The Case for Technology in the Knowledge Economy

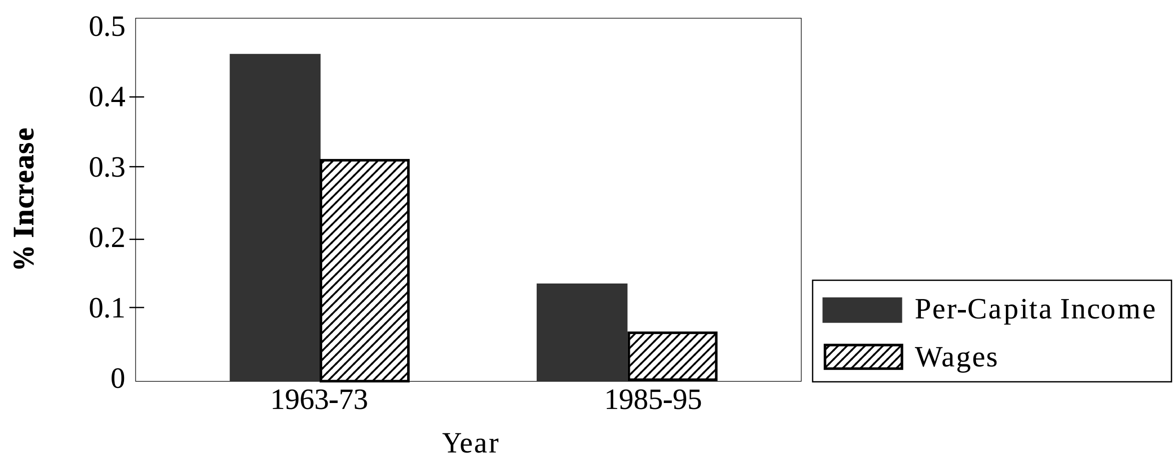
R&D, Economic Growth, and the Role of Government[1]

Kenan Patrick Jarboe and Robert D. Atkinson

In the midst of a seven-year economic expansion and a booming stock market, it might seem like the last thing Washington policy makers should be considering is how to get the economy to grow faster. Yet, while the stock market may be booming, the underlying economy and the wages of American workers have been creeping up at a meager pace.

Productivity, the factor that determines economic growth, has grown slowly over the last 25 years. While productivity rose at an annual rate of 3.1 percent between 1947 and 1973, it has grown at an anemic 1.3 percent per year since then. Even with the recent spurt, productivity growth in the 1990s has been the lowest since the 1960s. If we had been able to sustain post-war productivity gains, the median annual wage would now be $52,000, instead of $35,000. And with current rates, it won't be until the year 2066 that real living standards for Americans double. Given this performance, and its impact on American workers' incomes, it is appropriate to look more carefully at what drives productivity and economic growth.

Chart 1. Growth in Wages and Per-Capita Income



This paper summarizes new research about the sources of economic growth and the role government can play in fostering growth in the knowledge economy. Policy makers can draw a number of important conclusions from this research:

- *Technology, innovation, and knowledge are critical factors in economic growth;*

- There is a significant private return on research and development (R&D) investment at the firm and industry level—but an even greater return for society as a whole;

- There is a positive social value of raising the level of investment in technology and knowledge creation over that determined solely by the market;

- Technology and knowledge interact with a number of other factors, such as investment in equipment and education; and,

- Knowledge creation and technological innovation require special attention to institutional arrangements.

