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Federal Reserve Bank of Cleveland

How Much of Economic Growth Is Fueled by Investment-Specific Technological Progress?

by Michael Gort, Jeremy Greenwood, and Peter Rupert

Gross domestic product today is only modestly bigger than it was 100 years ago,[1] at least if it's measured in tons! While this may seem an absurd way to measure GDP, the point is that how economic variables are measured is important.

The last century has witnessed the arrival of many new forms of durable goods: aircraft, computers, lasers, robots, television, microwave ovens, x-ray machines, and cellular phones. It is obvious to any layperson that technological progress is *embodied* in new and improved capital goods, yet economists have been unable to discover any evidence that this is so. Instead, they have found that nearly all technological progress is *disembodied*, that is, it affects the productivity of all inputs in production equally. Apparently it makes no difference whether the inputs are capital, labor, or land or, for that matter, whether the capital is new or old. Nobel Prize winner Robert M. Solow describes this laughable situation. "It is," he writes, "as if all technical progress were something like time-and-motion study, a way of improving the organization and operation of inputs without reference to the nature of the inputs themselves. The striking assumption is that old and new capital equipment participate equally in technical change. This conflicts with the casual observation that many if not most innovations need to be in new kinds of durable equipment before they can be made effective."[2]

What has gone wrong with economic measurement? The already-daunting task of adding up all the goods and services produced in an economy is further complicated when new products appear, old ones disappear, and the same ones get better as technology advances. One might be tempted to think that although it puzzles economists, the measurement question doesn't much matter to anyone else, but this turns out not to be so.

The Importance of the Embodiment Question

Ever since Adam Smith's *Inquiry into the Nature and Causes of the Wealth of Nations* (1776), economists have tried to identify the engines of growth; such identification can be important for public policy. For example, if technological progress is largely embodied in the form of new investment goods, then policies that reduce the costs of acquiring new equipment (such as investment tax credit for buyers or R&D subsidies for producers) may stimulate growth.

The source of technological progress may also have implications for issues such as unemployment. In the U.S. economy, an industry's best plant can produce much more output per hour of work than its average plant can.[3] Newer plants will tend to have better technology because they have newer capital, at least in a world with investment-specific technological progress. Over time, older plants and capital will tend to be displaced by newer, more efficient ones. If a worker must be trained to use technology that is embodied in a capital good, that worker becomes obsolete when the technology does. In such a case, policies for retraining workers might be called for.[4] So it does matter whether technology is embodied or disembodied because the source of technological progress has implications for economic growth, unemployment, and other issues that society cares about.

Discovering how economies grow is vitally important for economists and policymakers alike. This *Commentary* shows that more than half of U.S. economic growth can be attributed to technological advance in equipment and structures.

Measuring Technological Progress

As Solow notes, the implementation of technological progress is not free; it requires investment in new equipment and structures. This type of technological progress may be called *investment-specific,* since one must invest to realize benefits from it. Then what share of economic growth arises from investment-specific technological progress in producing new capital goods, both equipment and structures, and what share comes from disembodied technological progress?

Think about progress, and equipment like computers or cars readily springs to mind. One is much less likely to think about structures, in which technological progress is far less obvious though present just the same. Take skyscrapers. The Home Insurance Building in Chicago, generally considered the world's first, was built in 1885 to a height of 10 stories. Compare this with Chicago's Sears Tower, completed in 1974 at 110 stories—a difference of 100 stories in less than as many years. The increase in height reflects significant advances in engineering and design, as well as the availability of new materials. The Sears

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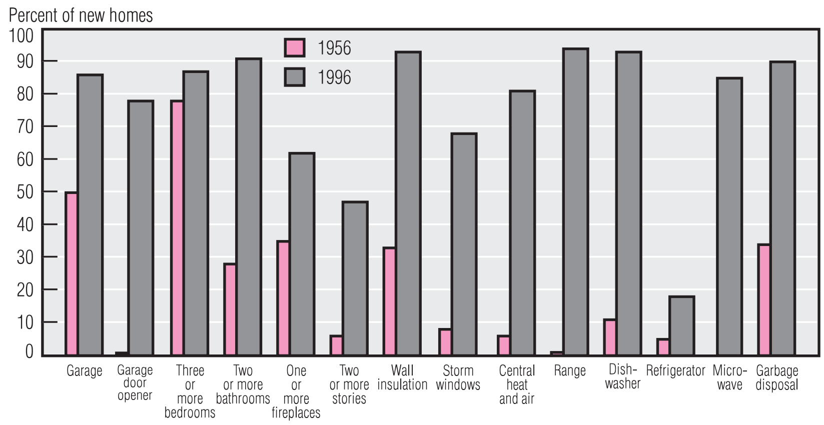
Tower is 200 feet taller than the Empire State Building (circa 1931), but it weighs much less (223,000 tons versus 365,000).

