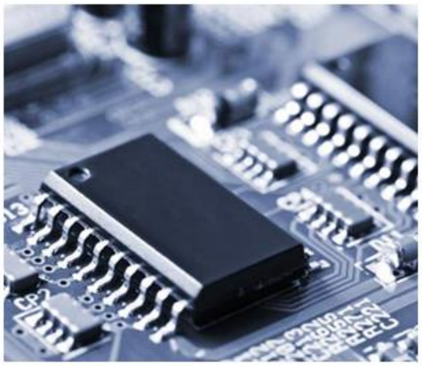
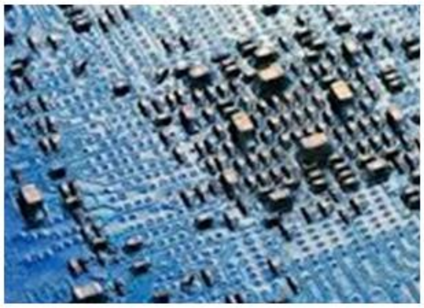
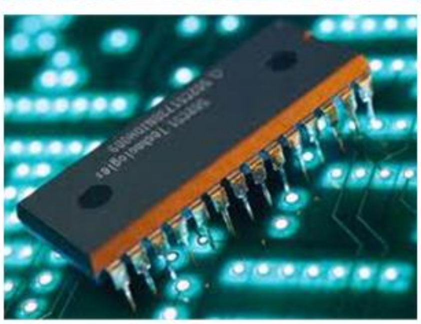



How Semiconductors Save Consumers Money: The Consumer Value of Semiconductor Innovation

Jim Vervuurt[1] | August 2016

The semiconductor industry has been a large contributor to consumer welfare over the last 20 years through providing improved product performance coupled with declining prices. In this respect, the semiconductor industry is unique compared to other industries. The semiconductor industry creates direct consumer welfare and indirect consumer welfare through spill-overs to other industries.

Key Takeaways

1. Since 1996, semiconductors have continued to experience vast product performance improvements.

2. Simultaneously, semiconductor prices have decreased, both on a per unit and per transistor basis.

3. Consumers have directly benefited from this phenomenon deriving more value from semiconductors

4. It is unique for an industry to provide as much value to consumers as the semiconductor industry does.

Introduction

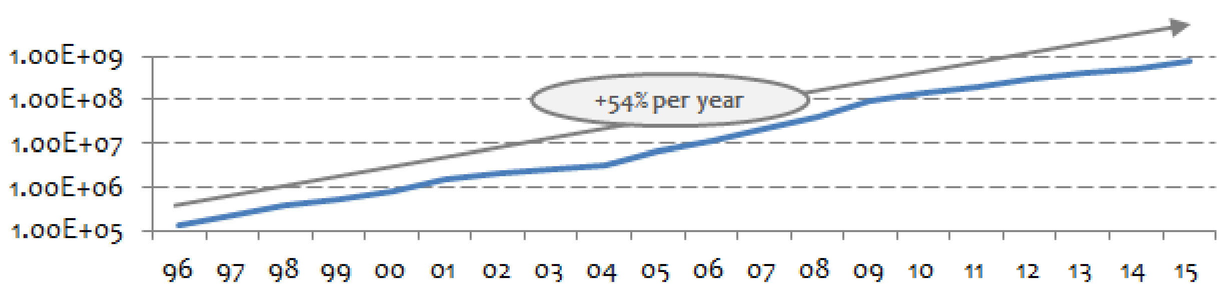
The world around us is changing rapidly. Electronics are increasing in speed, performance, and efficiency every year, benefitting among others computers, cars, communication devices, and healthcare equipment. What all these goods have in common are semiconductors. Semiconductors are the key component to these products, and their improvements are due directly to semiconductor innovation. These semiconductor-driven developments increase the value consumers derive from their purchases.

In 1997, Dr. Kenneth Flamm published a comprehensive study on the consumer value of semiconductor innovation. He concluded that from 1976 to 1995, the improvement in semiconductors against declining prices accumulated in an amount of $378 billion in consumer welfare per year, each year from 1995 onwards.[2] This paper asks whether the semiconductor industry has continued to provide an increasing amount of consumer welfare through improved product performance coupled with declining prices since 1995. The answer is a resounding yes.