Implications for Federal Policy

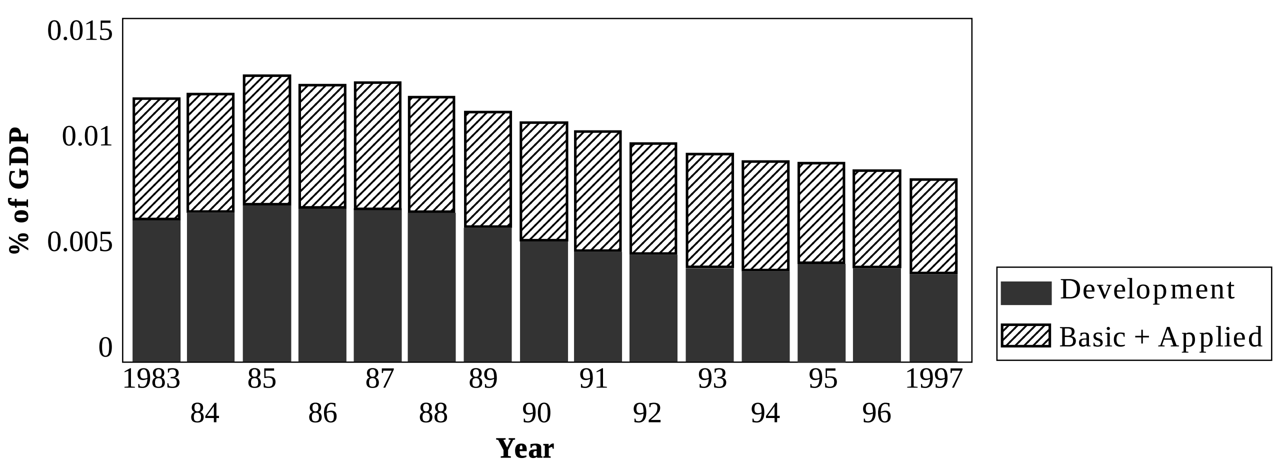
To effectively spur economic growth in the new knowledge economy, government must go beyond its traditional roles of spurring consumption Keynesian style or simply cutting taxes on capital. In the New Economy, science, technology, and innovation are the major drivers of economic growth. There are three major implications for federal policy in this area.

First, one of the messages from economic research is that there is a clear role for federal support of research and that role is increasing, not decreasing, in the new knowledge economy. **Support for research needs to be one of the key foundations of a new growth policy to get the U.S. per-capita incomes growing again at post World War II rates.**

But at a time when it should be rising, government support for non-defense R&D has been steadily dropping, from about 1 percent of gross domestic product in the 1960s to less than half (0.4 percent) that number today. The share of the federal budget invested in non-defense R&D fell from 5.7 percent in 1965 to 1.9 percent in 1997. The decline is actually gaining steam, with federal investments in all research having shrunk at an average annual rate in constant dollars of 2.6 percent between 1987 and 1995. Moreover, U.S. government investment in civilian R&D relative to the size of its economy is lower than that for Germany and Japan, and governments in both countries have announced plans to increase their R&D expenditures. Clearly, **a central task for economic policy in the New Economy is to boost federal support for research.**

Sens. Joe Lieberman (D-CT), Phil Gramm (R-TX), Jeff Bingaman (D-NM), and Pete Domenici (R-NM) argue that it is time to turn that trend around and rebuild public invest-

Chart 2. Federal Support for R&D as Share of GDP



ment in basic research. They have co-sponsored the National Research Investment Act of 1998, S. 1305, that would double federal expenditures for basic scientific, medical, and engineering research over a 10-year period, reaching an aggregate level of $68 billion in 2008. All the additional investment would be in "pre-competitive" stages of research.

Second, because the social benefits of R&D outweigh the private benefits, market-oriented policies to support R&D, such as the R&D tax credit, need to be in place to support innovation. Up until now, neither Congress nor the Administration has agreed to a permanent extension of the Research and Experimentation tax credit. Rather, they have continued to reauthorize it one year at a time. However, the uncertainty this generates for companies reduces the effectiveness of the policy.

Third, just as the private sector develops innovative institutional arrangements to support and advance research, so should federal policy. In particular, one of the defining features of the knowledge economy is the increased importance of learning and innovation. Partnerships and alliances, including between the private sector, universities, and government laboratories, play a key role in facilitating innovation. As a result, federal support for research in the knowledge economy needs to explicitly encourage research collaboration between industry, government labs, and universities. PPI will soon release a policy briefing exploring this issue in more depth and laying out specific policy recommendations.

Economists Unravel the Growth Puzzle

Just as the CEO told Dustin Hoffman to go into "plastics" in the movie "The Graduate," the advice for policy makers today who want to spur economic growth would be equally succinct: "technology." Economists have long agreed that technology is the most important engine for economic growth. Early studies of what was called "growth accounting" found that the accumulation of the traditional inputs of capital (K—physical capital in the form of land, buildings, and equipment) and labor (L—the number and hours of people working) contributed surprisingly little to economic growth. Nobel economist Robert Solow described the residual—what was left over after accounting for capital and labor—as "technical advances," defined as any change in how we produce goods and services, thereby increasing the growth potential above the rates of accumulating more capital and labor. Ever since these path-breaking studies, economists have been seeking to better understand this residual in order to reduce what Abramovitz called the "measure of our ignorance."