The people who work in skyscrapers must be kept comfortable, and this takes space. For instance, the 29th floor of the Sears Building is occupied by five air chillers, three of them weighing 5,000 tons apiece. After being used in the chillers, water is pumped up 77 floors to four three-story-high cooling towers (floors 106 through 109). The water, cascading down the tower wall, is cooled by enormous fans. Obviously, as technological progress decreases the amount of space necessary to provide the expected level of comfort, the value of the building will increase, since more floor space will be available for rental.

Technological progress in equipment and structures has eased the burdens of life for the average household, too. In 1956, not one home had a microwave oven. Few had central heat and air or even insulated walls and storm windows. Only half of new homes had a garage. Now, the vast majority come equipped with these features as a matter of course (see figure 1).

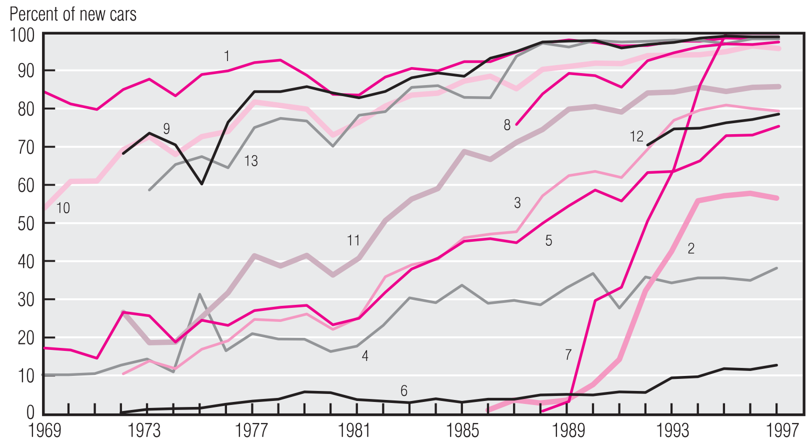
So how much of economic growth *is* fueled by investment-specific technological advance in the production of new capital goods, both equipment and structures, and how much derives from disembodied technological advance? To answer, one must determine the rates of investment-specific and disembodied technological progress.

FIGURE 1 FEATURES OF NEW HOMES



SOURCE: *Time Well Spent: The Declining Real Cost of Living in America.* Federal Reserve Bank of Dallas, 1997 Annual Report.

FIGURE 2 FEATURES OF NEW CARS



1. Power steering; 2. Antilock brakes; 3. Power door locks; 4. Power seats; 5. Power windows; 6. Sun roof; 7. Air bags; 8. Windshield-wiper delay; 9. Tinted glass; 10. Air conditioning; 11. Adjustable steering column; 12. Cruise control; 13. Remote-control sideview mirror.

SOURCE: *Time Well Spent: The Declining Real Cost of Living in America.* Federal Reserve Bank of Dallas, 1997 Annual Report.

Measuring Investment-Specific Technological Progress in Equipment

In the equipment-producing sector, the pace of technological progress can be tracked using the price of new producer durables relative to the price of new consumer nondurables. This shows how many new units of equipment can be bought in place of a forgone unit of consumption. Over time, ever-increasing quantities of new equipment can be purchased for a forgone unit of consumption. But what is a unit of equipment?

