

Key Findings:

- *Technology is the single most important driver of long-term growth*
- *New technologies drive both new products & services and overall productivity*
- *Technology-based industries provide higher paying jobs*
- *Government and industry roles in the development of technology are complementary*

Some Evidence of Technology's Impacts on Economic Growth

*Gregory Tasse*y (gtassey@nist.gov)

Economic studies over several decades have consistently shown a strong impact of R&D investment on both productivity and output growth, with a number of these studies also implying significant underinvestment.

Macroeconomic Studies

- "Growth accounting" studies have estimated that technology accounts for more than one-half of economic (GDP) growth in all OECD countries except Canada (Boskin and Lau, 2000).
- The average productivity advantage of the United States over OECD countries as a group accounts for three quarters of the per capita income difference (McGuckin and van Ark, 2002).
- Changes in technology are the only source of permanent increases in productivity (Basu, Fernald, and Shapiro, 2001).
- For the period 1995–99, the combination of innovation and capital deepening (acquisition of technology through capital investment) accounted for two-thirds of productivity growth (Oliner and Sichel, 2000).
- The *acceleration* in productivity growth in the last half of the 1990s was due entirely to investments in information

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technology (Basu et al., 2001 and Jorgenson, 2001).

- While three-quarters of US industries contributed to the acceleration in economic growth in the late 1990s, the four IT-producing industries were responsible for a quarter of that acceleration while only accounting for 3 percent of the GDP (Jorgenson, 2005).
- Technologically stagnant sectors experience slow productivity growth and, therefore, above average cost and price increases; the rising prices actually increase these sectors' measured share of *nominal* GDP, thereby lowering national productivity growth (Baumol, 1967; Nordhaus, 2006).
- Economists have estimated the private rate of return from R&D to be 2.5 to 4 times the estimated rate of return on physical capital (Hall, Mairesse, and Mohnen, 2009). Jones and Williams (1998, 2000) estimate the rate of return from R&D to be four times that from physical capital, "implying that R&D investment should be increased by a factor of four".
- The Bureau of Economic Analysis (BEA)'s satellite R&D account for the first time provides an explicit estimate of "R&D's" contribution to economic growth (under the traditional system of national accounts, most of GDP growth is attributed to labor and capital). BEA's average annual estimate is 6.7 percent between 1959-2007 (by comparison, the 40-year average contribution of buildings and factories is less than 2 percent).
- However, this estimate of R&D's contribution is much lower than the growth accounting studies. In addition to methodological differences (the BEA approach is potentially much more accurate), the huge difference appears due, to a significant degree, to the fact that the growth accounting approach approximates the total impact of *technology* on the economy. In contrast, the BEA estimate is only for the impact of *R&D investment* on the industry in which the R&D is conducted. Thus, for example, BEA is only estimating the impact of computer industry R&D on the computer industry and does not include an estimate of this investment's impact on all the industries that use computers. Over time, BEA's intent is to expand the scope of R&D impact assessment.

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Microeconomic Studies—Private R&D

- Analyses of industry-level R&D indicate levels of impact similar to the macroeconomic analyses: about one-half of output growth and three-quarters of productivity growth are attributable to R&D investment (Griliches, 1995).
- Studies of return on investment from R&D have shown a social (aggregate internal) rate of return to R&D of between 50–100 percent, which is about double the estimates of private rates of return (Nadiri, 1993, Popper, 1995). It is important to note that these studies used the internal rate-of-return method, adapted from corporate finance where the R&D is a narrowly defined (project-level) time series. Other studies have used the production-function approach where the elasticity of R&D investment with respect to productivity growth is assessed (Hall, 1996; Hall, Mariesse, and Mohnen, 2009).
- Research has indicated significant variation across industries in the impact of R&D. This supports the R&D management literature, which identifies numerous factors affecting the productivity of R&D. However, no evidence has been produced to indicate diminishing returns from increased R&D across the range of R&D intensities found in manufacturing industries (Cameron, 1999). Thus, no support exists for the argument that some industries need less R&D than others.
- The rate of return on basic science is about three times that of applied R&D (Griliches, 1995)

Note: because an important phase of R&D between basic science and applied R&D, namely generic technology platform research, is not part of the NSF data collection scheme, companies are forced to allocate those funds (such as their budgets for central corporate research to basic science. Most of this research is not basic science but, rather, generic/fundamental *technology* research (e.g. Bell Labs proof of concept for the transistor). Thus, references, such as this one to industry basic science, really means the long-term, high-risk generic technology research in central corporate labs

- High-tech industries are not only producing the higher rates of productivity growth but exhibit the highest

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wages and salaries. Specifically, Bureau of Labor Statistics (BLS) analysis shows that the median earnings in all but one of the 71 BLS technology-oriented occupations exceeded the median for all workers in 2004. In six high-tech occupations, earnings exceeded three times the median. In 34 more, earnings were twice the median; in another 17, earnings exceeded the median by 50 to 99 percent (Hecker, 2005).

