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Technological Change

This Economic Letter *summarizes the papers presented at the conference "Technological Change," held at the Federal Reserve Bank of San Francisco on November 14–15, 2002, under the joint sponsorship of the Bank and the Stanford Institute for Economic Policy Research. The papers are listed at the end and are available at http://www.frbsf.org/economics/conferences/0211/index.html.*

In the latter part of the twentieth century, information technology (IT) came to be used everywhere—in offices, factories, and homes—and transformed the way things are done in activities as diverse as jet aircraft design, document production, and home entertainment. This technology also has improved tremendously, as evidenced, for instance, by the quick succession of more powerful computers with faster processors, greater storage capacity, and so forth.

Two of the conference papers noted that the use of computers in diverse applications was similar to the use of earlier technologies, such as steam and electricity, and looked at the evolution of those older technologies to understand both how computers diffused through the economy and the effects they were likely to have on it. Another theme at the conference was "technological embodiment," which refers to technological change that is embedded in the machine and is the reason one must buy a new computer every few years in order to use the latest technology. Among other things, embodiment can explain why it took a long time for the effects of technological change in the computer industry to show up in higher productivity in the economy. Other papers at the conference were concerned with the spread of technology across countries, asking, for instance, whether the process of technological diffusion ensured that all countries grew at the same rate.

Industrial revolutions and the diffusion of technology

Nick Crafts (2002) uses two recent developments in economic analysis to study his well-known finding that the pace of productivity growth and technological innovation during the industrial revolution was not as rapid as had been believed. The first is work on general purpose technologies (GPTs), which Lipsey, et al. (1998) define as "...a technology that initially has much scope for improvement and eventually comes to be widely used, to have many uses, and to have many...technological complementarities." The most cited examples of GPTs include electricity, steam, and IT. Second, because conventional methods of growth accounting do not account for the improvement in the quality of capital over time (and so tend to understate the contribution of technological change to growth), Crafts uses some recent techniques that explicitly account for embodiment.

An analysis of data incorporating these new developments leads him to confirm his earlier conclusion, which is that it takes a long time for GPTs to have a significant impact on productivity. In fact, he finds not only that steam power had a relatively small impact on productivity growth initially, but also that this impact was smaller than that of comparable GPTs, like electricity and IT, at a similar point in their development. An important reason was that the real price of steam power stayed high for many decades. And while he does find that using the new method of growth accounting rather than the traditional method raises the estimated effect of technological change on British output growth between 1780 and 1860, the difference is not very large.

Atkeson and Kehoe (2001) study technology diffusion during the "second industrial revolution" (1860–1900), when a host of new technologies were invented, including those based on the use of electricity. Economic historians have argued that the full effects of these technologies were not felt until many decades after their introduction. It is not hard to see why; for instance, in order to reap the benefits of electrification, manufacturing firms had to replace old machinery (which relied principally on steam power) and reorganize their production processes.

The authors' model reproducing this slow diffusion contains two key assumptions. First, new technologies are embodied in capital goods. Second, a plant's productivity rises with its age, reflecting a process of learning-by-doing. The authors then consider what happens when there is a sustained acceleration in the productivity of capital goods. While the standard model for studying this phenomenon predicts a rapid transition to a higher long-run growth rate that is at odds with the historical experience, the authors' model yields a pattern of slow diffusion of new technologies through the economy, which is similar to the pace of electrification of the manufacturing sector in the first part of the last century.

Interestingly, their model does not imply slow diffusion during the "Information Technology Revolution." Recent high rates of embodied technological progress imply that, compared to the past, capital goods now get obsolete much more quickly and firms have less time to accumulate experience with their capital (the learning-by-doing effect). As a result, firms scrap their old capital much more rapidly than before. This prediction of rapid diffusion counters the arguments of some economic historians, who use the slow diffusion of technology in the early twentieth century to explain why the introduction of IT late in the twentieth century did not have a more immediate impact on productivity growth.

International diffusion of technology

In a world with embodied technology, trade in capital goods provides a means for the international diffusion of technology. Caselli and Wilson (2002) look at what determines the kinds of capital goods countries import and the effects of these decisions on a country's level of income. They begin by specifying a production function where output depends upon labor and different kinds of capital and show that this can be rewritten as the product of two terms: a conventional production function where output depends upon the quantity of labor and of capital plus a term that contains information about the different kinds of capital in use. They hypothesize that the amount a country invests in a particular kind of capital depends upon the relative efficiency of that capital and upon its complementarity with various characteristics of the country in question (such as the skill level of its labor force). The relative efficiency of capital depends upon the amount of research and development embedded in it.

Since most countries acquire embodied technologies by importing capital from a relatively small number of technological "leaders," they argue that capital imports provide a measure of technology adoption by "follower" countries. Data on capital imports then can be used to draw inferences about the kinds of capital investments different countries make. They find a wide variation in the kinds of capital imported by different countries, with the mix depending upon country-specific factors such as human capital (or the skill level of the countries workers), institutions (such as property rights), and the level of financial development. They also show that taking the quality of capital into account provides a significantly better explanation of income differences across countries than a specification where only the quantity of capital is accounted for.

