economy was in recession over 40 percent of the time.[47] The post-war period was better, but still the economy was in recession 21 percent of the time from 1953 to 1983. In contrast, between 1983 and 2003 the economy was in recession less than 6 percent of the time (Atkinson 2004, 259). The benefits of this are considerable. In a world without business cycles, lifetime consumption could potentially be as much as 10 percent greater, or $120,000 for the average U.S. high school graduate and $440,000 for the average worker with a professional degree (Barlevy 2005, 4).[48]

Not only has the economy been less prone to downturns, it has also been more stable (McConnell and Perez-Quiros 2000). The quarter-to-quarter volatility of the economy (as measured by the standard deviation of quarterly real GDP growth) fell by more than 50 percent between the periods from 1960 to 1984 and 1985 to 2004 (Dynan, Elmendorf, and Sichel 2006, 132). This decreased volatility allows businesses to avoid some of the costs associated with risk, such as having to keep higher inventories **(See Figure 11)**.

Although the causes of this tempering of the business cycle are not certain, economists believe that four main factors are at work. The first two factors, better monetary policy and milder economic shocks, may not be directly affect-

Figure 11: QUARTERLY CHANGE IN U.S. REAL GDP, 1947-2006[49]



ed by the IT revolution, but the other two factors, financial innovation and improved inventory management, clearly are.[50]

Financial innovations, including the "democratizing of credit," have helped smooth business cycles (Wachter 2006, 4). Dynan, Elmendorf, and Sichel (2006, 127) emphasize that "technological advances have made it easier for lenders to collect and disseminate information on the creditworthiness of prospective borrowers." By allowing lending institutions to better assess and price risk, many firms and individuals who would not have had access to credit can qualify, smoothing their consumption through tough times and staving off major downturns in the economy.

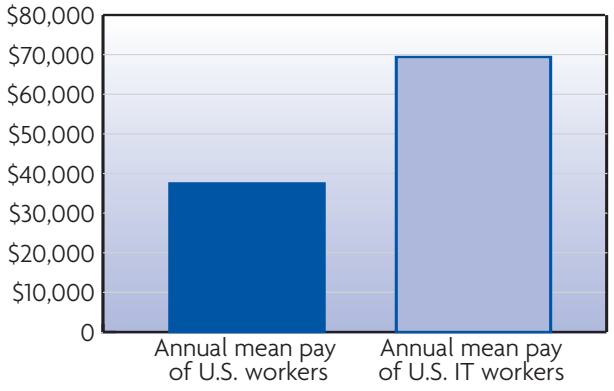
Perhaps the most important factor, however, in the decline of business cycle volatility has been the reduced instability in inventories. Historically, the build-up of inventory, particularly in durable goods industries like autos, steel, and appliances, has been a major cause of economic slowdowns. Because of the inflexibility of production systems, coupled with the difficulty in assuring fast replacement of inventories, companies had a propensity to build up high levels of inventory. When this happened and companies cut production in order to sell off some inventory, they made fewer products and bought less from suppliers, leading workers to be laid off, which dampened consumer demand, and which in turn cut sales even more. This in turn led to more layoffs and the downward cycle would continue until the whole process had worked its way out over the course of a year or two (Atkinson 2004, 260).

Large inventory cycles are really just a reflection of an econ-

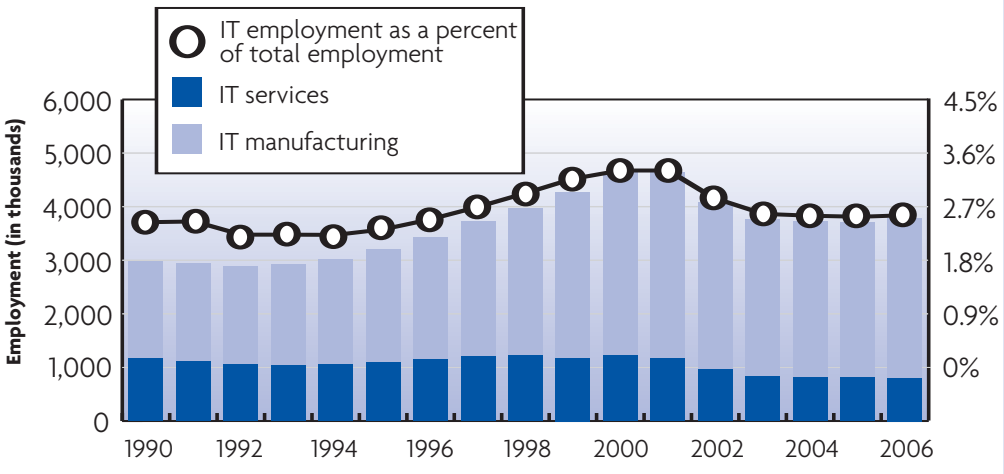
Box 6: JOBS IN THE IT INDUSTRY

IN THE HEY-DAY of the 1990s boom many looked to the IT industry itself as a major source of new jobs. However, because of the bust of 2000, the growth of IT offshoring, and faster productivity growth in the IT sector, the jobs picture is not as clear. IT jobs reached their peak in 2000 and as of March 2006 accounted for 3.76 million jobs, or 3.36% of total private sector employment. IT jobs have rebounded, but are not growing faster than the overall economy. Moreover, going forward, it is unlikely that the IT industry will be producing job gains out of line with its size. In part this is because productivity in the IT industry itself has been strong, allowing it to produce more output with fewer workers. However, even if the IT industry is not likely to be the source of a disproportionate number of new jobs, it is important to note that the industry is the source of higher-wage, higher-skilled jobs. Compared to the average wage of $38,000 for all U.S. jobs, IT jobs pay on average $70,000.

Box 6, Figure 1: WAGES IN THE IT INDUSTRY[51]



Box 6, Figure 2: TRENDS IN IT EMPLOYMENT[52]



IT lets more people participate in the economy and society.

omy that has difficulty adapting to change. Like an oil tanker that takes two miles to change course, an inflexible economy is slow to adapt. However, the digital economy has led to several structural changes that have boosted the economy's ability to respond to change. In particular, there has been a significant reduction in volatility of inventory investment, particularly in durable goods, and this factor in turn explains a significant share of the overall reduction in GDP volatility. In other words, the production of durable goods more closely tracks economic demand and is less likely to swing from feast to famine. The emergence of this real-time economy has helped reduce recessions.

One big factor for this is the rise of just-in-time (JIT) inventory systems that allow firms to deliver inputs to the assembly factory much closer to the time that the product is actually being made. Because of IT the production system operates more in real time. If the old economy was like a U.S. household that shopped every two weeks at a shopping mall and stored food in a large freezer and refrigerator, the New Economy is more like a Paris household where the homemaker goes out every day to buy what she needs for that night's dinner. As a result of JIT, the average production lead-time for supplies has declined from 72 days during the 1961 to 1983 period, to 49 days over the 1984 to 1998 period. In other words, in the earlier period, on average, parts (like a car radiator) would be made 72 days before they were actually used in the product (assembled into the car). The inventory-to-sales ratio has been declining since the early 1990s and in 1999 was at its lowest rate since it was first calculated in 1967. The ratio of non-farm inventories to sales fell from about 2.35 percent in 1989 to 1.75 percent in 2002 (Coy 2002). Wen (2005) finds good evidence that inventory follows "stockout avoidance" behavior, in which producers try to avoid running out of products. This creates greater volatility in production than sales, since JIT allows production to more closely follow demand, and producers are less afraid they will run out of stock and so engage in less over-production.