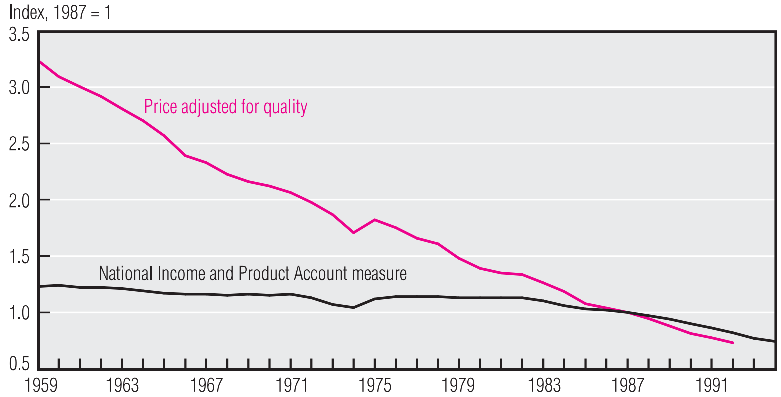
Consider the car, by no means a homogeneous product. Technological progress made a 1995 automobile vastly different from a 1965 model (figure 2). In 1965, no new car had antilock brakes, power locks, airbags, adjustable steering columns, remote control, side-view mirrors, cruise control, or a windshield-wiper delay. By 1995, most new cars had these features.[5]

Think of a car as a bundle composed of characteristics that customers want, just as a chemical compound is built up from a set of elements. When calculating the price of a car, an economist must adjust for the fact that the list of features included in an average car is expanding over time. That is, the same amount of money (taking inflation into account) spent on an automobile today may buy a much better car than yesterday. Therefore, the price must be adjusted for quality improvements that have taken place over time.

When prices are adjusted for quality (figure 3), one can see a steady decline in the relative price of new producer durable goods since World War II. Again, this represents the price of a unit of new equipment in terms of the consumption forgone to purchase it. Considered this way, the prices of new producer durable goods dropped at the rate of 3.2 percent a year.[6] Figure 3 also shows the National Income and Product Account measure, which only partially adjusts for quality improvement. Observe that it fell by much less.

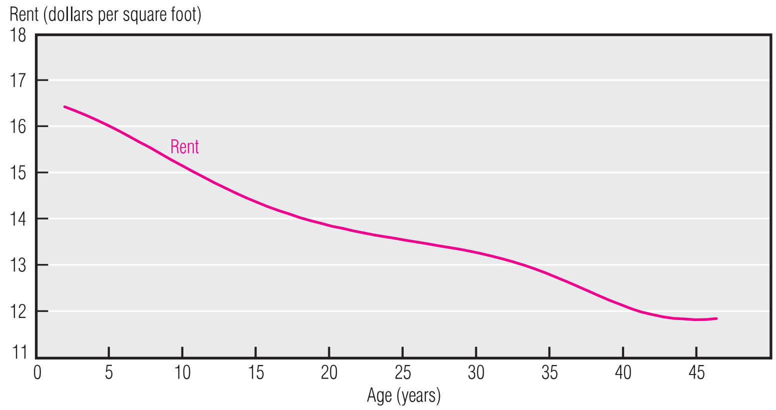
To understand why, think about computers. An IBM mainframe cost $4,674,160 in 1970. Today a personal computer can be bought for under $1,000. Cutting prices by a factor of 4,674 is indeed tremendous, but it is still likely to be a gross underestimate! Suppose that a computer had just one characteristic, the speed of

FIGURE 3 RELATIVE PRICE OF EQUIPMENT



SOURCES: U.S. Department of Commerce, Bureau of Economic Analysis; and Robert J. Gordon, *The Measurement of Durable Goods Prices.* Chicago: The University of Chicago Press, 1990.

FIGURE 4 BUILDING AGE AND RENT



SOURCE: Michael Gort, Jeremy Greenwood, and Peter Rupert (see footnote 8).

its calculations. The 1970 computer could carry out 12.5 million instructions per second (MIPS), while today's PC can do 166 MIPS. The price per MIPS, or for a unit of a standardized computer, has fallen meteorically (from $373,933 to $6), so the number of MIPS that can be purchased for $1 has increased by a factor of 62,322![7]

Measuring Investment-Specific Technological Progress in Structures

Quality-adjusted prices do not exist for new structures, so the economist must measure the rate of technological progress indirectly. If new buildings embody technological progress, they should rent for more than old ones. This turns out to be true. Figure 4, which plots buildings' rent as a function of age,[8] is based on a sample of rents collected from 200 office buildings across the United States between 1988 and 1996. Observe that rents decline at a rate of about 1.5 percent for each year that a building ages (relative to a new building). This curve is called the rent gradient. By using an economic model—a set of theoretical relationships spelling out the connections between the demands for equipment and structures, the rent gradient, and technological progress—the gradient can be linked to an estimated underlying rate of technological progress in structures. With this approach, the underlying estimate turns out to be 1 percent annually. That is, each forgone unit of consumption can purchase 1 percent more "standardized" units of structures each year.

