The Promise of Growth in the Information Age

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The resurgence of the U.S. economy from 1995 to 2000 outran all but the most optimistic expectations. It is not surprising that the unusual combination of rapid growth and low inflation touched off a strenuous debate about the productivity of technology investment and whether improvements in U.S. economic performance could be sustained. This debate has intensified with the onset of recession, the collapse in technology company stock prices and, more recently, with last summer's meltdown in the U.S. stock market. So, the question: *Can* the rapid productivity acceleration of the 1990s be maintained? The answer is a resounding "It depends."

The technological underpinnings of the last decade's remarkable economic performance should not be confused with the rapid pace of investment. The investment boom was not sustainable, since it depended on substantially *more* growth in the number of hours people worked than in the labor force itself. Had the breakneck pace of investment continued, the economy would eventually have exhausted the pool of available labor. This is precisely what motivated the Federal Reserve to sharply increase interest rates beginning in May 1999, ending the boom and bringing on the mild recession that began in March 2001.

The investment boom and the productivity resurgence were driven by a remarkable decline in information technology (IT) prices. The decline in IT prices followed a dramatic acceleration in the semiconductor product cycle. The pace of innovations that dramatically reduced the size of semiconductor devices opened up opportunities for technological advances in computers, communications, biosciences, and other IT-using industries. While advances in semiconductor technology have found their broadest applications in computing and communications equipment, they have also reduced the cost and improved the performance of automobiles, aircraft, scientific instruments, and a host of other products. This process is likely to continue and even intensify.

Faster, Better, Cheaper

A mantra of the "new economy"–*faster, better, cheaper*–captures the speed of technological change and product improvement in semiconductors. In 1965, Gordon E. Moore, then Research Director at Fairchild Semiconductor, made a prescient observation, later known as "Moore's Law." He observed that each new chip contained roughly twice as many transistors as the previous chip, and was released within 18–24 months of its predecessor. This implied exponential growth of capacity, at 35–45 percent per year!

The rapidly rising capacities of microprocessors illustrate the exponential growth predicted by Moore's Law. The first logic chip, introduced in 1971, had 2,300 transistors; the Pentium 4, released by Intel in November 2000, had 42 million! Over this 29-year period, the number of transistors increased by 34 percent per year, tracking Moore's Law with astonishing accuracy.

Moore's Law also captures the fact that each successive generation of semiconductors is *faster* and *better*. This relentless improvement, continuing for three decades, makes the role of information technology in the U.S. economy unique. The revolution in computing capability means that memory and logic chips have become cheaper at a truly staggering rate (see chart on page 3). The challenge for economics is to capture both the continuous improvement *and* the rapid pace of advance of semiconductor technology, both in price measurements and in understanding the sources of economic growth.

Prices of memory chips *declined* by a factor of 27,270–41 percent per year–between 1974 and 1996. Similarly, prices of logic chips available for the shorter period of 1985–96 *declined* by a factor of 1,938–54 percent per year. In 1994 and 1995 alone, the microprocessor price decline leapt to more than

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90 percent per year as the semiconductor industry shifted from a three-year product cycle to a greatly accelerated two-year cycle. These extraordinary advances in computing power translate into tremendous potential cost reductions for downstream users. These reductions have only just begun to be realized.

Indeed, communications technology—one of the most important drivers of the technological revolution—has been undervalued because appropriate price measures have not been developed to capture the enormous gains in capability and, by implication, productivity. This technology is a crucial ingredient in the development and diffusion of the Internet, and perhaps the most striking manifestation of information technology in the U.S. economy.

Communications equipment is an important market for semiconductors, but constant performance price indexes have been developed only for switching and terminal equipment. Much communications investment, however, takes the form of the transmission gear connecting data, voice, and video terminals to switching equipment, fiber optics, microwave broadcasting, and communications satellites. Innovations in this equipment have progressed at rates that outrun even the dramatic pace of semiconductor development.