JIT is not something that companies just decided to do; it was enabled by the new production technology, including electronic data interchange (a predecessor to the Internet) that lets companies place orders electronically, overnight air delivery that lets companies get parts in a crisis rapidly, and by more flexible production systems that let companies more easily shift from producing one kind of part to another (for example, shifting from producing tires for an SUV to producing tires for a mid-sized compact).

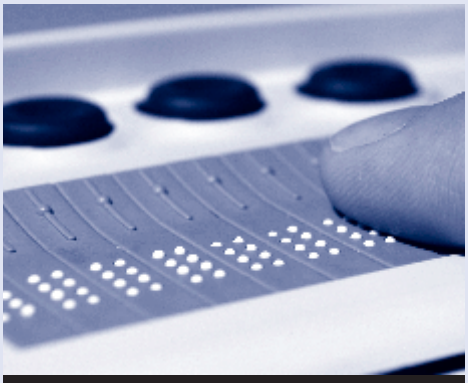
IT ENABLES MORE PEOPLE TO WORK AND BOOSTS ECONOMIC OUTPUT

IT helps boost economic output by making it easier for people to work who otherwise could not. This includes people who now have more work flexibility and people with disabilities who previously would have limited their involvement in the labor market.

One way IT helps people to work is by enabling self-employment and work from home. IT has made it easier for individuals with responsibilities to care for dependents (either children or aged parents) to work part-time from the home. Twenty-five years ago, only companies could afford the technologies needed to operate a truly effective office environment. Today, individual "free agents" can have technologies almost as sophisticated as the largest corporations. Computers, software, video displays, and digital switching technologies make it possible for the home to be as connected to work as an office. For example, a significant share of

Box 7: IT AND DISABLED WORKERS

INFORMATION TECHNOLOGY is helping the 19 million Americans aged 16-64 who have a disability that limits their participation in the labor force (U.S. Census Bureau 2005, table 2). A host of new technology applications is helping to empower people with disabilities. For example, a new system employing audio-based GPS is making it easier for blind people to be more mobile. One blind user of the technology relied on a driver to take him places. Now because of the GPS system he can walk (USA Today 2006). Blink and eyebrow operated software lets quadriplegics control computers with only facial expressions. Infrared headsets let workers use a computer without a keyboard or mouse. Even more powerful is software under development that allows a person's brain waves to move a cursor on a computer screen. Such technology could also potentially lead to mind-activated artificial limbs (Grauman, Betke, Lombardi, Gips, and Bradski 2002).



IT-enabled tools provide disabled individuals with new opportunities.

A newly developed Braille printer by ViewPlus Technologies called EmPrint™ prints in Braille and text so that both visually impaired and sighted people can read the same manuscript and collaborate better (California Foundation for Independent Living Centers (2006). Software that reads text has long been in use for the blind, as well as screen magnifying software for the visually impaired, but voice recognition systems now give the blind more ability to control computers and other IT devices (Mergenhagen 1997). For example, Publishers Circulation Fulfillment's call center in Pensacola, Fla., uses an application that interfaces with call centers and lets blind agents hear computer-driven data (Mottl 2001). Overall, IT is making it easier for people to work. One study (Forrester 2003) found that 60 percent of working-age adults would either likely or very likely benefit from accessible technology. Another (Taylor 2000) found that the Internet is improving the lives of people with disabilities generally.

IT could also play an important role in helping older Americans stay active in the labor force, whether by choice or by necessity. This includes remote and on-site employment. In the near future, age-related limitations are likely to be the primary market condition that drives innovation in assistive technology, with distinct spillover benefits to the rest of society. For example, 13.4 percent of individuals 35 to 44 have some functional limitations that affect their working, but 45 percent of individuals 65 to 69 have functional limitations (Luigart 2003).

IT can help older Americans participate economically, in part by making it easier to work from home. In fact, the ability to work at home connected by broadband networks will enable the elderly to be more productive later into life. Robert Litan (2005) estimates that allowing the elderly to work more at home through accelerated deployment of broadband telecommunications would boost economic output by between $114 and $228 billion.

The Internet can also play a particularly important role in helping retirees plug into volunteer opportunities. As baby boomers retire in droves, tapping into their talents will help ease the loss to the economy their retirements would otherwise bring. Sites such as dinosaur-exchange.com are springing up to connect retired professionals not content to spend the next couple decades playing shuffleboard, with employers desperate for expertise (Essick 2006). YourEncore.com connects the technology and product development opportunities of member companies with the talents of retired scientists and engineers (Essick 2006). Instead of bringing in untested outside talent, retirees serve as a safe and flexible workforce and these sites keep that pool of talented workers in close contact with the potentially undermanned companies in case a contract or salary position is needed on relatively short notice.

airline Jet Blue's reservation agents works from home, using a personal computer and broadband telecommunications connections.

Not only has the digital economy enabled more people to work in the paid, market economy, it has enabled more people to contribute through volunteer efforts. In the wake of Robert Putnam's 2000 book, *Bowling Alone*, there has been considerable concern that Americans are participating less in civic activities. Yet, while perhaps not making up for the loss of face-to-face volunteering, the Web, particularly since the emergence of the more social Web 2.0, has made it easier for people to volunteer online. One study (Kiesler and Sproull 2005) estimates that between 10 and 15 million people worldwide participate in online volunteer communities, ranging from online volunteer technical support groups (more than 50,000 of them) that win industry awards for their quality support, to volunteer mentoring and tutoring programs that give career advice and even provide matching services between individuals considering a field and experts already in it. Quality is sometimes assured by rating systems or averages of group work. For example, NASA recently invited online volunteers to click on craters found on maps of Mars, then used a composite of 50 independent volunteer clicks to build the final map of Martian craters. In what is sometimes termed a "crowdsourcing" (Howe 2006) project, 85,000 people participated and the final product was "virtually indistinguishable from [that] of a geologist with years of experience in identifying Mars craters" (Kiesler and Sproull 2005). Likewise hundreds of thousands of people log onto espgame.org where they play a game to label pictures on the Web. The labels in turn help blind people hear a description of the picture through a screen reader that reads text pages aloud. The deployment of high-speed broadband will make online volunteering even easier as it enables high quality two-way video. For example, the city of Fort Wayne, Indiana, where Verizon has deployed extensive fiber optic broadband, has set up a system where retired nurses help provide health evaluations for low income residents without health insurance through means of two-way broadband connections.[53]

The Internet is also making it possible for individuals to be producers, not just consumers. Increasingly, individuals are producing content that others consume. The phenomenon of peer production is increasing rapidly as users generate and consume content from each other, blurring the lines between producers and consumers. Between blogs, social networks, YouTube videos, and wikis, users are creating real additions to the Internet (Anderson 2006). For example, consumers around the world now have free access in over 200 languages to Wikipedia, the online encyclopedia created by volunteers. Not only does Wikipedia have significantly more entries than a typical paper or CD-based encyclopedia, like Britannica, but the accuracy of the entries closely approximates them as well (Giles 2005). In Korea, OhmyNews relies on 33,000 volunteer reporters who submit articles to its staff of 35 who review and compile them into an online publication that has surged in recent years as more conventional media outlets have lost readership (Schroeder 2004).

IT enables the necessary communication to bring together multitudes of individuals with similar interests, sometimes creating the perfect environment for collaboration. One area is the development of open-source code for software. Open-source can't be a substitute in many software areas (*e.g.*, there is no push, for example, to have the FAA air traffic control system developed by open source developers), but for some applications, like the development of the Firefox browser, it has created software that is widely used (Malone 2004).