Since 1996, Semiconductors have continued to Experience Vast Product Performance Improvements

Semiconductor product performance improvement can be measured by the growth of the number of transistors per semiconductor over time. Simply put, the more transistors per semiconductor, the more functionality or power semiconductors contain (for more information on transistors, see Box 1). Figure 1 shows the annual rate of growth of transistors per semiconductor since 1996. The annual growth rate is an astounding 54 percent increase in the number of transistors per semiconductor since 1996, which is even higher than Moore's Law predicts (for more information on Moore's Law, see Box 1). Setting aside the incredible engineering feet of maintaining this pace of transistor growth on silicon, this rate has resulted in semiconductors that are far more powerful today than they were in 1996.

Figure 1. Average Annual Transistor Count per Semiconductor, Worldwide, 1996 – 2015



Source: WSTS and SIA

Box 1. Transistors and Moore's Law Explained

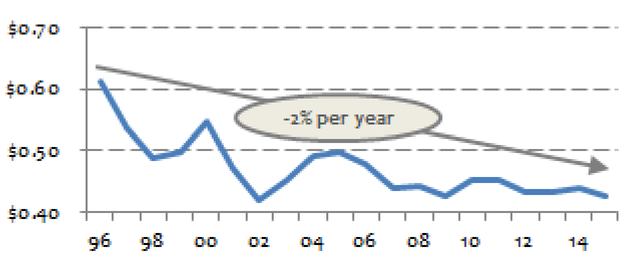
A **transistor** is a semiconductor device used to amplify or switch electronic signals and electrical power. Transistors are the fundamental building block of modern electronic devices and are present in virtually all modern electronic systems. The main result of semiconductor innovation is the ability to pack more transistors into the same space, which allows for growing the transistor count per semiconductor. This improves performance, as this decreases the power usage and increases the clock speed at which it can be operated. This development is strongly related to, for example, the increases in memory capacity, microprocessor computing power, and the number and size of pixels in digital cameras. The semiconductors within your computer today often comprise billions of transistors while being not much larger than the size of a quarter. In comparison, the control units of the first NASA Apollo space programs only had 12,300 transistors in total.

Moore's law is the forecast that the amount of transistors in a dense integrated circuit doubles approximately every two years. It is named after co-founder and former CEO of Intel Corporation, Gordon Moore, who made the prediction in 1975.

Since 1995, Semiconductors have Decreased in Price, both on a per Unit and per Transistor Basis

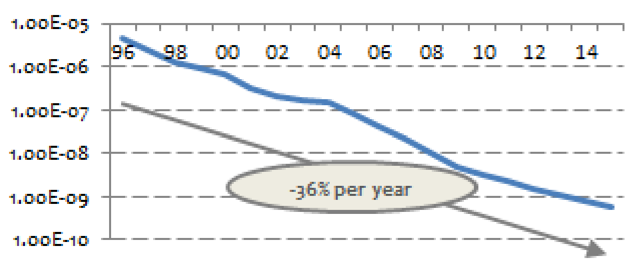
Product improvement alone does not translate into consumer benefit; it must be accompanied by simultaneously decreasing prices. From 1996 onwards, the semiconductor industry also experienced annual price decreases both on a per product and per transistor basis. On a per product basis, the average semiconductor price decreased by 2 percent annually from 1996 to 2015 (Figure 2). More striking, on a per transistor basis, the average price per transistor decreased by 36 percent per year (Figure 3).

Figure 2. Average Annual Semiconductor Price, 1996 – 2015



Source: WSTS and SIA

Figure 3. Average Annual Transistor Price, 1996 – 2015 (logarithmic scale)

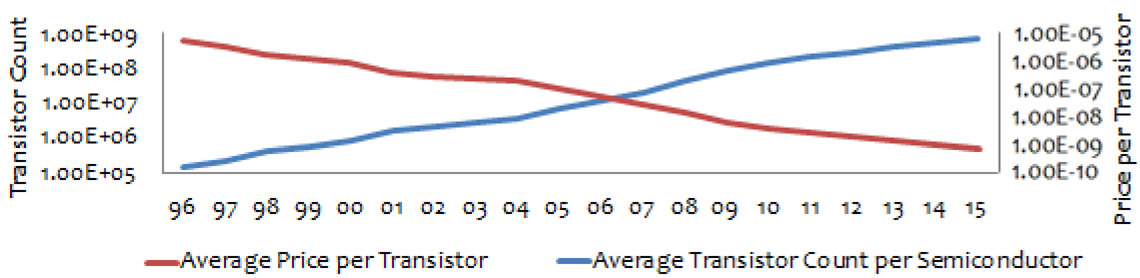


Source: WSTS and SIA

Consumers have Directly Benefited from this Phenomenon Deriving More Value from Semiconductors

The combined increase in transistor count per semiconductor (+54 percent per year) and decrease in price per transistor (-36 percent per year) over the past 20 years (Figure 4), has resulted in a vast increase in the value consumers derive from semiconductors. We see a continuation of what Flamm described as "more for less" to consumers from the semiconductor industry (figure 4). Every year, consumers pay less for a given amount of semiconductors while semiconductor performance vastly improves. This phenomenon means that consumers have been gaining value yearly, or in economic terms; they have been gaining consumer surplus. While this paper does not quantify the amount of consumer surplus consumers have gained over the past 20 years the way Flamm's work did in the late 1990s, the bottom line is still consumers have gained consumer surplus. Box 2 further explains both this phenomenon and the concept of consumer surplus itself.