One such innovation is dense wavelength division multiplexing (DWDM), a technology that simultaneously sends multiple signals over an optical fiber. The installation of DWDM equipment, which began in 1997, has doubled the transmission capacity of fiber optic cables every 6–12 months. Yet we have no adequate price measures for capturing the value of this innovation to the economy. In other words, we are significantly underestimating the investment boom and the productivity gains from communications investment because our price measures are faulty. Indeed, had there been better measures of the true impact of these investments, the extent of overcapacity might have been recognized at a much, much earlier stage and the recent implosion in the communications sector avoided.

Software is also an increasingly important enabler in the technology space. Here again, appropriate price measures–and accurate measures of the capacity generated by these investments–are lacking. These huge gaps in our ability to measure technological change challenge our ability to understand its impact on economic growth.

Economists identify the contributions of outputs and inputs to U.S. economic growth by means of *growth accounting*. In a system of growth accounts for the U.S. economy, the *contribution of each output* is its growth rate, weighted by its share in the value of the GDP. Likewise, the *contribution of each input* is its weighted growth rate. When we lack adequate price measures, we fail to accurately measure the growth rates of both outputs and inputs.

The final component of a system of growth accounts is growth in *total factor productivity* (TFP), defined as output per unit of input, including both capital and labor inputs. Economies increase the productivity of both labor and capital by pushing out the technological frontier. Massive increases in computing power like those experienced by the U.S. economy have the potential to extend this technological frontier and drive growth in two ways.

First, as IT *producers* become more efficient, more IT equipment and software is produced from the same inputs. This raises productivity in IT-producing industries and contributes to TFP growth for the economy as a whole. Labor productivity also grows at both industry and aggregate levels.

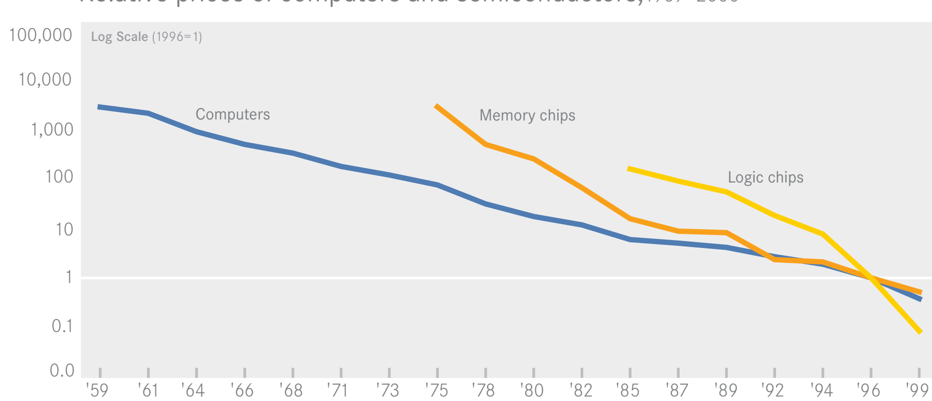
Second, investment in information technology leads to growth of productive capacity in IT-*using* industries. Labor is working with more and better equipment, and this increases labor productivity through capital deepening. If the contributions to aggregate output are entirely captured by capital deepening, aggregate TFP growth is unaffected, since output per unit of input remains unchanged. But major technological advances can increase productivity even when capital deepening is taken into account.

Unlocking the Future With the Past

To understand the distinctive features of economic growth since 1995, we need to examine the sources of the growth of the U.S. economy for the past half-century and see how our recent experience compares. Input growth, not surprisingly, is the source of almost 82.5 percent of the 3.5 percent per year GDP growth over the last 50 years. The ability to combine labor and capital in innovative ways–TFP–accounted for only 17.5 percent of the growth during that period. In other words, the economy grew largely because we put more people to work, they worked longer hours, they were better educated, and, most significantly, they worked with more and better capital. How labor and capital are combined to achieve new ways of doing business accounts for a much smaller share of long-term growth.