VIII) IT Enables Goods and Services to Be Allocated More Efficiently

While producing goods and services efficiently is important, economists also stress the importance of ensuring that those goods and services are allocated efficiently. If an economy produces one million widgets with high levels of efficiency but no one wants to consume the widgets or the widgets don't get to the people who want them, the production is wasted. The digital economy is helping to make the allocation of goods and services more efficient. This shouldn't be a surprise, since a key to allocation efficiency is information (either in the form of prices or information about where to find a product or service).

Well-functioning markets are the principal way to ensure high levels of allocation efficiency. But well-functioning markets depend on at least three important factors: prices that reflect costs, well-functioning exchange markets, and good information by buyers and sellers. In many areas particular markets lack some or all of these factors. IT can remedy these deficiencies.

IT boosts allocation efficiency by enabling the creation of markets and market signals where before there were none.

IT boosts allocation efficiency by enabling the creation of markets and market signals where before there were none. This is particularly true in areas like energy and transportation, where market signals have not generally existed. For example, IT enables roadway space to be allocated on the basis of demand and price. Economists have long recognized that road pricing (charging by distance traveled, place traveled and/or time of day), is the most efficient way to allocate scarce transportation resources. But until recently, it was too expensive and cumbersome to institute road-pricing schemes. Now the emergence of inexpensive vehicle transponders and other technologies are allowing regions to institute road pricing. For example, Singapore's electronic road pricing program almost doubled average speeds in the restricted area surrounding the central business district, reducing morning traffic volume by 45 percent (Fraser and Santos 2006, 268). Other metropolitan areas, like London and Stockholm, are getting in the game, using IT to institute road-pricing schemes to dramatically improve traffic flow.[54] In the United States IT is allowing regions to make more efficient use of the more than 1,600 miles of high-occupancy vehicle (HOV) lanes operating in 31 metropolitan areas. Most of the time, these lanes are underutilized. However, IT-based transponders (*e.g.*, E-ZPass systems) allow regions to let cars willing to pay a toll use the lanes, with the result that throughput goes up without having to invest in new, expensive roads.[55]

IT is also making energy markets more efficient. While consumers have long paid for electricity, it was only recently that it was cost efficient to charge residential consumers based on the time of day and time of year. It costs power companies much more to generate electricity at peak periods than in slack periods. Smart meters allow electricity companies to charge higher prices during periods of higher demand and lower prices for use in other times. By giving more choice to consumers and letting them decide how much they value scarce energy during peak periods, large savings are possible. If smart meters were installed across California, for example, during the recent heat wave they would have saved an estimated 5,000 megawatts of power, the equivalent of the output of 10 power plants (Tribble 2006).

When a market reacts more quickly to changes in the environment, conveys more information, and costs less to participants per transaction, that market is better and peo-

Smart meters use market signals to encourage more efficient use of electricity.

ple are getting what they want faster and with less hassle than before. IT is playing this role in both producer and consumer markets. By creating online markets for a wide variety of products and services, companies can more easily find the particular product and service they need, and the resulting market intensification boosts competition. For example, the Pan European Fish Auction directly links fish retailers to fish harvesting companies in real time auctions.[56] Chemconnect connects buyers and sellers of chemicals into a more efficient online market.[57] At the consumer level, sites like Craigslist.org enable markets for things like apartment rentals to work better. Originating in San Francisco, Craigslist allows users to post classifieds for everything from apartments to jobs to personals at greatly reduced prices relative to conventional means.

This type of online matching technology is letting labor markets work better as well. Sites like *Monster.com* enable better matching between employers and employees, making the process cheaper and faster, and enabling both employers and employees to have more information on which to base their decisions. In fact, the Conference Board found that the Internet produced over 38 percent of job offers. Soon video conferencing will add a valuable addition in the form of video job interviews (Rosemarin 2006). Employers can find the best candidates for the job, while employees can find the job that best suits them.

In developing nations, IT can play an important role, not just in boosting productivity but in enabling the poor to get better information on markets. This allows them to get better terms of trade with wholesalers and other intermediaries, and also to make better decisions about what and when to produce. For example, Kaushik and Singh (2004) found that installing Internet-enabled kiosks in rural Indian villages improved access to government services and education. One study of access to phones (including mobile phones) by poor rural Chinese villagers found that villages that got telecommunications access had 15 percent higher income growth in the two subsequent years than villages that did not gain access, in part because they enabled better market access (Eggleston, Jensen, and Zeckhauser 2002, chapter 7).

IT also makes it easier for organizations and individuals to participate in markets, particularly by linking individuals with products that others may not find of much value. There is no better example of this than eBay. eBay doesn't lead to more production, but it does lead to more value because it enables items to be reallocated from individuals or businesses who value them less to individuals and businesses who value them more. What once might have been thrown out (or stored in an attic) in the old economy is now used and provides value to someone else in the new economy. Likewise, services like Amazon.com's used book service make it just as easy to buy a used book as a new book, better allocating books that otherwise would have been thrown away or left in an attic. Without the Internet, this kind of

reallocation was confined to weekend swap meets, garage sales and other haphazard and time consuming exchange mechanisms.

IT helps markets be more efficient by expanding consumer information. Buyers need information to make the best possible choices. Knowing what products are available, how they are priced, and the precise nature of those products is critical for finding the best combination of goods and services for one's money. Where buyers are sophisticated (*e.g.*, buyers of jet airplanes), markets generally work well. But in many markets buyers may lack sufficient knowledge. A host of institutional innovations have emerged to deal with this, from advertising to warranties to publications like *Consumer Reports.* However, the Internet has moved consumer empowerment to a new level by lowering the main hurdle to getting comprehensive information on prices and products: search costs. The Internet makes it dramatically easier to find information on products and services, including prices and quality. For example, using a service like Google's shopping search engine Froogle, consumers can easily compare prices of an item.

This increased ease of price comparison is leading to significant price savings for consumers. Brynjolfsson, Dick, and Smith (2004) found that price comparison Web sites make consumers more sensitive to prices, reducing price dispersion and increasing the relative importance of differences in retail services, such as delivery options and ease of Web site use, in deciding who to buy from. Brown and Goolsbee (2002, 483) found that Web sites designed to search and compare life insurance policies between providers clearly reduced on- and off-line prices of life insurance by 8-15 percent, producing a consumer surplus of $115-215 million annually. The Pew Research Center on the Internet and Society found that 32 percent of online Americans say that the Internet has greatly improved their ability to shop by a lot (Madden 2006).

The Internet has moved consumer empowerment to a new level by lowering the main hurdle to getting comprehensive information on prices and products: search costs.

IT makes it easier for consumers get more information to make better purchasing decisions. For many products and services, deciding which one to buy can be quite difficult. In the past, brands were one way consumers gained assurance of product or service quality. But establishing brand reputations can be quite expensive and can lead to higher prices. Waldfogel and Chen (2003) found that the increased information available through Internet shopping and third party product review sites decreased the effectiveness of branding. No longer must consumers rely heavily on past performance of producers to make their purchasing decisions. Instead they are increasingly using third party information and word of mouth spread over the Internet to determine the quality of products, independent of producers. Web-based consumer reviewers are another way of providing information on products and services. One study (Chevalier and Mayzlin 2003) found that positive user-supplied book reviews on e-retailer sites Amazon.com and BarnesandNoble.com caused other users to purchase more of those books, all else being constant.

Another way in which the Internet is increasing consumer information is by enabling more targeted advertising. Instead of advertisers putting an ad on TV or in the paper for anyone to see, Web-based advertising can be targeted to a consumer's likely interests. For example, with Google's Adsense, advertisers can advertise to only those people who have demonstrated through their search terms that they are interested in the advertised product type (Boslet 2006). Instead of being subjected to irrelevant ads for products most consumers would never want or need, ads are more likely to be for items in which a consumer is likely to have a real interest. But this is just one of a wide array of applications that use information about a person to better target information and deals to them. For example, if a person has booked several trips to Las Vegas several times a year on a travel Web site, the next time the person goes to the site it can display special Las Vegas flight and hotel packages. Such targeted marketing not only is much more likely to provide information of value to a consumer, it significantly increases the value of the marketing to the companies, therefore lowering the relative cost of advertising, and thereby reducing prices.