Figure 4. Annual Transistor Count and Transistor Price Developments, 1996 – 2015



Source: WSTS and SIA

It is Rare that an Industry Provides Increasing Value with Decreasing Prices; the Semiconductor Industry is Unique

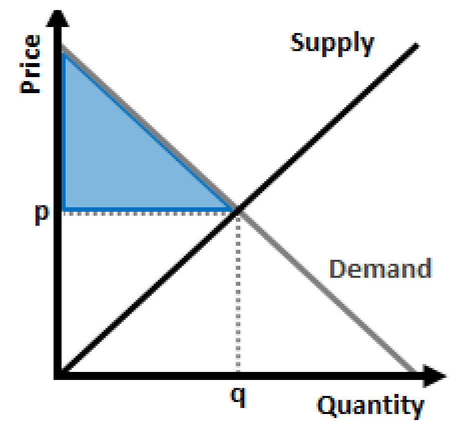
Today's semiconductors have slightly more than 5,500 times as many transisors compared to semiconductors in 1996, while costing 31 percent less.[3] Simply put, the industry operates under a constant state of deflation, as prices for the same products decline each year at a rapid rate. The semiconductor industry is unique in this respect among industries; prices for most products tend to rise over time, whether they improve or not. This is because price inflation has been a constant historical reality in our economy. For example, one pound of white bread in 1987 cost $0.57, while it costs $1.43 in the beginning of 2016.[4,5] The prices of almost all products have increased over time, while those of semiconductors have decreased, while performance continued to increased. Here is a tangible analogy: suppose the lighting industry had achieved similar price declines and performance improvements as the semiconductor industry over the past 20 years. If so, then one 60 watt incandescent lightbulb from 20 years ago would cost only less than one cent today (price decline) and contain enough wattage to light a high school football stadium (power increase).[6]

Box 2. Consumer Surplus Explained

Consumer surplus is the economic term for the value consumers derive from buying a certain good. Simply put, it is the difference between the price consumers are willing to pay for a good and the price they actually have to pay. This difference is surplus value that consumers do not have to spend on a good, which they can then spend on other goods and services. For example, say you want to buy a loaf of bread and are willing to pay a maximum of $3 for it. If the actual price is only $2, the consumer surplus is $1, as this is the extra amount you are willing to spend, but do not *have* to spend. It is the value you derive from the transaction.

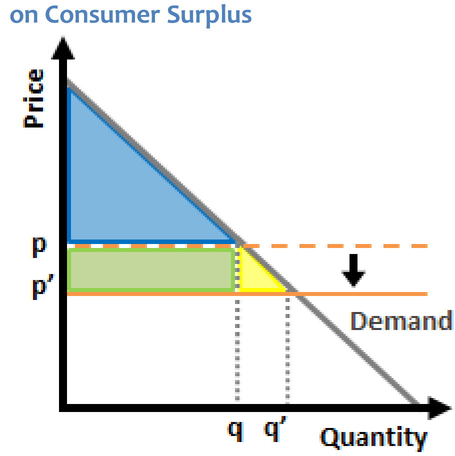
The total amount of consumer surplus from a product is determined by the aggregate supply and demand for it. Figure 5 represents this concept graphically; a higher price leads to a higher supply but a lower demand, while a lower price leads to a higher demand and lower supply. Simply put, the intersection of supply and demand determines the quantity sold (*q*) and the price paid for it (*p*). Looking at the demand curve we can see that there are consumers willing to pay more than price *p.* The difference between actual price *p* and their willingness to pay is the consumer surplus, which is represented by the blue area.

Figure 5. Consumer Surplus



As we have seen, the price for semiconductors with a given performance decreases greatly each year. So, what happens if the price of semiconductors decreases because of lower production costs through innovation? Figure 6 represents the effect of a decrease in price from *p* to *p'* on consumer surplus. Current consumers will be paying less than they did before for the same value. Their consumer surplus will increase by the green area. We also see that the quantity sold increases from *q* to *q'* because some consumers are willing to pay less than *p*, but more than *p'* for semiconductors. They will start consuming the product and will add to consumer surplus as represented by the yellow area. To conclude, consumer surplus increases by both the green and the yellow area. Through this process, semiconductor innovation adds to consumer surplus.