Relative to the early 1990s, output growth increased by 1.7 percent in 1995–2000. The contribution of IT production almost doubled, but still accounted for only 27 percent of the increased growth of output. Almost three-quarters of that increase can be attributed to non-IT products. Both labor and capital made significant contributions to the growth surge of the late 1990s. The growth rate of labor input accelerated to 2.2 percent for 1995–2000 from 1.9 percent for 1990–95. This is

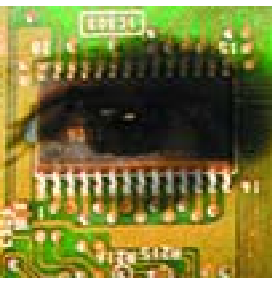
Relative prices of computers and semiconductors, 1959–2000



primarily due to the growth of hours worked, which rose from 1.2 percent for 1990–95 to 2 percent for 1995–2000, as labor force participation increased and unemployment rates plummeted.

The growth of labor quality, defined as labor input per hour worked, declined considerably in the late 1990s, dropping from 0.7 percent for 1990–95 to 0.3 percent for 1995–2000. With exceptionally low unemployment rates, employers were forced to add workers with limited skills and experience. But using the U.S. labor force more intensively was far from the whole story.

Between 1990–95 and 1995–2000, the contribution of capital input jumped by a full percentage point, and TFP accelerated by 0.5 percent. The contribution of capital input reflects the investment boom of the late 1990s. Businesses, households, and governments poured resources into plant and equipment–especially computers, software, and communications equipment. The jump in the contribution of capital input since 1995 raised growth by nearly a full percentage point, and IT accounts for more than half this increase.



The acceleration in U.S. economic growth after 1995 and the enormous contribution of capital is unmistakable. Its relationship to information technology is now transparent. The most important contribution of IT is through faster growth of capital input, reflecting higher rates of investment. This growth in capital is due not just to the *quantity* of capital stock but its increasing *quality*, defined as capital input per unit of capital stock. Improved capital quality reflected the very rapid restructuring of capital to take advantage of the sharply accelerating decline in IT prices.

Finally, the increased ability to combine labor and capital in productive ways was a major boost to growth at the end of the 1990s. Investment and labor utilization was higher, but it was also more productive–largely because of the technology revolution. Even though TFP growth for 1995–2000 is lower than during the "golden age" of 1948–73, the U.S. economy is definitely recuperating from the anemic productivity growth of the previous two decades. The question is whether this improvement is sustainable.

These huge gaps in our ability to measure technological change challenge our ability to understand its impact on economic growth. Indeed, improved IT price data are essential for understanding the links between semiconductor technology and the growth of the U.S. economy.

Doubts about both technological momentum and growth in employment mean that the U.S. is unlikely to find its way back to the resurgent economic growth of 1995–2000 anytime soon. Given the current IT information gap, this creates both a challenge and an opportunity for economic policy makers.

What Happens Next?

Falling IT prices will continue to provide incentives for substituting IT for other productive inputs. The decline in IT prices will also serve as an indicator of ongoing productivity growth in IT-producing industries. But it would be premature to extrapolate the recent acceleration in productivity growth into the indefinite future, since this depends on the persistence of a two-year product cycle for semiconductors.

The economic forces that underlie the two-year cycle reflect intensifying competition among semiconductor producers in the United States and around the world. If this rapid rate of technological progress is to persist over the next decade, new technologies must be exploited. This is already generating a massive research and development effort that will strain the financial capacities of the semiconductor industry and its equipment suppliers.

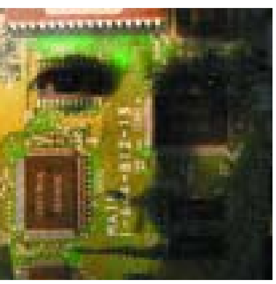
The 2001 edition of the *International Technology Roadmap for Semiconductors* projects a two-year product cycle through 2005 and a three-year product cycle thereafter. This seems to be a reasonable basis for projecting the growth of the U.S. economy–a continued two-year cycle provides an upper bound for growth projections, while reversion to a three-year cycle gives a lower bound.

