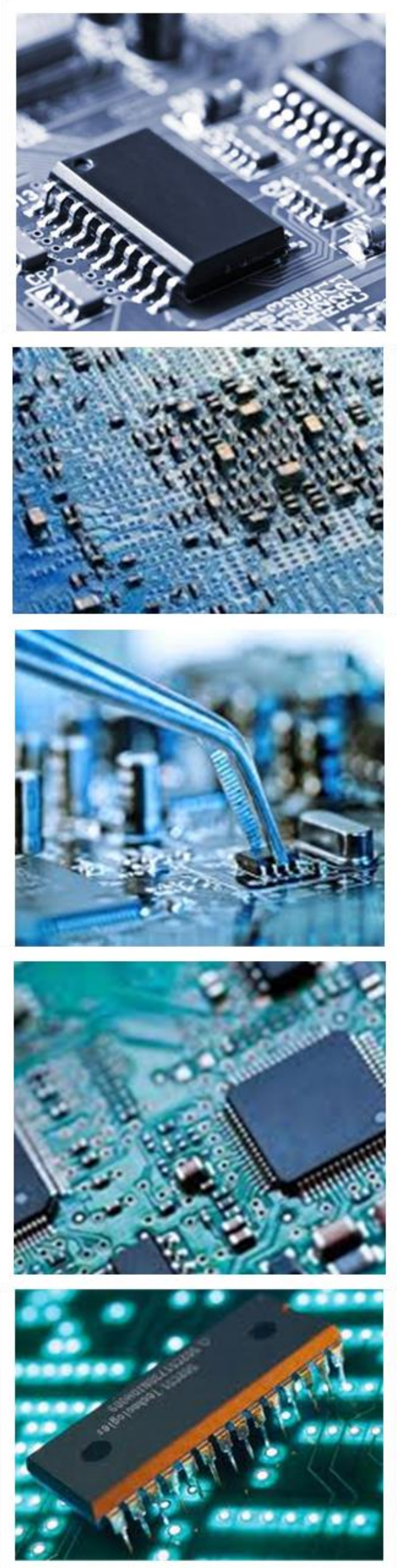


The U.S. Semiconductor Industry: Growing Our Economy through Innovation

Matti Parpala[1] | August 2014

A key to U.S. economic growth is innovation, which enables us to increase our economic output without added inputs. The U.S. semiconductor industry has been a major innovator among all U.S. industries: from 1960-2007, it accounted for 30.3 percent of all economic growth due to innovation in the United States.[2] Thanks to rapid innovation, the U.S. semiconductor industry's impact on U.S. GDP growth is outsized – the industry contribution to real economic growth was more than seven times its share of U.S. nominal GDP.[3]

Key Takeaways

1) Innovation (or total factor productivity) is crucial for U.S. economic growth: from 1948-2010, 23 percent of total economic growth was generated by innovation. Between 2000-2005, this share was as high as 44 percent.[4]

2) Researchers estimate the importance of innovation to economic growth will continue: roughly a quarter of U.S. productivity growth will be generated by innovation during 2010-2020.[5]

3) In the U.S. semiconductor industry, new innovation leads to increased microchip performance along with decreased prices. Because of this unique phenomenon, semiconductor innovation has made it possible for other industries to invest in developing technologies, thereby helping them to grow their own productivity. In fact, IT-using and IT-producing industries are estimated to generate nearly *all* economic productivity growth in the U.S. economy from 2010-2020.