Figure 6. Effects of Price Decreases on Consumer Surplus



End consumers hardly ever purchase semiconductors directly; they typically buy an end product that has semiconductors as components. Academic research has found that the surplus gained by direct consumers (e.g. cell phone manufactures) represents the surplus gained by final consumers of products (e.g. persons buying a cell phone). [7] In reality we see that a large part of the price/quality improvement of telecommunications and computers can be attributed to semiconductor innovation.[8]

Semiconductor Innovation has led to Significant Spillovers to Other Industries such as Technology, Manufacturing and Services

We have seen that semiconductor innovation leads to decreasing product prices combined with increasing performance resulting in large amounts of consumer value. Besides the direct benefits of this phenomenon, many other industries experience enormous positive spill-overs from semiconductor innovation. Semiconductor innovation has resulted in the tools that allowed for labor productivity gains and operational improvements down the line in numerous other industries such as logistics, financial services and healthcare. The U.S. semiconductor industry accounted for as much as 30.3 percent of all economic growth due to innovation in the United States from 1960 to 2007.[9]

Besides decreasing prices of semiconductor-based products, semiconductor innovation also allows for more high-wage employment, innovation, profits, and economic growth in these downstream industries. For example, semiconductor innovation has allowed the electronics industry to continually produce products that are smaller, more powerful, and that offer more value to consumers. If the automotive industry had achieved similar price declines and performance improvements in the last 30 years as the electronics industry, a Rolls-Royce would cost only $40 and could circle the globe eight times on one gallon of gas – with a top speed of 2.4 million miles per hour.[10] This is a development that has only been possible because of semiconductor innovation.

Tremendous Consumer Value through Semiconductor Innovation

This paper continues where Flamm's research on the consumer value of semiconductor innovation from 1976 to 1995 left off. It concludes that the semiconductor industry has continued to improve performance at astonishing rates under decreasing prices. When we combine these research findings with Flamm's, we find that this trend has occurred over the last 40 years. It proves that semiconductor innovation has been able to overcome the challenges that have arisen through time and that it has generated tremendous amounts of consumer value while doing so. In the future there seems little doubt the semiconductor industry will continue to generate more consumer value through increased functionality and decreased prices.

ENDNOTES

[1] Global Policy Intern (Summer 2016), Semiconductor Industry Association (SIA); Master in Finance Candidate, Tilburg University. Opinions expressed in this paper are the author's own and do not necessarily reflect those of the organization with which the author is associated.
[2] Flamm, Kenneth. (1997). More for Less: The Economic Impact of Semiconductors. Semiconductor Industry Association.
[3] World Semiconductor Trade Statistics (WSTS) and Semiconductor Industry Association (SIA), Bluebook data.
[4] Bureau of Labor Statistics. One Hundred Years of Price Change: the Consumer Price Index and the American Inflation Experience. Accessed on July 22, 2016.
[5] Bureau of Labor Statistics. Average Retail Food and Energy Prices, U.S. and Midwest Region. Accessed on July 22, 2016.
[6] Semiconductor Industry Association. It All Starts Here: A Pocket Guide to America's Most Innovative Industry. p. 15
[7] Flamm, Kenneth. (1997). More for Less: The Economic Impact of Semiconductors. Semiconductor Industry Association. P. 19 – 20.
[8] Aizcorbe, A., Flamm, K., & Khurshid, A. (2007). The Role of Semiconductor Inputs in IT Hardware Price Decline: Computers versus Communications. In Hard-to-Measure Goods and Services: Essays in Honor of Zvi Griliches (pp. 351-381). University of Chicago Press.
[9] Matti Parpala. (2014). The U.S. Semiconductor Industry: Growing Our Economy through Innovation. P. 1
[10] McKinsey & Co. (2011). McKinsey on Semiconductors. Creating Value in the Semiconductor Industry. p. 1

BIBLIOGRAPHY

Aizcorbe, A., Flamm, K., & Khurshid, A. (2007). The Role of Semiconductor Inputs in IT Hardware Price Decline: Computers versus Communications. In Hard-to-Measure Goods and Services: Essays in Honor of Zvi Griliches (pp. 351-381). University of Chicago Press.

Flamm, K. (1997). More for Less: The Economic Impact of Semiconductors. Semiconductor Industry Association.

McKinsey & Co. (2011). McKinsey on Semiconductors. Creating Value in the Semiconductor Industry.