# MOORE'S LAW AND THE EMERGENCE OF THE NEW ECONOMY

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The resurgence of the American economy since 1995 has now survived the dot-com crash, the short recession of 2001, and the tragedy of 9/11[1]. The unusual combination of more rapid growth and slower inflation has touched off a strenuous debate about whether improvements in America's economic performance can be sustained. A consensus has emerged that the development and deployment of information technology (IT) is the foundation of the American growth resurgence[2]. The mantra of the "new economy"—faster, better, cheaper—characterizes the speed of technological change and product improvement in semiconductors, the key enabling technology.

## THE ECONOMICS OF INFORMATION TECHNOLOGY BEGINS WITH THE PRECIPITOUS AND CONTINUING FALL IN SEMICONDUCTOR PRICES.

In 1965 Gordon Moore, then research director at Fairchild Semiconductor, made a prescient observation, later known as Moore's Law[3]. Plotting data on integrated circuits, he observed that each new device contained roughly twice as many transistors as the previous one and was released within 12–24 months of its predecessor. This implied exponential growth of chip capacity at 25–50 percent per year! Moore's Law, formulated in the infancy of the semiconductor industry, has tracked chip capacity for 40 years. Moore recently extrapolated this trend for at least another decade[4].

The economics of information technology begins with the precipitous and continuing fall in semiconductor prices. Moore emphasized this price decline in his original formulation of Moore's Law and dramatically plunging prices are used almost interchangeably with faster and better devices in describing the evolution of semiconductor technology. The rapid price decline has been transmitted to the prices of a range of products that rely heavily on this technology, like computers and telecommunications equipment. The technology has also helped to reduce the costs of aircraft, automobiles, scientific instruments, and a host of other products.

Swiftly falling IT prices provide powerful economic incentives for the rapid diffusion of information technology. A substantial acceleration in the IT price decline occurred in 1995, triggered by a much sharper acceleration in the price decline for semiconductors. This can be traced to a shift in the product cycle from three years to two years as a consequence of intensifying competition in semiconductor markets. Continuation of this shorter product cycle for the next decade is consistent with the technological developments projected in the most recent International Technology Roadmap for Semiconductors[5].

The accelerated IT price decline since 1995 signals faster productivity growth in IT-producing industries—semiconductors, computers, communications equipment, and software. These industries have accounted for a substantial share of the surge in U.S. economic growth. It is important, however, to emphasize that accelerating growth is not limited to these industries. To analyze the impact of the accelerated price decline in greater detail, it is useful to divide the remaining industries between IT-using industries, those particularly intensive in the utilization of IT equipment and software, and non-IT industries.

Although three-quarters of U.S. industries have contributed to the acceleration in economic growth, the four IT-producing industries are responsible for a quarter of the growth resurgence, but only 3 percent of the GDP. IT-using industries account for another quarter of the growth resurgence and about the same proportion of the GDP, while non-IT industries with 70 percent of value-added are responsible for only half the resurgence. Obviously, the impact of the IT-producing industries is far out of proportion to their relatively small size.

In view of the critical importance of productivity, it is essential to define this concept more precisely. Productivity is defined as output per unit of input, where input includes capital and labor inputs as well as purchased inputs[6]. This definition has the crucial advantage of clearly identifying the role of purchased goods and services, such as semiconductors used by other IT-producing industries. The purchased goods and services are the components of the industry's inputs that are "outsourced" in order to make the most of the advantages of specialization.

Industry inputs consist of capital, labor, and purchased inputs. It is remarkable that four IT-producing sectors taken together have the most rapid growth of all three. The surging growth of the four IT-producing industries has its sources in both inputs and productivity; however, the relative importance of these sources differs considerably. All the IT-producing industries have large contributions of purchased goods and services, including inputs from other IT-producing sectors. The software industry has the most rapidly growing labor input, but almost no productivity growth.