As a result, growth accounting models now include a factor for this residual generally called technology or knowledge. Models sometimes also add human capital to account for improvement in worker skills and knowledge. Some even include the contribution to growth from increased economies of scale (e.g., larger plants and businesses).

While economists disagree over details, they generally agree on the relative contribution of technical progress once methodological differences, like how to incorporate factors such as quality changes, are removed. Based on a review of most growth accounting models, Boskin and Lau (1992) estimated that half (49 percent) of economic growth came from technical progress. (See Table 1, p. 9) **When per-capita growth is measured, eliminating economic growth solely from a growing labor force, Solow (1957) estimated that 87.5 percent of growth in the first half of the century came from technical change. Coe and Helpman (1995) found that every 1 percent increase in a nation's investment in research increased productivity by 0.23 percent. The Congressional Budget Office found that basic research has significant positive effects on productivity.**

Economic Growth Theory for the Knowledge Economy

These studies clearly show the importance of technology to economic growth. But traditional models have provided policy makers little guidance as to the levers of economic growth. In this decade, in part to overcome this lack of knowledge, a new variation of the growth model called the "new growth theory" or "endogenous growth theory," has been developed.

New growth theory reformulates the growth model so that knowledge and technology are not simply treated as something that just happens outside of economic activity (exogenous). Under traditional growth accounting, technical progress is taken as a given and is viewed as occurring inside a "black box." The new growth theory views technical progress as inside of economic activity (endogenous) and seeks to explicitly understand and model how technological advance occurs, seeing it as a result of intentional activities by economic actors, including government. In the private sector, investment in the production of knowledge requires sufficient incentive; that is, an expected economic rate of return that exceeds some established hurdle rate. This "knowledge capital" is self-perpetuating and, therefore, economic growth is continuous with no need for constant boosts from outside "technical change." Because knowledge is cumulative, increased knowledge actually makes it easier and cheaper to produce even more knowledge and innovation. In a knowledge economy, this ability to "stand on the shoulders of giants" means that as long as government and business continue to invest, innovation grows.

As Grossman and Helpman (1991) explain:

> These spillovers allow successive generations of researchers to achieve technological breakthroughs using fewer resources than their predecessors. The resulting declines in the real [per unit] cost of invention counteract any tendency for profits to fall. In short, the process of knowledge accumulation generates endogenously the productivity gains that sustain growth in the long run.

One of the reasons for the rise of the new growth theory was the increasing recognition that the old economic models created in an industrial era dominated by commodity goods production could no longer adequately explain growth, especially in an economy fundamentally powered by knowledge and innovation. Endogenous growth theory stresses the difference between "knowledge" and other forms of capital. Previously, knowledge was assumed to be a pure public good that moves freely. New growth theory assumes that technology/knowledge varies in terms of the ability of more than one person to use it at the same time (rivalry) and the ability of someone to prevent others from using it (excludability). For example, a software program is a non-rival good that can be used by more than one person at a time, but is excludable to the extent that intellectual property protections (and the physical control of the disks) can prevent others from using the program without the permission of the owner of the software. The non-rival but excludable characteristics of knowledge means both that there are spillovers and that the economic benefits cannot be solely captured by the innovator. Thus, knowledge is neither a pure public nor private good.

The development of endogenous growth theory has changed the terms of the policy debate. Whereas before it was not always clear that there was a role for government in economic policy beyond managing the business cycle and protecting intellectual property rights, **the new growth theory makes it clear that there is a pro-active role for government to promote growth in the knowledge economy**. As Stanford economist Paul Romer (1998) states:

> Theoretical models. . . are not to the stage where they can give us much specific

> guidance about, say, the optimal share of R&D in GDP or the best mechanism for government support. However, it [new growth theory] has changed how we should think about the problem. Before, we started from a presumption that strong property rights and market trading were the optimal institutions for supporting economic activity. Departures from these institutions could be justified only on specific grounds—external effects, income distribution, etc. What the theory of endogenous growth has established is that while this traditional conclusion continues to apply with full force in the realm of objects, it does not, indeed logically cannot, apply when dealing in the realm of ideas. **Thus, there should no longer be any debate about whether some departure from market mechanisms is called for. Instead, what we should be asking is what the right institutions are in this new area.** (emphasis added)

The Government's Role in Preventing Under Investment in R&D

New growth theory argues that investment in knowledge creation is critical to economic growth and that new mechanisms are needed to sustain that investment. But why won't the private sector alone generate the level needed for optimal economic growth? The answer lies in the concept of spillovers and the differences between the private and social rates of return from investment in research (i.e. between the returns to those who developed the technology and the returns to society in general, including the returns to other companies who build upon the technology and the returns to consumers through better products and / or lower prices).