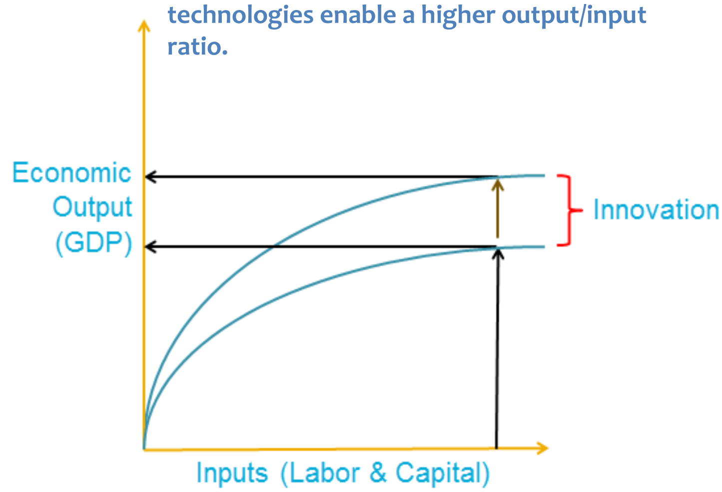
What Is Innovation?

According to economic theory, two factors define labor output in our economy: how much we work, i.e. labor hours, and much output we produce per worker, i.e. labor productivity. The amount of labor hours changes mostly as the working population changes, for example from 1990 to 2010 labor hours contributed 0.5 percentage points to annual economic growth.[6] Labor productivity, however, has a much bigger impact on economic growth; recent research suggests that as much as 70 percent of increase in U.S. economic output from 2010 to 2020 will be generated by labor productivity growth.[7]

The growth of labor productivity is generated by three components: increases in labor quality, capital deepening, and increases in total factor productivity – or new innovation. The first, labor quality, relates to education level: the more and better educated the labor force, the more output can be created per hour of work. This is relatively straightforward to understand: e.g. more education is likely to increase a worker's skill level. The second component, capital deepening, is also easily understood: the more and better machines per worker, the more productive workers can be, at least to a certain extent – a worker with a computer is most likely more productive than a worker without, but a worker with two computers is not necessarily doubly productive.

The third component, innovation, is harder to measure and less intuitive than the first two components. In fact, the effect of innovation is often measured as a residual after accounting for other changes in productivity. The increase of output growth that cannot be associated with other measurable changes is interpreted as innovation. This is illustrated by Figure 1.[8] Economists call this contribution of innovation total factor productivity, or TFP.[9]

Figure 1: The Innovation Effect: New technologies enable a higher output/input ratio.



Source: Author's drawing.

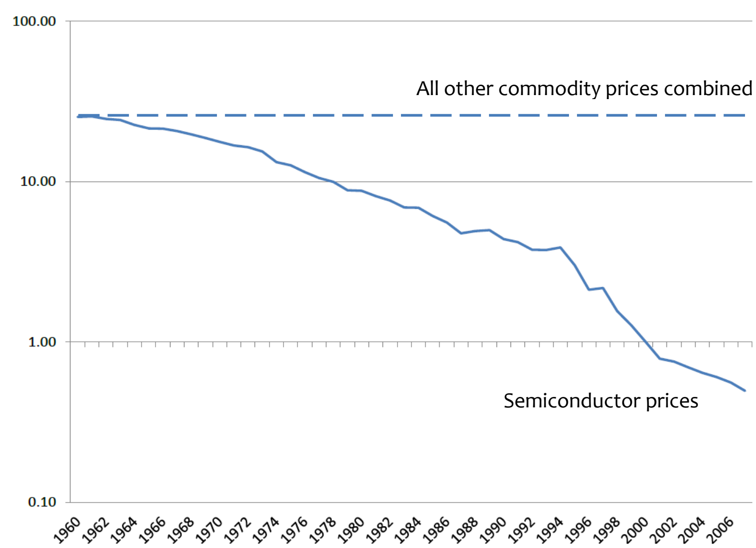
Innovation can refer to new technologies, or simply general knowledge that enables us to do things in a more clever and efficient way. It is important to notice the difference between education and innovation: whereas education accumulates in one person (for example, everyone has to earn a high school degree of their own), innovation, once discovered, eventually becomes available to all of society. Examples of transformative innovations and discoveries include fire, the combustion engine, and computers.