Two industries responsible for much of IT hardware—computers and semiconductors—exhibit truly extraordinary rates of productivity growth, as well as a substantial acceleration in the growth of productivity after 1995. As a group, the four IT-producing industries contribute more to economy-wide productivity growth than all the other industries combined. In fact, the contributions of the IT-using and non-IT industries

# 25%

**SINCE 1995, INFORMATION TECHNOLOGY INDUSTRIES HAVE ACCOUNTED FOR 25% OF OVERALL ECONOMIC GROWTH, WHILE MAKING UP ONLY 3% OF THE GDP.** AS A GROUP, THESE INDUSTRIES CONTRIBUTE MORE TO ECONOMY-WIDE PRODUCTIVITY GROWTH THAN ALL OTHER INDUSTRIES COMBINED.

to the economy's productivity growth have been slightly negative, partly offsetting the positive contribution of the IT-producing industries.

However, investment rather than productivity has been the predominant source of U.S. economic growth throughout the postwar period. The rising contribution of investment since 1995 has been the key contributor to the U.S. growth resurgence and has boosted growth by close to a full percentage point. The contribution of IT investment accounts for more than half of this increase. Investment in computers has been the predominant impetus to faster growth, but communications equipment and software investments have also made important contributions.

Accelerated capital growth reflects the surge of investment in IT equipment and software after 1995 in the large IT-using sectors like finance and trade. However, virtually all industries have responded to more rapid declines in IT prices by substituting IT for non-IT capital. Capital from IT products has grown at double-digit rates during most of the last three decades. By contrast non-IT capital has grown at about the same rate as the economy as a whole, an order of magnitude more slowly. Half of U.S. industries actually show a declining contribution of non-IT capital.

While the IT-producing industries demonstrate accelerating growth in every dimension, the impact is limited by their relatively small size. IT-using sectors are especially prominent in the accelerated deployment of IT equipment and software, while the non-IT industries contribute impressively to faster productivity growth. After 1995, IT-producing industries show sharply accelerating growth in productivity, while IT-using industries diverge from this trend by exhibiting a more rapid decline. Productivity growth in non-IT industries has jumped very substantially, accounting for much of the acceleration in economy-wide productivity.

The very modest acceleration in employment growth after 1995 has been concentrated in IT-using industries. Since the number of workers available for employment is determined largely by demographic trends, the acceleration in IT investment is reflected in rates of labor compensation and changes in the industry distribution of employment. The rapidly growing IT-using industries have absorbed large numbers of college-educated workers, while non-IT industries have shed substantial numbers of non-college workers.

The surge of IT investment in the United States after 1995 has counterparts in all other industrialized economies. Using "internationally harmonized" IT prices that rely primarily on U.S. trends, the burst of IT investment in all industrialized economies that accompanied the acceleration in the IT price decline in 1995 is revealed unmistakably. These economies have also experienced a rise in productivity growth in the IT-producing industries. However, differences in the relative importance of these industries have generated wide disparities in the impact of IT on economic growth. Among the G7 countries—Canada, France, Germany, Italy, Japan, the U.K., and the U.S.—the role of the IT-producing industries is greatest in the U.S.

To conclude: The mechanism underlying the resurgence of U.S. economic growth has now come into clear focus[7]. The surge was generated by the accelerating decline of IT prices, propelled by a shift in the semiconductor product cycle from three years to two in 1995. The price decline set off an investment boom that achieved its peak during the last half of the 1990s and has now recovered much of the momentum lost during the 2001 recession. Achievement of the ambitious goals of the International Technology Roadmap for Semiconductors (2004) will greatly help to assure that America's improved economic performance can be sustained.

1 Jorgenson, Ho, and Stiroh (2004) http://www.newyorkfed.org/research/current_issues/ci10-13.html present projections of U.S. economic growth.

2 The role of information technology in the American growth resurgence is discussed in detail by Jorgenson, Ho, and Stiroh (2005).

3 Moore (1965) ftp://download.intel.com/research/silicon/moorespaper.pdf.

4 Moore (2003) ftp://download.intel.com/research/silicon/Gordon_Moore_ISSCC_021003.pdf.

5 On International Technology Roadmap for Semiconductors (2004), see: http://public.itrs.net/.

6 In economic jargon this definition is often referred to as "total factor productivity." This must be carefully distinguished from the more common "labor productivity," output per hour worked.

To avoid confusion I will use the term "productivity" only in the sense of total factor productivity or output per unit of all inputs.

7 More detail on this mechanism is provided by Jorgenson (2001).

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