IX) IT Enables Higher Quality Products and Services

Our standard of living is not just a function of the efficiency of production, but of the quality of products and services. IT is improving the quality of goods and services.

IT helps firms boost quality in at least two ways. First, IT enables more information about quality to be collected, giving organizations greater opportunity and incentive to boost quality. Second, IT makes it easier for organizations to design more customized products and services, which by definition are of higher quality because they more closely fit the wishes of consumers. IT also makes it easier for organizations and individuals to participate in markets, particularly by linking individuals with products that others may not find of much value.

QUALITY MONITORING

One key way IT boosts quality is by helping organizations better monitor internal processes, thereby improving the quality of output. For example, IT lets hospitals remotely monitor intensive care units by feeding video, audio, and vital data to a single interface that allows a doctor, nurse, and assistant to monitor multiple beds in multiple hospitals all at once.[58] By improving surveillance, two ICUs in Norfolk, VA, reduced deaths by 27 percent in the first year and reduced the costs per ICU case by about 25 percent (Mullaney 2006). In hospital emergency rooms, IT reduces time spent preparing patients and enables them to see the proper specialist more quickly (Gabor 2004). IT is also being used by hospitals to reduce patient errors, saving money and lives. A 2005 survey of IT adoption in the healthcare industry showed significant potential gains. One study estimated that unplanned drug interactions kill 44,000 to 98,000 people a year in the United States, while another study found that IT could prevent 2 million adverse drug interactions and 190,000 hospitalizations per year (*The Economist* 2005).

IT also allows for more accurate and seamless maintenance of after-sales service. For example, parts for Boeing's new Dreamliner jet have RFID tags on them that store the history of the part, when it was serviced, etc., letting maintenance staff to better maintain the plane. Likewise, wireless GPS technology lets owners of fleets of vehicles quickly pinpoint vehicles with excessive idle times, speeds and inefficient miles per gallon, helping companies maximize fleet efficiency and minimize costs.

IT is enabling governments to benchmark the quality and effectiveness of their services. For example, Baltimore's City Stat program looks at data in order to identify strengths and weaknesses in government programs. Built on the New York COPS program, the city collects and puts in an easily understandable form a wide range of data on topics including the amount of overtime worked by employees, the frequency and type of citizen complaints, and response-time to specific cases.[59] One of the keys of City Stat is its emphasis on the accountability of managers. The system can be used to hold mid-level managers accountable, who in turn have tools to hold front line workers more accountable. Such systems can also make government more transparent, increas-

IT enables higher quality health care.

ing pressures from citizens for even better performance. Governments are also using these systems to cut waste in government services. For example, the Credit Alert Interactive Voice Response System, a HUD-initiated Federal government database that allows for Federal lending agencies to conduct credit checks for Federal debt foreclosure or default, reduces the risk of endorsing a mortgage for FHA insurance without knowledge of previous delinquencies or defaults in Federal programs.

IT is enabling governments to benchmark the quality and effectiveness of their services.

IT not only gives organizations more information to benchmark the quality of their products and services, it is also giving more consumers information about quality, in turn putting competitive pressure on organizations to boost quality. In the old economy, if an organization provided poor service or shoddy products, it might be able to get away with it, because it was difficult for affected consumers to communicate their displeasure beyond their immediate circle of family and friends. Moreover, organizations had very little capability to determine if their customers were satisfied. Now with IT, online surveys allow organizations to more easily tease out customer preferences. Such improved customer information can help a business catch a poor decision before it causes long-lasting damage, and it helps businesses tailor their services more closely to their customers' wants and needs. This is one reason why over half of the firms surveyed in the EU reported that IT had a positive impact on customer service, with just 2 percent reporting a negative impact.[60]

By drawing on the power of large communities of users, the Internet improves the quality of services. For example, eBay's seller rating system allows buyers to rate eBay sellers on the quality of the service, enabling future buyers to avoid sellers with low ratings and spurring sellers to provide good service. Likewise, community rating systems allow Web users to get recommendations on the kinds of books (*e.g.*, Amazon) or movies (*e.g.*, Netflix) they might like based on what other users liked.

Moreover, the Web is giving consumers power to hold organizations more accountable and to check many different sources to benchmark quality, from on-time performance of airlines, to test scores in elementary schools, to the quality of physicians.[61] Now, when consumers are unhappy, they can let the whole world know. For example, when a Comcast technician repairing a customer's Internet connection was recently caught asleep on the job, instead of writing a letter of complaint that would have probably gone nowhere, the customer videotaped the nap and posted it on YouTube, an Internet video sharing site (Hill 2006). After the posting spread virally across the Web, Comcast quickly moved into damage control, firing the technician and apologizing to the customer. A similar incident occurred with AOL when a customer tried to cancel his service in a recorded telephone conversation that revealed AOL´s determination to retain customers (Stross 2006). The exasperating incident was posted online and spread through blogs, leading AOL to alter its customer retention policies. Instances like these of customers actively informing business of their wants, needs, and qualms through the Internet will only increase as IT advances.

MASS CUSTOMIZATION

An economy that gives consumers more choices in products and services provides more value to people than one that provides fewer choices for the simple reason that more

The Internet is giving consumers vastly enhanced choices. 1-800 CONTACTS, an Internet-based contact lens stores, stocks over 20 million contacts.

choices are more likely to better match the different interests and needs of more individuals (Schwartz 2004). IT plays the central role in creating an economy that gives consumers vastly more choice. In the same way a large supermarket gives shoppers a wide variety of products to choose from, IT is reducing the costs of giving consumers more choices, creating what *Wired Magazine* editor Chris Anderson calls the "long tail." Anderson (2004) shows how the Internet economy has created marketplaces where it is economical for even the most obscure goods to be sold. Brynjolfsson, Smith, and Hu (2003) analyze this phenomenon, showing that while a typical large bricks-and-mortar store carries 40,000 to 100,000 book titles, Amazon.com carries around 2,300,000. This variety is possible because Amazon's large centralized inventories and market allow it to stock books that might not sell many copies in a year and would be prohibitively expensive to stock in a bricks-and-mortar store. The authors estimate that the total consumer welfare gained from this variety in books alone was between $731 million to $1.03 billion in 2000.

The long tail doesn't occur just in book retail, it is in virtually any product distributed on the Web from music to videos. For example, Posters.com stocks over 300,000 different posters. Ties.com stocks over 2,500 different ties. Online DVD rental site Netflix stocks 65,000 different DVD titles, compared to a typical neighborhood video store that stocks around 3,000. Approximately 40 percent of sales at online music service Rhapsody are songs that are not available in music stores (Hof 2006, 88). Over 65,000 videos are posted to YouTube daily with people watching 70 million on the site a day.

The Web is enabling sellers and producers who might otherwise never be known to find an audience, and conversely is enabling consumers to find products or experiences that they might otherwise never find.

The Web is enabling sellers and producers who might otherwise never be known to find an audience, and conversely is enabling consumers to find products or experiences that they might otherwise never find. For example, Clap Your Hands Say Yeah, an emerging Indie band, has managed to sell over 100,000 copies of its self-released debut CD without a record deal (*Wired Magazine* 2006). Likewise, when Chris Bliss gave an amazing juggling performance with the Beatles "Golden Slumbers" in the background, a few hundred people saw it live. The video clip remained a largely unnoticed posting on Bliss's personal Web site until early 2006 when someone came across it and sent to a group of friends. The video quickly became an Internet sensation and, thanks to the wonders of viral marketing, was viewed over 20 million times by mid-April, 2006. As of this writing, it has been viewed over 7 million times on Google Video alone.