Semiconductor Innovation Changes the World

The semiconductor industry is a perfect example of innovation: output, or performance delivered by a semiconductor chip, has improved at outstanding rates compared to the inputs required to produce that chip. Improvements in semiconductor technology at ever lower cost have been foundational in making information technology ubiquitous today. And its impact has not only been seen on everyday consumer electronics; many businesses and industries have been transformed by IT. Just think how a modern automobile factory runs: robots and computers do a big part of the work. Numerous service-providing industries depend on information technology, as well, such as commercial aviation, retail, and banking. Semiconductor innovation continues to change the world with high-tech products, such as LEDs, renewable energy, and driverless cars relying on ever-progressing semiconductor innovation.

This technological progress is clear when looking at constant-quality prices – that is, by seeing how the performance of a semiconductor has improved per a dollar paid. Figure 2 shows this continuous change in semiconductors' constant-quality prices over time.[10] When the pace of technology was at its fastest in the 1990s, prices decreased by more than half every year. Had the automobile industry followed a similar trend, today everyone could buy a supercar for the price of a television.[11]

Figure 2: Semiconductor Prices Decline Exponentially Compared to Other Prices. Note: Graph in Logarithmic Scale.



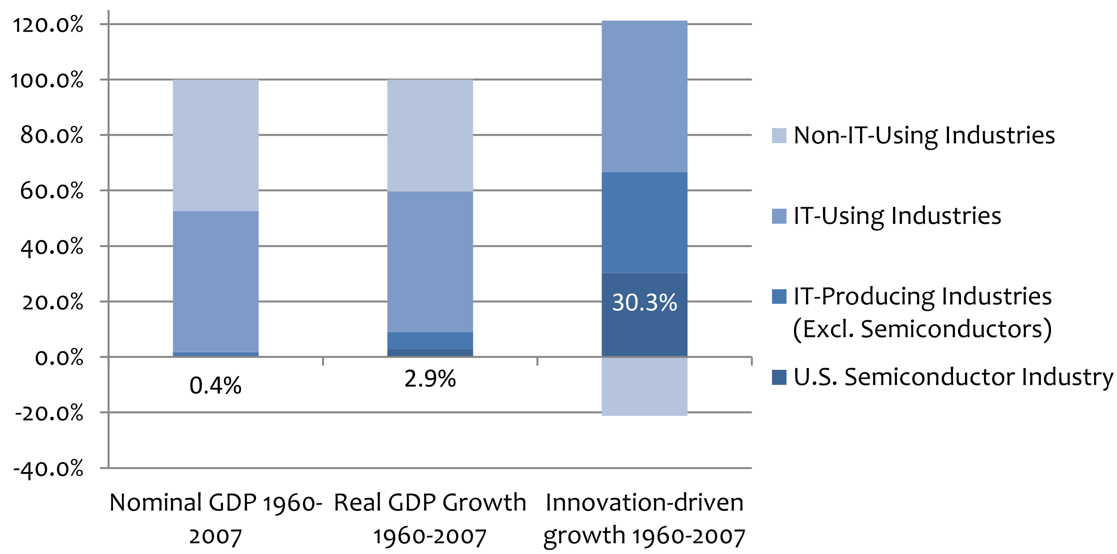
Source: Jorgenson, Ho, and Samuels (2011), page 165, figure 1.

The U.S. Semiconductor Industry Has an Outsized Effect on U.S. GDP

Semiconductor technology started conquering the world soon after the Second World War. Jorgenson, Ho & Samuels (2011) have done extensive research into information technology's impact on U.S. economic growth from 1960 to 2007.[12] During that period, the U.S. semiconductor industry accounted for as much as 30.3 percent of total economic growth due to innovation (Figure 3). The U.S. semiconductor industry was third to wholesale and retail trade industries, which only had bigger innovation effects because of their massive size relative to the U.S. semiconductor industry.[13]

Jorgenson et al. (2011) also calculated the total contribution of different industries to aggregate value added (GDP) growth from 1960-2007, and the U.S. semiconductor industry's share proved to be outsized. The industry accounted for as much as 2.9 percent of the total real GDP growth (i.e. after adjusting for price changes) – seven times more than the industry's share of nominal GDP from 1960 to 2007. Figure 3 illustrates how outsized the U.S. semiconductor industry's contribution to U.S. economic growth and innovation is compared to its share of GDP and to all other U.S. industries, categorized by IT-producing, IT-using, and non-IT-using industry groups.[14]

Figure 3: Outsized Economic Impact of U.S. Semiconductor Industry: Industry's Contribution to Growth Much Higher than Share of U.S. GDP.