Measuring the Economy's Capital Stock

Computing the value of the economy's stock of equipment and structures is a formidable task. Conceptually, the capital stock at a given point in time is the sum of all previous purchases of capital that are still in use. This raises two problems. First, investment-specific technological progress causes a dollar of investment spending in 1999 to differ from a dollar of investment spending in 1945. Hence, spending on capital at different times needs to be converted into standardized units. Second, it is difficult to calculate what portions of past investments are still in use. Some investments will have been abandoned, some will be operating at less-than-full efficiency because of wear and tear (this is called physical depreciation), and some may not be used because they are economically obsolete, though still capable of operating.

The National Income and Product Accounts adjust only partially for the quality improvement in investment over time, so they underestimate growth in the economy's capital stock. For example, they calculate that over the postwar period, the economy's stock of equipment has grown at an annual rate of 2.5 percent and its stock of structures at 0.75 percent. Contrast these numbers to the estimates of 4.4 percent and 2.2 percent that are based on the 3.2 percent and 1 percent rates of technological progress in equipment and structures discussed earlier.

■ Accounting for Growth

How much of economic growth is due to investment-specific technological progress? Economists often think of GDP as being made from three factors of production: equipment, structures, and labor. Other things being equal, GDP will increase whenever one of these factor inputs grows. The part of GDP growth that cannot be explained by growth in any of these inputs is disembodied technological progress, which is why Moses Abramovitz called it "a measure of our ignorance."

Now, factor inputs grow as a result of technological progress, among other things. The fact that equipment is more productive over time is likely to imply that businesses, governments, and households will demand more equipment. It may imply that they will demand more structures as well. The value of a building increases when it can work with more productive equipment. Likewise, the value of equipment may rise when it is housed in better structures. Therefore, the economist must calculate how much of the increase in the equipment stock arises from technological progress in equipment and how much arises from technological progress in structures or other factors, that is, from disembodied technological progress. Again, this can be done with the aid of an economic model. This means breaking down GDP growth into growth of factor inputs and then breaking down factor input growth according to the various sources of technological advance. The results of doing all this suggest that 37 percent of economic growth results from technological progress in equipment and 15 percent from structures.[9] In other words, investment-specific technological advance accounts for more than half of economic growth. Evidently, Solow was right.

Footnotes

1. See Alan Greenspan's remarks at the Economic Conference of the Federal Reserve Bank of Boston, June 1996.

2. See Robert M. Solow, "Investment and Technological Progress," in Kenneth Arrow, Samuel Karlin, and Patrick Suppes, eds., *Mathematical Methods in the Social Sciences.* Stanford, Calif.: Stanford University Press, 1960, pp. 89–104.

3. W.E.G. Salter noted some time ago that the best plant in the U.S. blast furnace industry operated at twice the average productivity level for the industry. Recent studies confirm that there is a large gap in other industries as well. See W.E.G. Salter, *Productivity and Technical Change.* Cambridge, U.K.: Cambridge University Press, 1966.

4. The key question for the policymaker is whether workers should finance the costs of such retraining themselves.

5. See *Time Well Spent: The Declining Real Cost of Living in America.* Federal Reserve Bank of Dallas, 1997 Annual Report, exhibit 6.

6. Robert J. Gordon, *The Measurement of Durable Goods Prices.* Chicago: The University of Chicago Press, 1990. This number probably underestimates the actual rate of decline in the prices of new producer durable goods, largely because the series did not adjust all producer durable prices for quality improvements.

7. *Time Well Spent: The Declining Real Cost of Living in America*, p. 19.

8. The data reported from here to the end of this *Commentary* are from Michael Gort, Jeremy Greenwood, and Peter Rupert, "Measuring the Rate of Technological Progress in Structures," *Review of Economic Dynamics*, vol. 2, no. 1 (January 1999), pp. 207–30.

9. Disembodied technological progress accounts for the remaining 48 percent of economic growth.

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