IT is giving all Americans more choice, but it's a special boon to the 60 million Americans who do not live in large metropolitan areas. One of the advantages of living in a place like New York City was that because the city was so big, specialty stores of every imaginable type could find enough customers to thrive. This was fine as long as you lived in New York, but if you didn't you were out of luck. The Web gives companies a potential customer base 20 to 30 times larger than those stores in New York. As a result, consumers who live in smaller metropolitan areas or rural areas and who were constricted in their choice of products and services, now have the same kinds of consumer options as someone living in Manhattan. A rancher in the middle of Wyoming has the same selection of music and books through iTunes and Amazon as anyone in New York. Even the services once thought to be non-traded, or impossible to export beyond the immediate market, such as doctor appointments and college education, are increasingly traded through IT so as to reach remote areas. Many schools have created online courses, while others, like MIT, have posted course materials online. Telemedicine can give rural patients the same access to care as the patient living in a major metropolitan area.

IT doesn't just enable the long tail; it enables the proliferation of more customized products and processes, often at the same prices as formerly mass-produced products and services. IT is the key enabler of such "mass-customization." In the old economy, changing factory-floor production technology usually took skilled labor many days or even weeks. Dedicated machines that could only do one thing (*e.g.*, stamp out a door) had to be taken down and replaced with new ones that could do something different. It was not much different in offices; to change software on

mainframe computers software engineers had to reprogram complex and expensive proprietary software systems. Now companies can develop 'flexible' factories and offices and expand the variety of their products at little additional cost (Davis and Pine 1999). One reason IT enables mass customization in manufacturing is that it reduces set-up times, allowing firms to produce many different types of products with few additional costs. For example, Bartel, Ichnioswki and Shaw (2005) found that valve-manufacturing firms that invested more in IT moved away from commodity mass production toward customized production of more products in smaller batches. This not only helps consumers directly, but it helps reduce output that is not valued by consumers.

Such customization is emerging in a wide array of product areas. Lands End has customers submit measurements online that are turned into custom-fit clothing. Nike lets customers customize their own shoes, while American Quantum Cycles lets customers order bikes to fit their unique measurements. Levi Strauss is able to custom-make women's jeans based on individual body sizes.[62] In 2002 more than $15 billion worth of custom integrated circuits were produced with users designing their own circuits (Von Hippel 2005, 128). Using the Internet to receive orders, CafePress takes basic commodities like tee-shirts, hats, and coffee mugs, and then prints onto them designs submitted by the customers (Walker 2005).

Customization is not confined to sales of goods, it also enables services to be customized. For example, Edelberg (2003) found that because of increased storage capacity and underwriting technology in the mid-1990s, lenders were able to personalize consumer loans based upon credit risk. Lending based upon individual risk allowed lenders to issue debt at lower interest rates to low-risk borrowers while extending loans to high-risk borrowers who otherwise wouldn't have been able to access risk otherwise. Credit card companies can provide thousands of different 'affinity' credit cards, for example, with colleges marketing their own credit cards to alumni, and the college getting a small share of the transaction fee.

X) IT Drives Innovation

Because IT makes it easier to uncover and develop good ideas, it is making it easier to create new products and services. For example, in the EU 32 percent of companies reported innovations, with IT enabling half of the product innovations and 75 percent of the process innovations.[63]

IT gives researchers powerful new tools. The most direct way in which IT boosts innovation is by giving researchers more powerful tools for doing research. Without powerful computing unraveling the mystery of the human genome would have been impossible. IT has become so powerful (and cheap) that it is letting even small companies engage in virtual product development that just a few years ago could only be done using expensive super-computers. Virtual product development lets researchers model the operational properties of a product without having to build expensive prototypes. For example, new software tools help chemists reduce the number of experiments they conduct because different conditions (*e.g.* temperature) are modeled.

IT enables new disruptive business models that transform entire industries.

IT enables small firms to significantly expand R&D. In the old economy most R&D was performed by large corporations that were more able to translate that research into marketable products and services. But the rise of computers and the Internet has made it much easier for small firms to enter markets previously dominated by large firms (Hunt and Nakamura 2006). Because small and mid-sized firms can now better compete in product markets, they have dramatically increased their R&D investments. In fact, while the R&D to GDP ratio more than doubled between 1980 and 2000, almost all of that increase was because small and mid-sized firms with fewer than 5,000 employees increased their R&D investments (Hunt and Nakamura 2006, 1). Indeed, in many industries, small and mid-sized firms now invest more in R&D than in larger firms.

IT boosts innovation by giving users more of a role. In *Democratizing Innovation*, Eric Von Hippel (2005) discusses how users are becoming more involved in helping develop and design product innovations. For example, kite surfing advocates created and participate in a Web site that has turned into a major site for innovation in this field.[64]

IT also enables companies to better tap into their own workforce for innovation. For example, in 2000, Whirlpool launched a "knowledge management" site to allow for employee input in innovation. The site received up to 300,000 hits per month and proved to be a great energizer for the company (Arndt 2006). Taking the concept of company-wide innovation one step further, Rite-solutions, a Rhode Island defense contractor, put in place a virtual stock market for ideas, called Mutual Fun, that allows employees of the company to suggest ideas for new products or services, list them on the exchange, and receive support from other co-workers in the form of "opinion money," a virtual currency allotted to each employee (Taylor 2006). The experiment has led to new profitable products for the company, including a 3D training technology that now accounts for 30 percent of total sales. Taking this idea outside the company, InnoCentive has created an online portal in which problems posed by business are outsourced to the general community for a reward (Taylor 2006). Over 90,000 "solvers" from 175 countries participate in the network. So far the highest reward for a solution is $100,000 and solutions have come from as far away as Russia, India, and China. Likewise, IBM has used the Web to put together what they call an "innovation jam" to brainstorm new ideas. The company has built an interactive Web site that enabled 53,000 participants (with 67 participating companies in addition to IBM) who made more than 37,000 posts (a record for Jams). Working closely with leaders from the participating Jam companies, IBM will distill the thinking into a core set of the most promising ideas.

IT lets organizations better manage the existing knowledge of its employees. Knowledge management software allows

companies to codify knowledge and lets employees reuse it without having to reinvent the wheel. As two knowledge management experts state, "It is IT that has made the organization of global knowledge management a theoretical reality." (Pan and Leidner 2003, 83). For example, one specialty chemical company had over 2400 technical case histories available for its employees worldwide to tap into (Pan and Leidner 2003). Prior to the Web, it could take weeks for employees in dispersed divisions to find answers from experts in their organization. Knowledge management changes that. For example, oil well equipment company Schlumberger used an online knowledge management system that reduced by 95 percent the time involved in resolving technical queries.

After finding a good idea, companies still must develop it into a marketable product, and for that, teamwork still seems to work best. Geographically-distributed team development, using IT for inexpensive communication or even virtual collaboration environments, is essential where flexibility is needed to bring together diverse workers (Ghosh, Yates, and Orlikowski 2004). A new generation of knowledge management tools and technologies that enable collaboration, including Web-based conferencing, shared computing, and wikis and blogs enable individuals in dispersed locations to communicate and share knowledge. The Boeing Dreamliner development team serves as a prime example. Bringing together 135 partner sites in around two dozen countries, the Dreamliner development team led by Boeing is proving that innovation and collaboration are not tied down by space. Using Boeing's Global Collaborative Environment, progress on the design could proceed simultaneously from all of these

These kinds of transformations, while they can be disruptive for the individuals in the incumbent industries, are a major driving force in economic advancement.