Source: Jorgenson, Ho, and Samuels (2011), pages 166-167, 170 (tables 3, 4, 6)

Dividing U.S. industries into IT-using, IT-producing, and non-IT-using industry groups provides a striking illustration of the major indirect effect the U.S. semiconductor industry has on the U.S. economy. As Figure 3 shows, IT-producing or IT-using industries – which are all deeply reliant on semiconductor technology – had a 52.7 percent share of nominal GDP (left bar) and accounted for a 59.7 percent share of real GDP growth (middle bar). Importantly, all growth due to innovation occurred due to IT-using and IT-producing industries (right bar).[15]

Even as a direct contributor to real U.S. GDP growth, the U.S. semiconductor industry beats many other major traditional U.S. industries. Table 1 shows the U.S. semiconductor industry's contribution (0.10 percent units of total GDP) in comparison with other selected industries.[16]

Table 1: The U.S. Semiconductor Industry's Contribution to Real GDP Growth Compared to Other Major U.S. Industries 1960-2007.

Industry	Contribution to real GDP Growth (%-units)
Semiconductor Manufacturing	0.103
Farms	0.036 – semiconductor industry's contribution is 2.9x higher
Mining except oil and gas	0.008 – … 12.9x higher
Motor vehicles bodies, trailers, parts	0.038 – … 2.7x higher
Textile mills, textile product mills	0.017 – … 6.1x higher

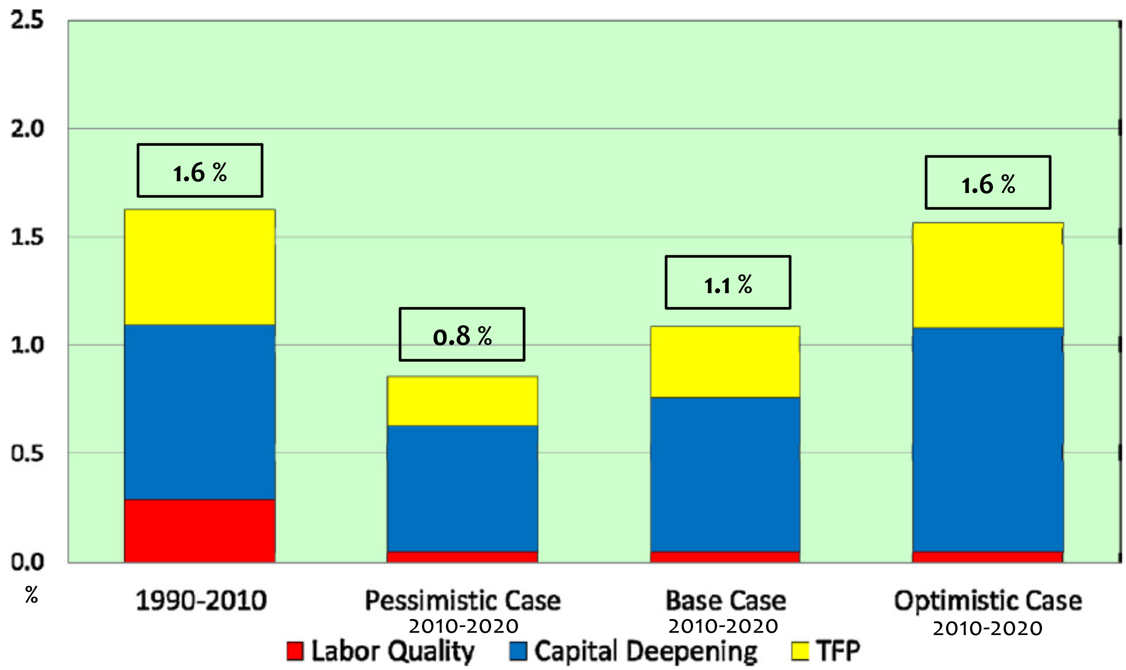
Source: Jorgenson, Ho, and Samuels (2011), page 170, table 6.