Benhabib and Spiegel (2002) examine the role of human capital in the process of technology diffusion across countries and show that the way this diffusion takes place matters for the long-run distribution of per capita income across countries. They point out that several previous studies (including one of their own) adopted a specification for the technology diffusion process that ensures that (a measure of) productivity in all follower countries will grow at a pace determined by technological innovation in the leader country. However, it is possible to specify the diffusion process in other ways, including those in which diffusion gets weaker as the geographical distance between the follower and the leader increases. Indeed, if the human capital stock of a follower is sufficiently low, this kind of process implies that productivity growth in the follower country may never catch up with the leader.

Using data on productivity growth rates for a sample of 84 countries over the 1960–1985 period, they find that human capital (schooling) facilitates catch-up in productivity across countries. However, their results also favor the specification of the diffusion process which implies that productivity growth in some follower countries may never catch up with the leader. They estimate that an average of 1.78 years of schooling was required in 1960 to ensure that productivity growth in a given country caught up (eventually) with productivity growth in the U.S. Under this criterion, they identify 27 countries that were predicted to exhibit slower productivity growth than the U.S. Over the next 35 years, 22 of these countries did fall farther behind the U.S. in productivity growth, while the bulk of the nations in their sample tended to catch up with the U.S. in productivity growth

Some other implications of technological change

Hornstein, Krusell, and Violante (2002) present a model in which the interaction of embodied technological change with labor market institutions helps to determine key labor market characteristics, such as the unemployment rate and the distribution of wages across different kinds of workers. The model also provides an explanation for the differences in the behavior of U.S. and European labor markets in recent years. For example, in 1965 the unemployment rate was lower in virtually every European country than in the U.S. However, while the U.S. unemployment rate rose by only 1.7% over the next 30 years, the average increase for European countries was 8.4%.

To understand how their model works, note first that capital must be used for a minimal period in order to recover investment costs. Labor costs matter as well. The U.S. economy has relatively low unemployment benefits, which implies low labor costs, so that capital can remain in use for a relatively long time. In contrast, Europe has high benefits and high labor costs, which forces firms to scrap capital earlier. Now consider what happens when there is an increase in the pace of technological change. The assumption of embodied technology means that the benefits of faster technological change can be obtained only by faster replacement of machines. This is relatively easy to do for U.S. firms, but it is hard for European firms because the life of capital in Europe is already very short. European firms must be compensated along some other margin; in their model this occurs through an increase in the probability that a firm's search for a worker will be successful. An increase in this probability, in turn, requires a larger pool of available workers, which is accomplished through longer spells of unemployment. In a quantitative exercise with their model, they show that a 2 percentage point increase in the rate of embodied technological progress raises the unemployment rate by less than 1 percentage point in a U.S.-type economy but by more than 8 percentage points in a European-type economy.

Greenwood, Seshadri, and Vandenbroucke (2002) use technological change to explain variations in fertility rates over time. According to the authors, two features stand out in the data on the fertility of U.S. women over the last 200 years. The first is a drastic decline: the average white woman had seven children in 1800 but only two in 1990. The second is a surprising recovery in fertility between the mid-1940s and the mid-1960s—the "baby boom."

Their model explains both features of the data by technological progress, although of different kinds. The long-run decline in fertility is explained by technological progress in the market sector. Ongoing technological progress over this period has raised individuals' wage rates. The implicit cost of having children has risen as a consequence, because individuals now must give up a greater amount of consumption goods for every hour spent on raising children; this tends to lower fertility. By contrast, technological progress in the household sector tends to raise fertility, because it frees up the time women used to spend on household tasks. Of course, having more children is not the only possible response to more free time; women could decide to spend some of this time in market activities as well, i.e., their labor force participation rates could increase as well. The authors argue that a burst of technological progress occurred in the household sector around the 1940s, arising from the second industrial revolution. For instance, refrigerators entered household service in the 1920s and the first fully automatic washing machine appeared in the 1930s. Consistent with their model, these innovations were followed by a period of rising fertility and rising female labor force participation rates. In fact, the biggest percentage increase in fertility during the baby boom was among working women.

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Conference Papers

Atkeson, Andrew, and Patrick J. Kehoe. 2001. "The Transition to a New Economy after the Second Industrial Revolution."

Benhabib, Jess, and Mark M. Spiegel. 2002. "Human Capital and Technology Diffusion."

Caselli, Francesco, and Daniel Wilson. 2002. "Importing Technology."

Crafts, Nick. 2002. "Productivity Growth in the Industrial Revolution: A New Growth Accounting Exercise."

Greenwood, Jeremy, Ananth Seshadri, and Guillaume Vandenbroucke. 2002. "The Baby Boom and Baby Bust: Some Macroeconomics for Population Economics."

Hornstein, Andreas, Per Krusell, and Giovanni L. Violante. 2002. "Vintage Capital as an Origin of Inequalities."

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Lipsey, R.G., C. Bekar, and K. Carlaw. 1998. "What Requires Explanation?" In *General Purpose Technologies and Economic Growth*, ed. E. Helpman. Cambridge, MA: MIT Press.

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