IT enables more sophisticated and powerful scientific instruments, in this case a state of the art flow cytometer.

135 sites and continue 24/7 around the world (Dassault Systemes 2006).

There are many other examples. New interactive software tools let hardware and software engineers collaborate at the earliest stages of circuit design, letting them simultaneously lay out hardware and software designs for integrated circuits. There are many other examples. For example, in current designs, typically, hardware engineers design the circuits and then software designers write new interactive software. Such tools are not just for large corporations. Research on SARS in 2003 proceeded in 11 laboratories in 9 countries and took "advantage of modern communication technologies (e-mail; secure website) to share outcomes of investigations of clinical samples from SARS cases…in real time."[65] Software such as Better Homes and Gardens Home Designer Pro or Google SketchUp allows homeowners to virtually construct their dream houses and then present these virtual models to architects and builders (Munoz 2006).

Even in teams where there is no clear ideal result, virtual collaboration can be better than what would otherwise be possible. Surprisingly, a study by Ocker (2001) found that virtual teams without face-to-face meetings are more creative than hybrids that mixed face-to-face with virtual collaboration. As the Internet becomes ubiquitous throughout society and online collaboration becomes more and more prevalent, Ocker's study suggests we might see more, and not less, creativity despite reduced face-to-face interactions.

At a broader level, IT enables new disruptive business models that transform entire industries. For example, the rise of e-commerce has changed the way many individuals buy and sell stocks, bringing considerable competitive pressures on bricks-and-mortar stock brokerages to lower prices and improve service. Likewise, an upstart website like YouTube is already having disruptive influences on the television broadcast industry, driving them to put more of their content online, and potentially some day could lead to the entire transformation of the TV network industry. These kinds of transformations, while they can be disruptive for the individuals in the incumbent industries, are a major driving force in economic advancement.

XI) The Downsides of IT

As with any major new technology system, IT brings with it both benefits and costs. Automobiles brought unprecedented mobility and increased productivity, but also pollution and accidents. But overall, the benefits vastly outweighed the costs. IT is no different. The benefits have been vast and will continue to grow. However, there are costs that the industry, government, and citizens should continue to work to minimize. These can be grouped into three areas: 1) economic costs; 2) risks to individuals in areas such as privacy; and 3) IT-induced dislocations.

Economic Costs: While the economic benefits of IT far outweigh the costs, there are costs beyond the simple purchase and installation of IT systems. Many of these are imposed by bad actors. For example, the costs of SPAM (unsolicited commercial e-mail) amount to over $10 billion a year in terms of fraud, time spent dealing with SPAM, and network costs (Krim 2003). Phishing, where individuals fraudulently acquire sensitive information, such as passwords and credit card details, by masquerading as a trustworthy person or business in an electronic communication, has grown considerably, with 154 brands highjacked through phishing in July 2006, compared to just 76 a year before (*Information Week* 2006). Likewise, malware—software designed to infiltrate or damage a computer system without the owner's informed consent—imposes costs on corporate and individual IT users. Cyber attacks are also growing, costing business $226 billion in 2004 (*Information Week* 2006).

Working to reduce these costs will require action by governments, IT companies and IT users. Better technologies can reduce the costs from malware. For example, Vista, the next version of the Microsoft operating system, promises significantly more robust security features, making it harder for bad actors to succeed. More use of encryption can play a role. For example, after a second laptop computer containing personally identifiable data from the Department of Veteran Affairs disappeared, the Department mandated that all computers and mobile data devices be upgraded with encryption technology. Now if computers are lost, the data cannot be accessed by outsiders. Likewise, greater use of digital signatures and biometric smart cards could reduce online fraud. Overall, while the arms race between the good guys and bad actors is always growing, computer security continues to improve and reduce risk.

Not all the costs of IT result from bad actors. Even legitimate e-mail contributes to work overload. Because it is so easy and inexpensive to send e-mails, more e-mails are sent than is probably efficient, with the result that individuals spend time dealing with unnecessary e-mails. A typical office worker receives more than 100 messages a day (McDougall and Malykhina 2006, 37). Moreover, the ease with which workers with desktop computers can surf the Web, has meant that inappropriate use of computers at work detracts from productivity. For example, the Department of the Interior's Inspector General found that employee online surfing of gaming, pornography and other non-work related sites led to wasted time amounting to more than $2 million in lost output annually (Kamen 2006). However, even in spite of such inappropriate use (which is best dealt with through effective managerial oversight), IT's impact on workplace productivity remains overwhelmingly positive.

Risks to Privacy and Community: While IT is leading to vastly increased convenience, choice and empowerment for individuals, some see an IT-enabled economy as a dystopia where our actions will be tracked by corporate and/or government leviathans. According to this view, IT has stripped us of our privacy, exposing our intimate lives to anyone who wants to see them. To be sure, as more and more information is in digital format, the ease of aggregating information and tying it to individuals has grown. But it is important to keep a sense of perspective. The fact is that many—but certainly not all—of the concerns raised by privacy activists are hypothetical and speculative (Atkinson, May 2006). Given the large amount of information in digital format today, it is worth asking how much harm has been done to date. Notwithstanding all the fear and gloom from privacy activists, there simply have not been widespread privacy violations, and of the data breaches that have occurred recently, many occurred precisely because the information was not in digital form. Moreover, the answer to many privacy risks in the digital age is not to ban IT applications, as many privacy advocates propose, but rather to ensure that the appropriate rules and practices governing privacy and civil liberties are in place and enforced.

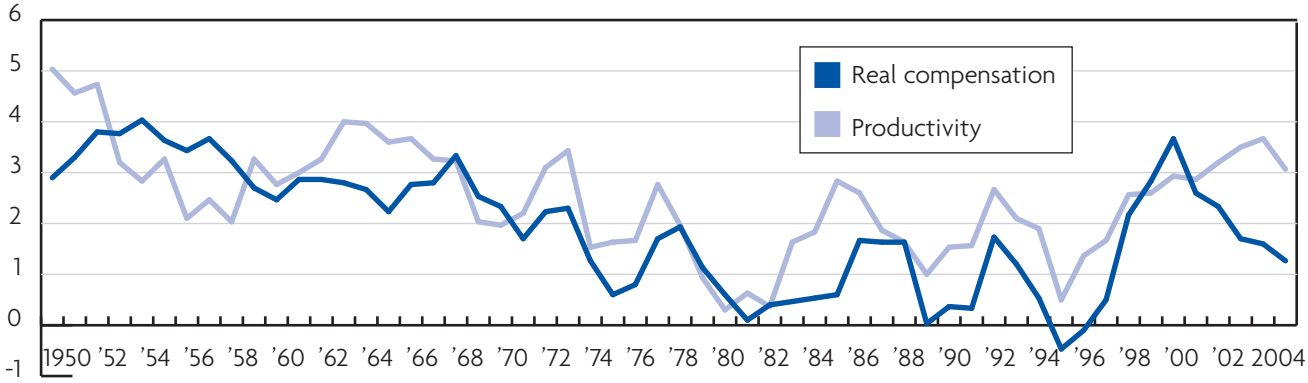
While some fear the IT economy is making us too exposed,

others fear that it's doing the opposite, reducing community and leading to isolation. To be sure, high-profile cases such as an addicted PC gamer in Korea dying after playing at a cyber cafe more than 80 hours straight, suggest that for some individuals PCs can be an anti-social source of escape (Gluck 2002). But for every case where IT might lead to isolation, there are many more cases where it enhances community. Because of the Internet, individuals are able to connect to individuals around the globe they might otherwise never encounter. IT is a powerful tool for enabling people interested in the same issues (*e.g.*, facing the same health problem) to form meaningful online communities.