Innovation and IT Continue to Play a Major Role in U.S. Economic Growth

Between 1947-2010, average annual U.S. economic growth was approximately 3.0 percent. Innovation played a major role in this growth, generating nearly a quarter of it, or 23 percent. Amazingly, from 2000-2005, innovation accounted for nearly a half of total economic growth.[17]

Figure 4 illustrates, in yellow, the effect of innovation (TFP) as a share of total labor productivity growth from 1990-2010, and projections for 2010-2020. The base case estimate expects GDP to grow by 1.93 percent annually during this decade, of which productivity growth is estimated to account for roughly 1.1 percentage points, as shown in the graph. According to the estimate, roughly a quarter of the labor productivity growth will be generated by innovation.[18]

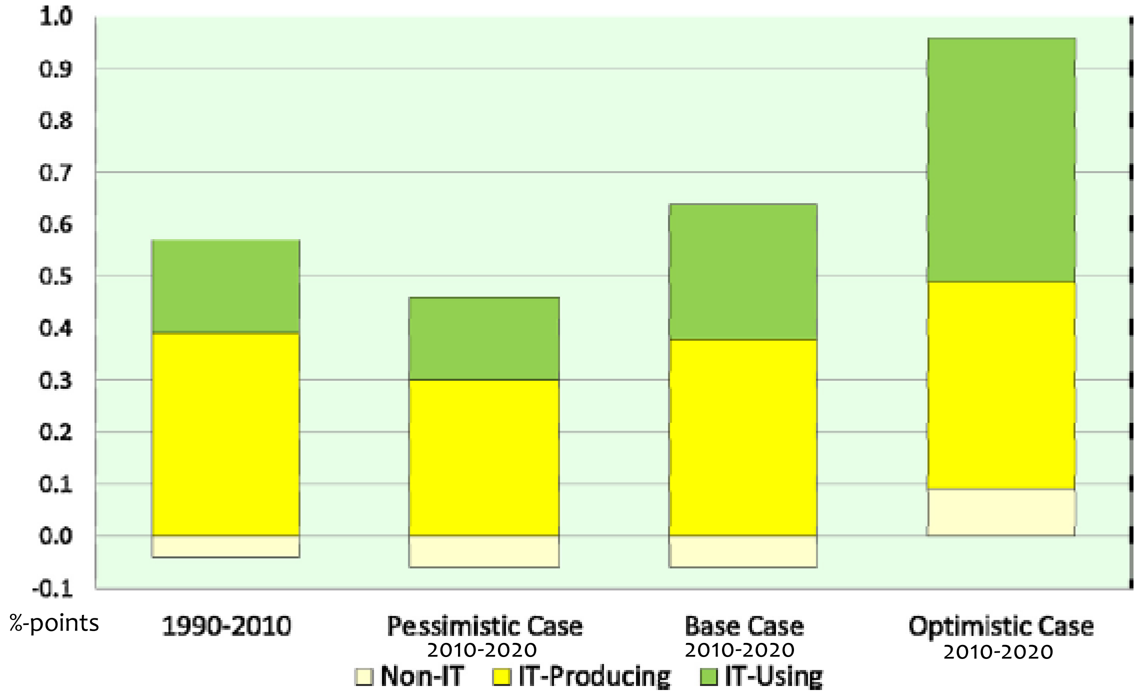
Figure 4: Range of Labor Productivity Projections, 2010–2020 Annual Percentage Growth Rates. TFP = Innovation.



Source: Jorgenson et al. (2014).

