



The diamond-wafer paradox: A modern mystery

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..... I confess that I did not intend to take an inventory of the modest wealth my wife and I had accumulated in nine years of married life. But a pair of birds got stuck in the attic, tried to find their way out the rear window, and made a mess of things. It was not as psycho as a Hitchcock movie, but it forced my wife and me to look hard at our belongings.

We found our daughter Rebecca's baby clothes, several pieces of luggage, and many used electronic gadgets, specifically, two stereos, several old PCs, a very old TV, a college dorm refrigerator, our first video camera, several phones, an answering machine, an old cellular handset, and many of the boxes and instructions for the electronics. There were no Rembrandts.

Such are the components of modest wealth; virtually all the gadgets worked except one computer, but all of them are worthless. Nothing could serve as collateral on a loan or fetch a dime on eBay.

There is a paradoxical connection between economic growth and old electronic gadgets. It is paradoxical because wealth is usually associated with accumulating durable goods, not turning them into paper weights in an attic.

Let's call this the diamond-wafer paradox. Specifically, in growing modern economies, goods embedded with silicon wafers lose their value much faster than other durable goods or jewelry, such as diamonds. And this is a good thing.

This mystery will take some explaining.

The value of durable goods

Working citizens of industrialized countries store most of their modest wealth in durable goods, such as automobiles, furniture, and houses. Hence, the resale value of these goods—less outstanding mortgages and loans—determines the wealth of most households.

A household's wealth grows as it accumulates durable goods. It declines as the value of these good depreciate, which they do at a variety of rates. For example, a heavily driven car tends to break down eventually, while the diamond on my wife's ring finger tends to retain its resale value.

To be sure, it is notoriously difficult to figure out the value of a particular durable asset. Indeed, the figuring can be quite involved if you want an answer without a shadow of doubt. Anybody who has ever bought a used car—not to mention a used diamond—knows about such figuring. Accordingly, market participants develop sophisticated procedures for forecasting the likelihood that a product will endure, and assign a price to durability. This holds true for automobiles, jewelry, or any other durable good, even computers.

Let's go back to those old computers in my attic. All of them date to the early 1990s, after the PC industry was no longer young and innocent. Despite age, most still work about as well as when I first used them. This feature reflects a general property of PCs, which have so few mechanical parts. If they have defective parts, then they break down quickly.

If not, they tend to work quite a long time. Eventually, the screen will fail and so will a hard drive, but it takes a while.

Most PCs continue to operate three, five, and 10 years later at about the same operational efficiency as when they were new. In other words, most computers are more durable than cars and only a little less durable than diamonds. The more interesting question is whether that durability has any market value.

Why might the resale markets for automobiles and computers differ? In both cases, the value of the used good depends on the willingness of the buyer to substitute between the new and the used.

In the case of cars, the commodity depreciates with use. Consequently, the used-car buyer trades off the additional risks of further repair (if he stays with the old) for the smell and feel of a new car. In the case of a PC, wear and tear is not a mystery. Instead, the used-PC buyer trades off owning a new system with owning the best upgrade the manufacturers offer for the old one.

Unfortunately, upgrades for PCs require knowing too much. New software applications use faster processors, more RAM, large hard drives, or link to different components, such as a Wi-Fi network card or yet another generation of DVD readers and burners. A sophisticated user can upgrade components until they are held together by glue and rope, but most users do not find the frenzy worth it. At some point it becomes easier to start anew.

The price of electronics goods

So why are those gadgets in my attic? How fast did electronics lose their value during the 1990s?

I asked Ernst Berndt and Neil Rappaport, who took a comprehensive look at PC prices over 25 years. Berndt is an economics professor at MIT, and Rappaport has an MIT economics PhD and works for the US military. They have been doing these estimates for years.

What they do is a bit complicated, but it is possible to explain it in an outline. The key question concerns the price of the same product made in two different years. In other words, if the speed and memory of the PC are the same, how much different are the prices for that specific model in two different years? Although different procedures give mildly different estimates, I will report the most conservative estimates, which are nonetheless eye-popping.

Berndt and Rappaport report that PC prices declined (at worse) an average of 35 percent a year between 1992 and 2002. That rate accumulates year after year, so it leads to fast declines in value. In other words, a \$2,000 computer purchase in 1992 would be worth \$330 five years later. Ten years later, it would be worth a tad over \$39, if you were lucky.

Desktops and notebooks differ slightly, with desktops declining faster than notebooks in the first half of the decade, and notebooks declining faster in the second half. For most users, these differences did not matter; it meant the desktops went to the attic a few months earlier. For more information, see the "Estimating the change in computer prices" sidebar.

The components inside the computer have a mildly more complex story to tell. To learn about these, I asked Ana Aizcorbe, who took a comprehensive look at electronic-component prices for the processors, memory, analog chips, and all the stuff that ends up in a typical computer, router, or switch. Aizcorbe is an economist at the Bureau of Economic Analysis, US Department of Commerce, the agency that measures US gross domestic product.

Estimating the change in computer prices

The basic procedure for estimating changes in the price of computers relies on breaking a computer's price into a weighted sum of its features. Let me illustrate the idea with a simple baseline model, known as the exponential model.

In such a model, the price of new computer model j in time t , P_{jt} , is an exponentially weighted sum of its features. Let there be n such features, measured as x_m in time t , where the various values of x_m correspond to speed, memory, screen size, and so forth.