IT-enabled Dislocations: The new digital, global economy is more turbulent and risky than the old post-war economy. As IT enables more work in manufacturing and services to be done in many more places in the world, it raises the risks to both companies and workers. But innovation and change are always disruptive. They displace workers and make some skills obsolete; they cause firms, and even entire industries, to fail; they lead to industrial and economic restructuring in cities and sometimes even whole regions; and they upset traditional ways of doing things and lead to wholly unexpected developments, impossible to predict ahead of time. Since innovation is disruptive, it tends to spark strong political demands to insulate affected segments of the economy and slow down economic change. But while innovation is disruptive and often frightening, it is also almost always good, creating new opportunities and increased incomes. As a result, demands to slow down change, create impediments to innovation and competition, and preemptively regulate nascent innovations, while understandable, inherently deny opportunities to less politically powerful interests in the guise of "protecting" those with clout. The answer to IT-enabled dislocations is not to ban the high wire of innovation but to mend the many holes in the safety net of social and economic supports **(See Box 8)**.

Box 8: PRODUCTIVITY'S IMPACT ON JOBS AND WAGES

Box 8, Figure 1: TRENDS IN WORKER COMPENSATION AND PRODUCTIVITY



EVEN THOUGH INFORMATION TECHNOLOGY has been responsible for driving the productivity turnaround, some policymakers and pundits are ambivalent towards higher productivity, worrying that workers will lose their jobs. But while higher productivity could lead some workers to lose their jobs, (for example, because companies can produce more with fewer workers) this does not mean that unemployment will be higher. Indeed, during the post-war boom the United States enjoyed robust productivity growth, but also high levels of employment. The reason higher productivity is actually correlated with lower unemployment and more jobs is that high productivity reduces the costs of products and services and increases wages, meaning that consumers have more money to spend, which in turn drives demand and job growth in other sectors. The reality is that without strong productivity growth and robust innovation, sustained income growth for working Americans is impossible. The key is not trying to throw sand in the gears of the productivity and innovation machine to slow it down to a more "human pace," but to ensure that the benefits of robust productivity and innovation flow to all Americans and that all Americans have tools to successfully navigate a dynamic labor market. This means, among other things, modernizing unemployment insurance, providing more health care security, and increasing support for education and training.

XII) Conclusion

It is now slightly more than a decade since the Internet became a mass phenomena and the digital economy began to take off. The United States, and indeed the world, have benefited greatly, with faster productivity and income growth, more innovation, higher quality products and services, and increased opportunity and convenience for hundreds of millions of IT users around the globe. It is not clear how long IT will power growth, but it seems likely that for a least the next decade or two IT will remain the engine of growth. The opportunities for continued diffusion and growth of the IT system appear to be strong. Many sectors, such as health care, education, and government, have only begun to tap the benefits of IT-driven transformation. Adoption rates of e-commerce for most consumers, while rapid, are still relatively low. And new technologies (*e.g.*, RFID, wireless broadband, voice recognition) keep emerging that will enable new applications. In short, while the emerging digital economy has produced enormous benefits, the best is yet to come. The job of policymakers in developed and developing nations alike, is to ensure that the policies and programs they put in place spur digital transformation so that all their citizens can fully benefit from robust rates of growth.

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ENDNOTES

1. Yet in spite of Carr's misleading title, even he admits that IT matters when it comes to the economy as a whole, producing new innovations and higher productivity (2003, 143). For example, he bemoans the effect of IT at lowering prices, which may not be good from a company's perspective, but is good from the consumers' and the economy's.

2. IPv6, a new standard governing how Internet devices communicate with each other, would have tremendous benefits, including allowing an almost unlimited number of Internet addresses, so that virtually everything could have its own IP address. Yet there are chicken or egg issues with widespread adoption as products and software will need to be upgraded but the applications to take advantage of the standard are not fully developed.

3. Pew Internet & American Life Project, "Digital Divisions." October 5, 2005, <www.pewinternet.org/pdfs/PIP_Digital_Divisions_Oct_5_2005.pdf>.

4. While it's true that lower income Americans are less likely to own a computer or be online, it is also true that the cost of both has fallen significantly over the last decade. It's now possible to purchase a very adequate computer with monitor—indeed one that just a few years ago would have been seen as a high-end consumer machine—for less than the cost of a 32 inch color (CRT) television. Moreover, is possible to get dial-up Internet access for around $5 a month, with broadband costing more (DSL can cost as little as $15 a month).

5. "Microsoft's Unlimited Potential," *Microsoft.com.* 27 Jun. 2003. <www.microsoft.com/about/corporatecitizenship/citizenship/giving/programs/up/digitalliteracy/default.mspx>.

6. North Carolina established its e-NC initiative to use the Internet as a tool for helping people, especially in rural areas, to improve their quality of life. <www.e-nc.org>.

7. Gordon Moore, "Intel Keynote Transcript," *International Solid-State Circuits Conference.* San Francisco, CA (10 Feb. 2003). <www.intel.com/pressroom/archive/speeches/moore20030210.htm>.

8. Ibid.

9. David Longstreet, "Software Productivity Since 1970," Longstreet Consulting. <www.ifpug.com/Articles/history.htm>.

10. Business historian Alfred Chandler (1977) discussed how railroads enabled nationwide catalog sales, which in turn transformed retailing. (See also Atkinson 2004).

11. Ray Kurzweil, <www.kurzweilai.net/pressroom/presentations>.

12. "Comparative Estimates: Broadband Households in the US, 2004-2010." in *Worldwide Online Access: 2004-2010.* eMarketer.com (1 May 2006).

13. One reason is that while it took four farmers to feed ten people in 1990, today four farmers can feed 388 Americans and 128 people in other nations.

14. U.S. Bureau of Labor Statistics.

15. Bureau of Economic Analysis, U.S. Department of Commerce.

16. Labor productivity averaged 1.46% annual growth between 1973:Q4 and 1995:Q4. (Jorgenson, Stiroh, and Ho 2006). Over the last decade this growth has been 2.91% per year over the 1995:Q4-2005:Q3 period. (Jorgenson, Stiroh, and Ho 2006)

17. By the early 1990s some economists began to speculate that the technology system represented by the personal computer held the potential to reverse to the productivity slump. But most economists were puzzled since there was an amazing new technology and yet productivity still slumped. Nobel Prize-winning economist Robert Solow famously quipped, "we see computers everywhere except in the productivity statistics." (Solow 1987, 36).

18. Consider the IT-based consumer technologies that have become widespread since the mid-1980s: the Internet and World Wide Web; cell phones, portable phones, pagers, wireless e-mail devices, call forwarding, call waiting and voice mail; credit cards with magnetic strips and smart cards with chips on them; personal computers and PDAs; spreadsheet, word processing, and data base programs; satellite dishes, big screen televisions, video cassette recorders, digital video recorders, and compact disc players; video games and "Game Boys;" laser printers and fax machines; camcorders and digital cameras; microwave ovens; global positioning systems; motion sensors; and cheap radio frequency tags for products.

19. In 2001 dollars.

20. In 2001 dollars.

21. U.S. Bureau of Labor Statistics.

22. *e-Business W@tch*, Chart Report 2006, slide 7. <www.ebusiness-watch.org/resources/charttool.htm>.

23. Ibid.

24. For example, in Poland, transport companies that used sophisticated software increased their market share from 45 percent in 200 to 60 percent in 2001. (Qiang and Pitt 2004, 5)

25. Declining growth in labor quality meant that total productivity growth was less than IT's share.

29. Jorgensen, Ho, and Stiroh 2005, 44-5.

27. "Ten Countries with the Highest Growth Rate of ICT Spending, 1993-2001," World Information Technology and Services Alliance (WITSA) 2002, as cited in Qiang and Pitt 2004, 16.