Importantly, economists also estimate that *all* productivity growth during the current decade will likely be generated by IT-using and IT-producing industries. The non-IT-using industries are only expected to improve their productivity in the optimistic case, as described in Figure 5. Given all IT systems' dependence on semiconductor technology, this information indicates that the U.S. semiconductor industry's outsized direct and indirect impact on U.S. economic growth will continue.[19]

Figure 5: Contribution of Industry Groups to Productivity Growth in the U.S. Economy, 2010–2020.



Source: Jorgenson et al. (2014).

ENDNOTES

[1] Research Fellow (Summer 2014), Semiconductor Industry Association (SIA); Master in Public Policy Candidate, Harvard Kennedy School. Opinions expressed in this paper are the author's own and do not necessarily reflect those of the organizations with which the author is associated.
[2] Jorgenson, D.W., Ho, M. S., & Samuels, J. D. (2011). Information technology and U.S. productivity growth: evidence from a prototype industry-level production account. *Journal of Productivity Analysis, 36*(2), 159-175. Page 170, table 6.
[3] Ibid. "Real" regards to a figure which takes into account the changes in price, which is a major result of progress in semiconductor technology.
[4] Jorgenson, D.W., Ho, M. S., & Samuels, J. D. (2014). What Will Revive U.S. Growth? Lessons from a prototype industry-level production account for the United States. *Journal of Policy Modeling* (36), 674-691. For this reference, see pages 684-685.
[5] Ibid. Page 688.
[6] Ibid.
[7] Ibid.
[8] Author's drawing.
[9] Note that there is a slight difference between the generally-used and economics definitions of the word "innovation". In this paper, the word innovation is used interchangeably with the economics term "total factor productivity", or "TFP". In more colloquial English, innovation is often used to describe a new idea, device, or method, which may or may not increase economic productivity.
[10] Data included in Jorgenson, Ho, and Samuels, J. D. (2011). Page 165, figure 1. Original graph from Samuels, J.D. (2012). Essays on technology and forecasting in macroeconomic. *The Johns Hopkins University*(3532375), 189 pages.
[11] This is a simplification that only compares the price-performance ratio in terms of horsepowers/semiconductor performance vs. price. Of course, cars have evolved in many other ways than just in terms of engine power.
[12] Ibid.
[13] The total share of innovation-based GDP growth is a product of the innovation rate and the industry's Domar-weighted share of GDP – if the latter is huge, even a small innovation rate creates a big share of innovation-based growth. See ibid. page 174, figure 6.
[14] For a discussion of industry classification, see Jorgenson, Ho, and Samuels (2014), page 677. In short, computers, electronic products, and two IT-services industries, information and data processing and computer systems design, are defined as IT-producing industries. An industry is IT-using if the intensity of IT capital input is greater than the median for all U.S. industries that do not produce IT equipment, software, or services. All other industries are non-IT-using.
[15] Non-IT-using industries show a negative innovation figure because their output compared to the amount of inputs has decreased after accounting for other measured changes in productivity (such as changes in capital and labor structure). For example, an industry that did not make any changes to labor and capital quantity or quality, but still experienced a decrease in output, would be assumed to have a negative rate of innovation (since we could not observe any other changes affecting the level of output).
[16] Ibid.
[17] Jorgenson, Ho, and Samuels (2014). Pages 678 and 684-685.
[18] Ibid. For basis of the estimates, see pages 686-687.
[19] Ibid. Page 687.

BIBLIOGRAPHY

Jorgenson, D. W., Ho, M. S., & Samuels, J. D. (2011). Information technology and U.S. productivity growth: evidence from a prototype industry production account. *Journal of Productivity Analysis, 36*(2), 159-175.

Jorgenson, D. W., Ho, M. S., & Samuels, J. D. (2014). What Will Revive U.S. Economic Growth? Lessons from a prototype industry-level production account for the United States. *Journal of Policy Modeling*(36), 674-691.

Samuels, J. D. (2012). Essays on technology and forecasting in macroeconomics. *The Johns Hopkins University*(3532375), 189 pages.