Without loss of generality, let there be two years, 1 and 2, and let $t_1 = 1$ during year 1 and zero in year 2, with just the opposite for t_2 . Then $P_{jt} = 100 \exp(a_{11}t_1 + a_{12}t_2 + b_{11}x_{11} + b_{12}x_{21} + \dots + b_{1n}x_{1n})$, where a_{11} and a_{12} are weights given to the two years, and b_{1m} are weights given to different features of the computers, as measured.

If x_m is the same in two different years, how much different are the prices? For the same product, the ratio of prices for the same product in two different years is $P_2/P_1 = 100 \exp(a_{11} - a_{12})$. After normalizing, the index is 100 in the first year. Since x usually becomes larger over time and P does not, this index is usually less than 100 in the next year. The appeal of this procedure is that it gives a sense of the percentage improvement, but denominates the decline in prices.

The procedure depends on how you estimate a_{12} , which depends on the estimates for the weights for features b_{1m} , the attributes that really improves over time.

Two previous publications offer more details about these techniques.^{1,2}

References

1. E. Berndt and N. Rappaport, "Price and Quality of Desktop and Mobile Personal Computers: A Quarter Century Historical Overview," *Am. Economic Rev.*, May 2001, pp. 268-273.
2. A. Aizcorbe, *Price Measures for Semiconductor Devices*, FEDS working paper no. 2002-13, Federal Reserve Board of Governors, Washington, D.C.

She reports that the price for MOS processors declined at an average of 52 percent per year between 1991 and 1999. In other words, a \$450 processor in 1991 would be worth seven dollars five years later. In 10 years, it would be worth next to nothing. No other electronic component had quite this abysmal record, but several important components still decline rapidly. MOS memory, for example, declined at 30 percent a year; MOS logic, at 13 percent.

Interestingly, some components hardly declined at all in price, notably analog chips, which end up in many communications goods. After looking at it closely, she found that their price had declined just a bit, but not much to matter.

In other words, wafers are losing their value in the leading edge, especially in the stuff that goes into computers, routers, switches, and other consumer electronics, except, perhaps, cell phones. The

record for electronic parts varies a bit across the component, but it is still impressive.

More generally, durable does not imply resale value. A five-year-old computer in mint condition has little resale value. A 10-year-old computer has its highest value as tax deduction donated to public schools.

Note the difference with any other durable good. A five-year-old car in mint condition does have resale value on a used-car lot. It is worth less than when it was first sold, but the mint condition will keep the value high. Similarly, a 10-year-old diamond hardly changes its market value at all, depending on the marketing practices at DeBeers, and the residual demand for industrial diamonds.

Said bluntly, computers might last forever, but their market value does not.

A symptom of wealth or a cause?

Is this pattern a symptom or a cause of

society's wealth? I conclude it is both.

In modern economies, there are two types of durable-goods markets, alike on the surface but different underneath, like two strangers on a train taking the same ride but with different purposes. In one situation, a used good depreciates primarily from use. In another, a used good loses value primarily because the new ones are better. Electronics are the latter. More to the point, these patterns reveal a lot about why economists often classify modern electronics markets as durable-goods markets, but these markets do not behave like traditional durable-goods markets. This second pattern is a symptom of wealth.

IC firms do not hesitate to change the designs of core products. Given ever-growing demand, producers keep finding ways to accelerate the redesign cycle and push the value of a new design, taking advantage of the temporary market window in which their design has high value.

Just imagine what cars would look like if they behaved like electronics. It would be as if Daimler-Chrysler upgraded its car models every three months and introduced a new car chassis every year. Why does Daimler-Chrysler not do this so frequently? Because it is expensive to do.

The company would do this only if it anticipated an enormous commercial benefit, such as greatly expanded sales, which would not likely be the case.

This is another way of saying that users in the two markets also behave with different expectations. Car buyers know that their cars will have resale value. It makes an enormous difference to the tradeoff between owning a new car or a used one. In contrast, few PC owners have any illusion about their PC's resale value. Users buy new PCs because they want the functionality today.

Think of it this way: As innovators discover technical frontiers at a faster and faster pace, the durability of the old product becomes less relevant to its resale value and, therefore, the anticipated durability of a new product becomes less relevant to its value. That is remarkable in light of the high price of a new computer. The purchase does not make sense unless users are anticipating making intense use of the good over a very short period of time.

Electronic components no longer make cameo appearances in consumer markets. They have a starring role, accelerating the rate of change. Stereos, televisions,

and cameras all used to have active resale markets, but that has changed. Depreciation is not the primary driver of resale value in electronics markets. Rather, the real driver is technical advancement: Depreciation does not send gadgets to the attic. Obsolescence does. And this change over in electronics creates wealth.

From a user's point of view, the timing of investment in such goods has to be done at the right moment. That is, if a PC is purchased too early—before a user is ready to take advantage of the improvement—the buyer is left holding a product that rapidly loses its value, but does not provide much additional valuable service. If purchased too late, then it is also a losing proposition. In that case, the user did not take part in new services that would have been worthwhile.

Society has reached a truly spell-binding moment in the accumulation of wealth: People have to shelve their previous wealth to accumulate more. Just thinking about it gives me vertigo.

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