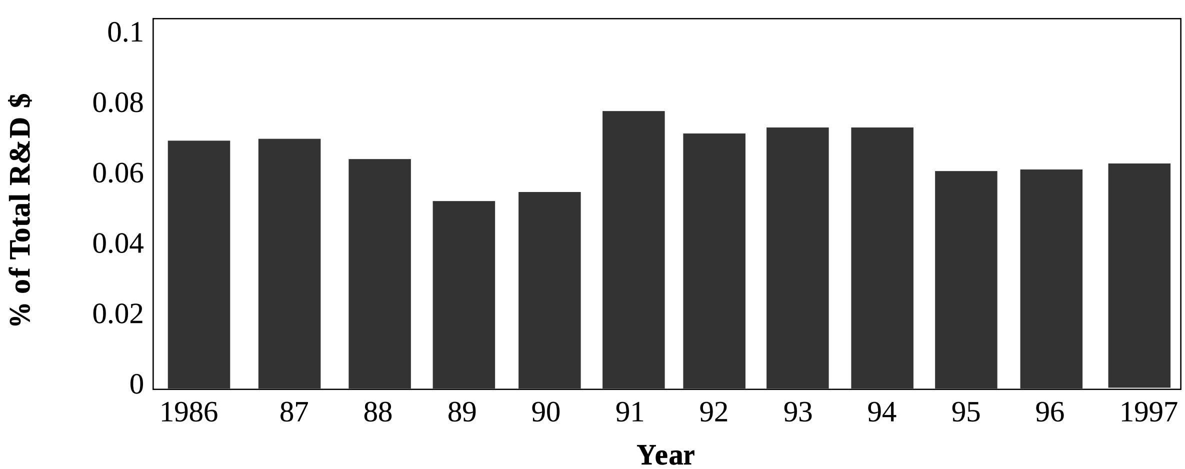
Since knowledge can be used by more than one (non-rival) firm, firms can often utilize the results of other firms' research to improve their own products and processes at a fraction of the cost of the original research. For example, the Xerox Corporation invested to develop the windows-icons-mouse paradigm of computing, but Apple and Microsoft made the money from this innovation. These kinds of spillovers create a free-rider problem whereby some gain freely from the efforts of others. This adds to the disincentive to invest in R&D, intensifying the problem of under investment.

Studies on the rate of return from research (RoR) have come to the same basic conclusion: **there is a significant private return on R&D investment at the firm and industry level—but an even greater *social* return**. (See Table 2, p. 10) For example, Coe and Helpman found that the average social RoR from R&D was 123 percent. Studies of specific technologies have shown equally large rates of return. For example, Trajtenberg (1990) calculated a social rate of return of 270 percent from development of the CT Scanner and Brynjolfsson and Hitt (1993) found the social rate of return of information technology to be over 80 percent. Similarly, Link (1981) estimated that the spillovers from company-funded basic research is even higher, over 150 percent.

The high social rates of return demonstrate the "public good" nature of research and development and indicate a positive role for government in R&D funding. **The large difference between the private and public rates of return means that absent public action, industry under invests in R&D**. Assuming a *conservative* estimate of 7 percent private return and 30 percent for the social rate of return on R&D, Jones and Williams (1997) estimate that the optimal level of R&D investment in the U.S. economy is four times larger than the total current level of private investment. That under investment means that economic growth will be slower than otherwise attainable.

Finally, the way in which many industries are structured leads not only to under investment in R&D, but to a skewing of funding toward less risky, short-term projects. One of the key market failures is uncertainty. In a rapidly changing technological environment, with the success of many technologies dependent upon the development and deployment of others (e.g., electric motor technology depends on developments in battery technology), it is increasingly risky to invest in particular technologies. As Tassey (1997) has argued, uncertainty blocks decision making and reduces R&D funding, while high levels of risk shift investment to short-term R&D projects. In fact, this is what appears to be happening in the United States. While companies are not decreasing their R&D expenditures, they are devoting a larger share of R&D to later stage, less risky development projects, and less to earlier stage basic and applied research.