28. Poh-Kam Wong, "ICT Production and Diffusion in Asia—Digital Dividends or Digital Divide?" *WIDER Discussion Paper* 2001/8 (2001) (cited in Qiang and Pitt 2004, 9.)

29. Qiang and Pitt 2004, 8.

30. From 1990 to 2000, telecommuting (defined as working at home most days during the week) increased by 23 percent, which was double the growth of the overall workforce. <www.census.gov/Press-Release/www/releases/archives/census_2000/002966.html>. Telecommuting has continued to gain market share since 2000. According to the American Community Survey, telecommuters went from 3.21 percent of the workforce in 2000 to 3.60 percent in 2005. <factfinder.census.gov/servlet/ADPTable?_bm=y&-geo_id=01000US&-qr_name=ACS_2005_EST_G00_DP3&-ds_name=ACS_2005_EST_G00_&-_lang=en&-_sse=on>.

31. There is also significant potential in the $2.1 trillion construction industry. Daily collaborations among contractors, engineers, architects, and suppliers are based on large amounts of paperwork. Companies such as Bidcom, Bricsnet.com and Cephren have collaboration tools that track project specs, enabling reduced cost and fewer errors.

32. In New York state, during a 3-month pilot test program, driver registrations over the Internet increased by over 10% in response to the Imagitas Enhanced Mailing Program. (Imagitas, 2006)

33. However, even Cisco was not immune to the dot-bomb collapse in 2000 and even with its electronic ordering systems it still had to write off over $2 billion in inventory (Berinato 2001).

34. Of the $17 it now costs to purchase a music CD, more than $9.50 is accounted for by distribution, shipping, and store markup, with additional share by the manufacture of the CD itself. Songs can be downloaded online as digital files for almost no production costs.

35. "Estimated Quarterly U.S. Retail E-commerce Sales as a Percent of Total Quarterly Retail Sales," *U.S. Census E-Stats* (17 Nov. 2006). < www.census.gov/mrts/www/data/html/06Q3.html >.

36. "2004 E-commerce Multi-sector Report," *U.S. Census E-Stats* (25 May 2006). <www.census.gov/eos/www/papers/2004/2004reportfinal.pdf>.

37. About 15 percent of users who have been online three months have made a purchase, compared to 60 percent who have been online more than three years <www. gartnerg2.com>.

38. Getloaded.com - The Internet Load Board for the Trucking Industry (2006) <www.getloaded.com>.

39. The site claims 96,562 members in the 202 countries and 14,384 cities. <www.couchsurfing.com/statistics.html>.

40. A three-minute telephone call between London and New York City cost $70 in today's dollars in 1964, but less than 50 cents today and close to zero as we move to Internet telephony. Between 1987 and 1997 the cost of a U.S. to London call declined by 90 percent (Burnham 1997).

41. The cost of a T-1 dedicated phone line between the United States and Manila has dropped from $30,000 a month to less than $10,000 in the past few years. Moreover, technology advances have allowed the number of voice channels that can be put on a T-1 line to increase about five fold ("In a Global Economy…" 2002). <knowledge.wharton.upenn.edu/article.cfm?articleid=642 >.

42. See forthcoming ITIF report on such mercantilist practices directed at the IT industry.

43.Quoted in David Broncaccio, "Marketplace: News Archives," Marketplace (14 Dec. 1995). <marketplace.publicradio.org/shows/1995/12/14_mpp.html>

44. "History of gTLD domain name growth." Zooknic Internet Intelligence. <www.zooknic.com/Domains/counts.html>.

45. PubMed, U.S. National Library of Medicine. <www.pubmed.gov>.

46. For example, economists David Berri and Martin Schmidt and Stacey Brook (2004) set out to use statistics to measure the impact of basketball players on their team. They found out that the most valuable players in terms of helping their teams win were not always the players coaches and fans would think. For example, the found that when Allen Iverson was voted the MVP, he was actually the 91st best player in the league.

47. "There were 19 business cycles in the twentieth century, or one every five years. According to Michael Cox at the Dallas Federal Reserve Bank, over the 100 years from 1853 to 1953 the economy was in recession 40 percent of the time." (Atkinson 2004, 259)

48. K. Storesletten, et al. found similarly significant increases in welfare when business cycles were eliminated (Storesletten, Telmer, and Yaron 2001).

49. "Table 1.1.1. Gross domestic product percent change from preceding period." U.S. Bureau of Economic Analysis (27 Oct. 2006).

50. IT could certainly play a role in better monetary policy. IT is increasingly enabling the creation of a more real-time economic statistics system. For example, companies like Monster.com are able to track on a daily basis job openings, a key factor in predicting future economic activity. Better and more timely information would let federal economic policymakers to make better decisions.

51. U.S. Bureau of Labor Statistics.

52. U.S. Bureau of Labor Statistics.

53. Not only does the Internet make it possible for people to volunteer online, it makes it easier for people to find offline volunteer opportunities. Sites such as volunteermatch.org match volunteers with service organizations needing their talents. In 2005 it made 475,000 referrals to 37,000 registered nonprofits. Matching sites are well suited to the Internet, since search costs are radically reduced and the community is global.

54. In 2003 the London Congestion Charging Scheme (LCCS) was put in place to reduce congestion in Central London. The LCCS is enforced using Automatic Plate Recognition software that records all plates that pass through the 174 entry and exit points surrounding the zone and then compares those plates to vehicle registration numbers, identifying who had passed the boundary during the day without paying the charge. Almost completely automated except for a final manual check of offending registrations, the LCCS would be impossible without IT. Stockholm has created a similar system. (Fraser and Santos 2006, 271).

55. For example, California's State Highway 91 Express Lanes in Orange County, which constitutes one-third of the physical lane capacity (2 out of six each direction), actually handle 49 percent of vehicle throughput during peak-period, peak-direction conditions when the regular lanes are congested (Personal communication with Robert Poole, Reason Foundation, June, 2006).

56. Pefa.com (2006). <www.pefa.com/pefaportal/en/index.htm>.

57. Chemconnect, Inc. (2006). <www.chemconnect.com/commodity.html>.

58.The Emergency Department at Exeter Hospital uses IT to improve diagnostics by allowing doctors to monitor multiple patients at once (Dolge 2006).

59. City of Baltimore. CitiStat (2006). <www.baltimorecity.gov/news/citistat/index.html>.

60. *e-Business W@tch*, Chart Report 2006, slide 7. <www.ebusiness-watch.org/resources/charttool.htm>.

61. For example, see Pacific Business Group on Health, "Advancing Physician Performance Measurement," Lumetra (Sep. 2005). <www.pbgh.org/programs/documents/PBGHP3Report_09-01-05final.pdf#search=%22online%20benchmarking%20consumer%20quality%22>.

62. Some even speculate that digital manufacturing will soon make it possible for consumers to download three-dimensional fabrication electronic files and make their own clothes by employing electro-mechanical devices <www.ennex.com /publish /200002-MB-MassCustom.asp>.

63. *e-Business W@tch*, Chart Report 2006, slide 8. <www.ebusiness-watch.org/resources/charttool.htm>.

64. "The Kiteboard Cookbook." Zero Prestige Mega-Corporation. <www.mit.edu/people/robot/zp/zeroprestige.html>.

65. Kamps, Bernd Sebastian and Christian Hoffmann, eds., "Timeline," *SARSReference.* <www.sarsreference.com/sarsref/timeline.htm>.