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Where to Find the Productivity Gains from Innovation?

The surge in U.S. productivity growth that began in the mid-1990s has generated considerable debate among economists. While most agree that the boom in information technology (IT) investment greatly contributed to this surge, many argue whether this contribution is mostly due to productivity gains in the *manufacture* of IT goods or whether the productivity gains "flowed downstream" from the IT manufacturers to the *users* of IT goods in other industries. If productivity gains do flow downstream to users, then it is more likely that aggregate productivity growth will persist for many years, even if the pace of innovation were to stall, as downstream industries continue to discover productive uses of the new technologies.

While the focus on the impact of IT innovations in recent years is understandable, innovations in equipment affecting users' productivity has been much broader. A key source of the innovation in business equipment has been industrial research and development (R&D). Thus, knowing the relative amounts of R&D spent to develop various types of business equipment gives a sense of the degree of "innovativeness" embodied in each type of equipment and allows us to move beyond a dichotomous world where only IT equipment is considered innovative. This *Economic Letter* reports the results of a study (Wilson 2002) that looks at industrial R&D spending on all types of business equipment and develops an index to measure how much R&D spending is embodied in a downstream industry's equipment. The results show that the extent of R&D embodied in the equipment used by a downstream industry is an important contributor to that industry's productivity growth. This finding provides strong evidence that much of the benefit of innovation does flow downstream from the innovating firms making equipment to the firms and industries that *use* the equipment embodying those innovations.

The downstream flow of productivity gains

Why might we believe that productivity gains would flow downstream from the firms manufacturing the innovative goods to the firms using them? The answer lies in viewing an innovation as a kind of new product and then appealing to an analogy with the well-established theory of consumer surplus. In this theory, if the seller of a product cannot set the price—for each and every consumer—at the highest price the consumer is willing to pay, then some consumers will get the product at the market price, even though they were willing to pay more. The difference between the price those consumers were willing to pay and the actual price is called consumer surplus. In the case of the productivity benefit from an innovative piece of equipment, the situation is similar: because the productivity benefit of the innovation varies from firm to firm, some are willing to pay more than others; yet, if all firms face a common market price, some will get more productivity benefits per dollar of equipment than others.

R&D spending

R&D consists of three components: basic research, which generates new scientific knowledge without a targeted application; applied research, which uses existing knowledge to invent or improve a specific application; and development, which commercializes new and improved applications. The majority of R&D spending is in applied research and development, and it makes up virtually all of industrial R&D (i.e., performed by private industry).

Applied R&D is either *process-oriented* or *product-oriented*. Process-oriented R&D improves a firm's production process by using its existing capital, labor, and raw materials more efficiently or by using different types of capital, labor, and materials. For example, Boeing's R&D unit, Phantom Works, devotes considerable resources to designing new assembly lines to use new high-speed, computer-aided machine tools most efficiently. In contrast, product-oriented R&D involves creating new or improved products; for example, machine tool companies expend product-oriented R&D on developing the innovative machine tools used in Boeing's assembly lines. In general, it is product-oriented R&D that generates innovations that are traded on a market at a common price. And, as discussed above, consumer surplus theory suggests that these are the criteria that generate downstream productivity gains. Although basic research also contributes to generating marketed innovations, its link to any particular innovation is far less visible than it is for applied R&D.

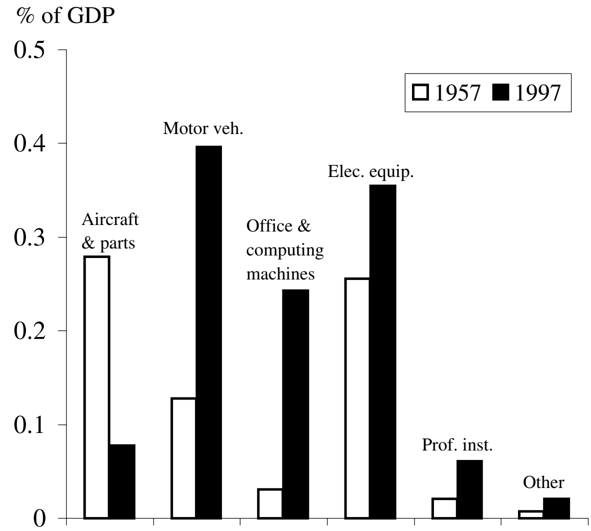
The National Science Foundation (NSF) publishes data roughly biannually from 1957 to 1997 on industrial applied R&D by "product fields," which include 13 types of business equipment. Figure 1 shows R&D as a share of GDP in 1957 and 1997 broken down by these equipment categories. ("Other Equipment Types" shows the median of the shares of six other fields that are not shown separately. Likewise, the data include two separate professional instruments categories, but only the median of their shares is shown.)

While real equipment R&D spending rose sixfold over the last four decades (rising from 0.8% to 1.4% of GDP), it was far from evenly distributed among types of equipment. For instance, real R&D directed at computers rose by a factor of 27 from 1957–1997, while aircraft R&D actually fell! (Interestingly, real aircraft R&D spending rose steadily from 1957 to 1987 but declined rapidly thereafter, ending up slightly below its 1957 level by 1997). As a share of GDP, R&D spending on computers rose from 0.03% to 0.24% while R&D on aircraft declined from 0.28% to 0.08%. The other categories all show substantial rises in R&D relative to GDP, though none are as dramatic as for computers.

These data also indicate which types of equipment have received the most in R&D spending on average over the four decades. R&D spending is generally highest in electrical equipment and motor vehicles; together these categories account for around 50% of equipment R&D on average. And because of the vast amounts of R&D that were done on aircraft prior to recent years, the cumulative *stock* of R&D knowledge regarding aircraft still remains quite high. So, unless the knowledge gained regarding aircraft and other types of equipment from the large amounts of R&D done in earlier decades has "depreciated" at a very high rate, the data suggest that computers are not the only, and perhaps not even the most, innovative type of equipment. One caveat here is that the data in Figure 1 do not include basic research, and it may be that computers embody a larger share of basic research than these other types of equipment.