Note: Most economic studies underestimate the contribution of R&D to productivity and output growth for two major reasons: (1) Much R&D (especially in the United States) is directed toward social goals, the output of which is difficult to measure (national defense, environmental quality, energy independence, space exploration, health care); (2) Measurement of the output in R&D-based industries (based on inaccurate price indexes) does not allow for quality improvements due to R&D (Griliches, 1995).

Microeconomic Studies—Government R&D

- Differences in the impacts of industry and government R&D are blurred because (1) most economic analyses of this topic used data from the period when much government R&D was mission-oriented (as opposed to the objective of stimulating economic growth); (2) the data were too aggregated; and (3) economists have incorrectly modeled government R&D as a substitute rather than a complement to industry R&D (Hall, 1996).
- Studies of one type of government technology research (infratechnology) have estimated high net aggregate (social) economic benefits. 21 NIST economic impact studies conducted over the past 12 years of technical infrastructure supplied to industry to increase R&D, production, and market transaction productivities have delivered an average benefit-cost ratio of 40:1.¹

¹ For a summary and assessment of economic impact analysis methods and an overview of the results of NIST economic impact studies, see Link and Scott (2012).

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- Most academic research is funded by government, so the economic impact of this research is a reflection on government funding policies. Mansfield's (1990) well-known paper indicated that about one-tenth of the new products and processes commercialized during 1975–1985 could not have been developed (at least not without substantial delay) without academic research.
- Most economic studies of technology's impacts suffer from treating R&D and hence economic benefits in homogeneous ("black-box") terms. This weakness prohibits assessing the determinants of important ("radical" or "breakthrough") technology research that have far greater economic impact; i.e., "forward spillovers" into applied R&D that targets specific market applications (Tassey 2007).
- A few studies have examined the impacts of breakthrough vs. incremental innovations. In one such study of 11 radical innovation efforts within major corporations, a team from Rensselaer Polytechnic Institute concluded that "the life cycle of a discontinuous innovation project is profoundly different from a continuous improvement project." The 11 projects studied exhibited several of the categories of market failure described in the next section. In eight of these projects, the researchers found that government was a major source of funds (Rice *et al*, 1998).
- That such radical innovations are more profitable was shown in a study by Kim and Morbougne (1997). They surveyed R&D-intensive companies in the United States and Europe to obtain sales and profits data on investments in incremental improvements based on the current generation of technology (product line extensions) and in new products based on new emerging generic technology platforms. For the average firm responding to the survey, product-line extensions dominate both in terms of number and sales. This result is hardly surprising, as companies focus most of their resources on extracting value from their current technology platforms. However, a majority of profits were found to be attributable to the relatively few "discontinuous" innovations (i.e., innovations based on radically new generic technology platforms).

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Anecdotes of Technology's Impact

- While automobiles' miles per gallon have improved 40 percent since 1978, and replacing a 1978 incandescent bulb with today's compact fluorescent bulb improves the lumens per watt by 339 percent, the improvement in computer systems' instructions per second per watt since 1978 has increased 2,857,000 percent.²
- Technology platforms developed by Bell Labs included fax transmission, long-distance television transmission, photovoltaic solar cells, the transistor, the UNIX operating system, and cellular telephony. Each laid the groundwork for vibrant new industries. "The transistor alone is the building block for computers, consumer electronics, telecom systems, high-tech medical devices, and much more. DARPA's creation of the Internet (as ARPAnet) in 1969 and Xerox PARC's development of Ethernet and the graphical user interface (GUI) set the stage for the PC revolution. These proofs of concept unleashed cycles of applied innovations that created new economic sectors."³
- IT has spawned a new class of companies and capabilities:
 - The first web browser was commercialized 1994. In March of 2009, there were 14 billion web searches.
 - The first text message was sent in 1992. Today, the number of text messages sent every day exceeds the population of the planet.
 - Skype launched computer-to-computer communications in 2003, registering 445 million users by first quarter 2009 and logging in 24 billion call minutes.
 - Twitter was launched in 2006. Now there are more than 32 million users.⁴
- The most powerful codes are no longer in strings of ones and zeroes, but in four letters: A, T, C and G. This is the programming language of life. Different combinations of those

² Technology CEO Council, "A Smarter Shade of Green – How Innovative Technologies are Saving Energy, Time, and Money," 2008.

³ Adrian Slywotsky (2009), "How Science Can Create Millions of New Jobs," *Business Week* (http://www.businessweek.com/magazine/content/09_36/b4145036678131.htm). August.

⁴ <http://shifthappens.wikispaces.com/Various+Versions+of+the+Presentations>. Also, van Opstal (2009)

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four letters—DNA bases—describe every life form on earth. The ability to understand and manage them will revolutionize the competitive landscape in every sector, from medical to agricultural.

- In the medical arena, the ability to treat disease by turning genes on and off will make today's medical therapies—amputations, consumption of toxic chemicals and irradiation—look primitive. With genomics, medicine can become predictive, preventive and personalized. And the industry will look considerably different when information technology—capturing the DNA profile for every individual—is as important, if not more so, as identifying chemical compounds with useful properties in treating disease. Decoding the first human genome took 10 years and \$3 billion dollars. The ability to produce a personal genetic code for about \$5,000 in an hour or two is not far off in the future (Van Opstal, 2009).

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