Chart 3. Industry $ for Basic Research (As Share of Total Industry R&D)



Investments in federally funded R&D can help overcome both this general under investment and the lack of investment in earlier stage research. Government support of basic research, especially academic and hospital research, is a long-standing and successful undertaking. Studies of academic research consistently show a significant positive rate of return. For example, Mansfield (1991, 1992) found a 28 percent RoR from academic research. Narin and Olivastro (1995) found a strong link between academic research and U.S.-invented patents and corporate technological competitive advantage.

Looking at the return from specific government R&D programs is fraught with more difficulty. The bulk of federal R&D spending is for non-economic, mission-specific research, especially military and space research. Since such mission-specific research, particularly defense-related research, does not result directly in marketable new products and processes, the benefits are not easily captured in the consumer surplus approach. However, there are innumerable cases where mission-specific R&D—witness Department of Defense's development of the predecessor of the Internet—has led to huge economic benefits. Moreover, federal research that is more closely related to commercial innovation appears to have significant social rates of return. Studies of publicly funded agricultural research show a consistent rate of return of around 40 percent (Griliches, 1992). A sample of fourteen National Institute of Standards and Technology (NIST) research projects studied yielded a median social RoR of 144 percent (Tassey).

Overall, Leyden and Link (1991) conclude that government funding complements private R&D and has the effect of spurring additional private funding. Because of its focus on learning and incentives for R&D, the new growth theory predicts this complementarity between private and public R&D.

It's Not Just Science: It's Broadly Diffused Knowledge

In spite of its importance, research alone is not the key to economic growth. Research must be commercialized, investments must be made in equipment, and workers must be trained in the skills to use it. Economic historians and theorists have pointed out that new technologies often require a host of other changes, including organizational and worker skills and knowledge, before they can be fully utilized. Romer (1994b) states: "when a new type of capital good like the railroad or the digital computer is invented, it takes lots of investment to reap the benefits from these discoveries." For example, when electric motors were invented, it took 40 years before the full impact of this change was felt in factories, because of the need for complementary changes in power transmission technologies, plant design, and organizational procedures. Similarly, while the Internet was discovered in the 1970s and 1980s, it won't be until at least the turn of the century that more than 30 percent of American households use it. Thus, investments that diffuse the results of research (e.g., technology) throughout the economy are needed.

This phenomena may explain some of the so-called "productivity paradox," whereby data on the overall productivity of the economy do not seem to show any impact from new computer and information technologies. It may be that those complementary assets for computer and information technologies are only now in place. If so, the economy may see a sustainable boost in productivity as a result of the last decade's increased investment in computer and information technologies. In fact, the increase in the last two years in productivity may be the result of the 20-year increase in R&D culminating in the late 1980s. This suggests that sustained increases in R&D and related technical changes are needed to continue this prosperity.

It's Not Just How Much, It's How to Create New Institutions and Mechanisms

While increasing federal support for science and technology is a key task, it's not enough. As the new growth theorists and other students of technological innovation stress, how institutions and individuals interact is just as important in determining technical advance. For example, Romer (1993) states that: "the most important job for economic policy is to create an institutional environment that supports technological change." The focus on institutions, mechanisms, and incentives is at the heart of improving our understanding of technology and economic growth. As Nobel Economist Douglas North (1996) points out:

> . . . a comprehensive understanding of economic performance through time requires a melding of theories of institutional, demographic, and stock of knowledge changes in order to have an overall approach to the issues. We have only begun to explore the interaction between these three sources of economic performance, but I believe we can go far in developing useful models of the interaction between them not only in terms of institutions providing the incentive structure for demographic and technological change, but also in terms of the ways in which demographic and stock-of-knowledge-perceived "imperatives" have in turn shaped the change in institutions.

The United States has a history of creating new research "institutions." Indeed, the research university itself was a major American innovation that helped boost innovation in the first half of the century. The development of large corporate research laboratories from the 1920s to the 1950s (e.g., Bell Labs) and the subsequent fueling of innovative startup firms by venture capital were other innovations. State government initiatives since the mid-1980s to link small enterprises with universities have been copied around the world. The passage of the Technology Transfer Act to encourage federal laboratories to work with industry is another innovation. It is these kinds of institutional innovations, often facilitated or enabled by government, which are just as critical to the innovation process as the amount invested in the research enterprise itself.