Figure 1

R&D in U.S. by equipment type



Building the "embodied R&D index"

The central idea of Wilson (2002) is that the primary source of the innovation embodied in capital equipment is product-oriented R&D. This implies that productivity gains from capital equipment depend on two factors: (1) the makeup of the capital equipment firms have, that is, their computers, their turbines, their hammers, desks, etc., and (2) how much R&D is embodied in each type of equipment.

The NSF data provide information on the second of these factors. Data on the first factor can be compiled from the U.S. Bureau of Economic Analysis's estimates of investment by capital type, which cover 63 industries throughout the U.S. private economy. A careful look at these data reveals two main facts. First, the distribution of investment across capital goods varies greatly across industries. Second, the economy as a whole has shifted gradually over time towards investing in more innovative (i.e., higher R&D) capital. The equipment types that account for a greater share of total investment now compared to 1957 are Computers, Electrical Equipment, Motor Vehicles, Aircraft, and Instruments—exactly those equipment types that have received the most R&D.

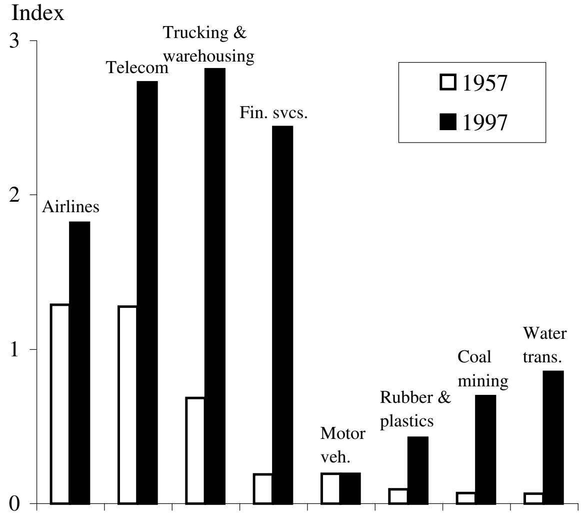
Wilson (2002) uses data from both sources to construct an "embodied R&D index," which measures the stock of R&D embodied in each industry's capital equipment. It is built on the assumption that the technological change embodied in an industry's equipment is proportional to a weighted average of the R&D associated with each type of equipment it uses. The R&D measure is a stock of past and present R&D by equipment type computed from the NSF data. The weights for an industry are the shares of each equipment type in the industry's total equipment investment.

What industries use the most innovative capital?
The embodied R&D index tells us which industries tend to use the most innovative capital, in the sense that it is undergoing rapid technological change, and how the innovativeness of any given industry's capital has changed over time. The index is independent of the *scale* of an industry's investment; it is meant to measure the innovativeness per dollar of investment.

The results of building this index are striking. Figure 2 illustrates the embodied R&D index (normalized to equal 1 in 1977 for the median industry) in 1957 and 1997 for a sample of industries. The industries with the highest value for the embodied R&D index in 1997 are Trucking and Warehousing, Telecommunications Services, and Radio and Television (not shown). Trucking and Warehousing's high value is due to the large amount of R&D directed at motor vehicles over the past four decades and to the fact that the Trucking and Warehousing industry's equipment capital is, not surprisingly, primarily motor vehicles. The top industry in 1957 was Airlines, but, reflecting the decline in R&D devoted to aircraft, this industry's rank fell to 24 (out of 63) by 1997. Services, such as financial, legal, and insurance services, have climbed up the rankings over the past four decades and now rank near the top in terms of embodied R&D. This shift is due to the combination of increasing amounts of R&D directed at computers and to the shift in service industries' mix of equipment towards computers. Though service industries buy far less equipment than most other industries, the equipment they buy tends to be very R&D-intensive.

The industries that rank near the bottom, such as Water Transportation, Coal Mining, and Rubber and Plastic Products, generally have been near the bottom of the distribution for the entire 1957–1997 period. One interesting case is that of the Motor Vehicles industry, which was second to last in R&D embodied in equipment in 1997. The low level of embodied R&D for this index illustrates the distinction between having an innovative product and having innovative capital. As Figure 1 showed, a great deal of R&D is devoted to improving the technology in motor vehicles. However, a relatively low amount of R&D is devoted to the types of equipment, such as metalworking machinery, used most intensively by the Motor Vehicle industry. This example instructs us to be careful when we call an industry "innovative"; an industry can be innovative either on the output side or the input side, and these two need not be related.

Figure 2
Embodied R&D index for selected industries



Does embodied R&D lead to productivity gains?
The embodied R&D index helps answer the question: Do industries with more embodied R&D tend to have faster productivity growth than others? As described in detail in Wilson (2002), the answer is *yes*, whether measuring productivity as output per worker or output per unit of capital, labor, and raw materials combined (the latter measure is known as total-factor productivity or TFP). For instance, over a quarter of the variation in TFP across industries can be explained by variation in the embodied R&D index. This result supports the hypothesis that productivity benefits from R&D flow downstream to the users of the equipment embodying that R&D. This result is supportive of other research findings that industries that use IT goods intensively exhibit higher productivity growth than other industries, holding all else equal. However, it also shows that the use of IT may not be the only road to fast productivity growth; it is the use of *innovation*, not just IT, that delivers rising productivity.

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Reference

Wilson, Daniel J. 2002. "Is Embodied Technological Change the Result of Upstream R&D? Industry-Level Evidence." *Review of Economic Dynamics* 5(2) (April), pp. 342–362.

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