The key assumption for intermediate-term projections of a decade or so into the future is that output and capital stock grow at the same rate. So the growth of output is the sum of the growth rates of hours worked and labor quality, plus the contributions of capital quality growth and TFP growth. A projection of U.S. economic growth depends on the outlook for each of these four components.

Future growth in hours worked will inevitably track the growth of the labor force of around 1.1 percent per year. Growth of labor quality during 1995–2000 dropped to about a quarter percent per year and will revive, modestly, to 0.3 percent per year, reflecting ongoing improvements in the productivity of individual workers. Thus, the overall growth rate of labor input over the next decade will average 1.4 percent per year. By contrast the growth rate of labor input from 1995–2000 was 2.2 percent.

The second part of a growth projection requires assumptions about the growth of TFP and capital quality. So long as the two-year product cycle for semiconductors continues, the growth of TFP is likely to average 0.7 percent per year, the rate during 1995–2000. With a three-year cycle, the growth of TFP might drop as low as 0.2 percent per year, the rate during 1990–95, reflecting the slower pace of technological change.

The rapid substitution of IT assets for non-IT assets in response to declining IT prices is reflected in the contribution of capital quality. The growth of capital quality will continue at the recent rate of 2.3 percent per year, so long as the two-year product cycle for semiconductors persists. But growth of capital quality will drop to 1 percent per year under the assumption of a three-year cycle, generating considerable uncertainty about future growth.



Assuming continuation of a two-year product cycle for semiconductors through 2005 and a three-year cycle after that, the intermediate-term growth rate of the U.S. economy will be 3.4 percent per year. The upper bound on this growth rate, associated with a continued two-year cycle, is 3.8 percent per year; the lower bound, associated with a three-year cycle, is 2.4 percent per year.

In other words, a resumption of the growth rate of 4.1 percent during the resurgence of 1995–2000 is extremely unlikely. This would require not only a continued rapid pace of technological advance, but also growth in employment that would soon exhaust the available labor force.

The benefits of technology are real and tangible, and the performance of the IT industries is crucial to future growth prospects. While recognizing the enormous benefits of the future development and diffusion of IT, we must give close attention to the uncertainties that surround this development. Highest priority must be given to a better understanding of markets for semiconductors and, especially, to the determinants of the product cycle. Improved data on the prices of telecommunications and software are essential for understanding the links between semiconductor technology and the growth of the U.S economy.

The semiconductor and IT industries are global in their scope, with an elaborate international division of labor. This poses important questions about the U.S. growth resurgence. We lack evidence on IT's impact on other leading industrialized countries, and we do not fully understand the future roles of important IT participants such as Korea, Malaysia, Singapore, and Taiwan–all "newly industrializing" economies. Moreover, what will be IT's economic impact on developing countries like China and India?

Information technology is altering product markets and business organizations, as attested to by the huge and rapidly growing business literature, but a fully satisfactory model of the semiconductor industry has yet to be developed. Such a model would have to derive the demand for semiconductors from investment in IT, and determine the product cycle for successive generations of new semiconductors.

As policy makers attempt to fill the widening gaps between the information required for sound policy and the available data, the traditional division of labor between statistical agencies and policymaking bodies is breaking down. The Federal Reserve has recently undertaken a major research program on constant performance IT price indexes. In the meantime, monetary policy makers must set policies without accurate measures of price change. Likewise, fiscal policy makers confront ongoing revisions of growth projections that drastically affect the outlook for future tax revenues and government spending.

The unanticipated U.S. growth revival of the 1990s has considerable potential for altering economic perspectives. In fact, a steady stream of excellent books on the economics of information technology already foreshadows this. Economists are the fortunate beneficiaries of a new agenda for research that could refresh their thinking and revitalize their discipline. Their insights will be essential to reshaping economic policy so that everyone can take advantage of the opportunities that lie ahead.

A detailed version of this essay–including data analysis, charts, and sources–is available at www.conference-board.org/annualessays.htm