It is clear that the development of such new institutions will require both experimentation and evaluation of public policies as we attempt to find our way in this new era of knowledge-based economics. A better understanding of the mechanisms of spillovers and the social and private rates of return will help design improved initiatives for government support of R&D. For example, policy initiatives should have the potential for significant public and private rates of return and a clear path to commercialization in order to maximize spillovers. Government assistance might be especially warranted when the projected social rate of return is high but the expected private rate of return to the innovator is below the existing corporate hurtle rate. Government initiatives that rely on public-private partnerships have recently begun to utilize the concept of limited appropriability and spillovers to ensure that the technology developed is commercially viable. For example, in a recent institutional innovation, the Semiconductor Research Corporation (SRC), a non-profit consortia of semiconductor firms and government, co-funds cutting-edge, mid- to long-term generic research at universities that is too risky or uncertain to be undertaken by companies.

In addition, the role of government initiatives in the diffusion and adoption of a new technology is key. Government activities in the diffusion of technical information and participation in demonstration projects and test-bed activities goes back to the early days of the Industrial Revolution, with the first demonstration of the telegraph and the creation of the agricultural extension service. Such diffusion activities are even more critical in today's rapidly changing information-driven economy. For example, NIST's Manufacturing Extension Partnership program works in partnership with states to help small manufacturers adopt existing, off-the-shelf technologies.

Finally, growth theory (both new and old) tells us that various factors (investment in machinery and equipment, education and skills, and R&D) interact. Creating and sustaining economic growth is a process of having the right mechanisms and policies in a number of areas—with each set of policies complementing rather than hindering the other.

Conclusion

The chorus for a new growth policy is growing. According to a joint MIT / Council on Competitiveness report: "The capacity of the U.S. to both develop new technology and to use it as a source of productivity improvement, economic growth, and rising living standards in the face of rising technical competence and competition around the world, will in large measure determine our ability to succeed and prosper into the next century." An Organization of Economic Cooperation and Development (OECD) report on the knowledge economy states: "We must recognize the knowledge-based nature of the economy. This means recognizing that long-term growth and employment depend less on short-term allocative efficiency measures ... than on a set of long-term policies aimed at enhancing the knowledge base of the OECD economies through increased investment in the knowledge infrastructure, the knowledge distribution system, and the human knowledge component (human resources, education, training, and organizational change)." [2] As a result, it is time to develop a 21st century growth initiative in which the development of technology, and the associated mechanisms to utilize that technology, play a central role.

Endnotes

[1] This paper is based in part on an earlier paper "Technology and Economic Growth: A Review for Policymakers" by Kenan Patrick Jarboe, which was commissioned by the Congressional Joint Economic Committee, Minority.

[2] OECD, "Employment and Growth in the Knowledge-Based Economy," 1996.

[3] Boskin and Lau (1992), Table 2.2. Note: percentages many not sum to 100% due to approximation errors.

[4] Taken from Jarboe, 1998.

Appendix

Table 1: Imputed Contributions to Economic Growth of Different Sources [3]

Study	***Time Period***	***Capital (%)***	***Labor (%)***	***Tech. Progress (%)***	***Scale (%)***
Abramovitz (1956)	1869-1953	22	33	48	
Solow (1957)	1909-1949	21	24	51	
Kendrick (1961)	1889-1953	21	34	44	
Denison (1962)	1909-1929 1929-1957	26 15	32 16	33 58	10 12
Denison (1967)	1950-1962	25	19	47	9
Kuznets (1971)	1889-1929 1929-1957 1950-1962	34 8 25	32 14 19	34 78 56	
Jorgenson / Griliches (1972)	1950-1962	40	8	51	
Kendrick (1973)	1948-1966	21	24	56	
Denison (1979)	1929-1976	15	26	50	9
Denison (1985)	1929-1982	19	26	46	9
Jorgenson, et al. (1987)	1948-1979	12	20	69	

Table 2: Examples of Private and Social Rates of Return from Private R&D [4]

Study	***Private Rate of Return (%)***	***Social Rate of Return (%)***
Tereckyi (1974)	20-30	50
Mansfield, et al. (1977)	25	56
Sveikauskas (1981	7-25	50
Scherer (1982, 1984)	29-43	64-147
Goto-Suzuki (1989)	26	80
Bernstein-Nadiri (1991)	15-28	20-110

Kenan Patrick Jarboe is a principal with Jarboe and Associates. Robert Atkinson, Ph.D., is director of the Technology, Innovation, and the New Economy Project for the Progressive Policy Institute.

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