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Technology Policy and Economic Growth

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*Between the idea
And the reality
Between the motion
And the act
Falls the shadow¹*

Technology policy is obscured in deep shadow: The idea in American practice is to let the market decide industrial fortunes; the reality—a half century of government-sponsorship of new technology industries from jet aircraft to electronics and biotechnology—suggests that sub-rosa US practice often contradicts what is preached, and to enormous economic benefit. With the cover of the Cold War gone, it is time to move technology policy into the light—not to the patchy fluorescence of Clinton’s first term, but to the bright spot of center-stage.

TECHNOLOGY AND PRODUCTIVITY

A nation's standard of living is the most significant indicator of national economic performance. Productivity (output per unit of input, usually output per worker), income distribution, and unemployment are the three variables that most directly affect the standard of living of large numbers of people. Over the last several decades, the US has been doing especially poorly on the first two relative to past performance, to our major competitors in Europe and Asia, and to what our resources ought to permit. *US performance on those variables remains poor*—even after 5 straight years of reasonable economic growth—despite the widely-held perception in the nation’s capital that mid-1980s’ problems with competitiveness have all been solved.

Essentially all economists agree that productivity growth is the key to doing better over the long term. Unfortunately, economists can not explain why productivity growth has slowed in

¹ From the poem, *The Hollow Men*, by T.S. Eliot (1925).

the US and therefore can not explain what to do to make it grow faster.² Most would agree that the answer lies in some combination of a higher level and altered composition of investment—investment in capital formation (including infrastructure), in people (e.g., training and education), and in technical progress (including new technologies and corresponding new ways of organizing industrial activities).

Of these variables, better technology is usually deemed the most significant. Even economists skeptical about technology policy admit that "technological progress is a vital source of economic growth and R&D a vital source of technological progress."³ More precisely, according to the widely cited growth-accounting literature, traditional factor inputs like capital and labor cannot account for a significant percentage of national economic growth. That very large residual—at least one-quarter and perhaps as much as one-half of the total US growth rate since the end of World War II—is normally attributed to advances in technical know-how.⁴

Aside from growth accounting, a number of other strands of the economics literature have touched on the relationship of technological progress to economic performance. The so-

² Prior to his recent vituperative attacks on popular concepts of relative economic performance, Paul Krugman made this point most succinctly for non-economist, policy audiences in his *The Age Of Diminished Expectations*, (Cambridge, Ma. and London: The MIT Press, 1990).

³ The words are by Linda R. Cohen and Roger G. Noll, in Chapter 1 of Cohen, Noll et.al., *The Technology Pork Barrel* (Washington, D.C.: Brookings, 1991) p.11.

⁴ See, e.g., Edward F. Denison, *Accounting for United States Economic Growth, 1929-1969* (Washington D.C.: Brookings, 1974). The role of technology and R&D has been studied by economists for more than forty years. The earliest studies almost stumbled upon the importance of technology-spawned productivity improvements as an explanation for economic growth. One, which examined the U.S. economy over the period 1909-1949 when gross output per household doubled, estimated that only 12.5 percent of this increased output was due to increased use of capital (i.e. more machines). More importantly, the residual growth of 87.5 percent could only be explained by technical change, i.e. new and better machines. (Robert M. Solow, 1957, "Technical Change and the Aggregate Production Function," *Review of Economics and Statistics*, 39: pp. 312-320). Attempting to overcome many restrictive assumptions of these initial studies, a recent study by Boskin and Lau examined economic growth in the five largest industrial economies and found that, consistent with the earlier work, technological progress is by far the most important source of economic growth (Michael J. Boskin and Lawrence J. Lau, "The Contribution of R&D to Economic Growth: Some Issues and Observations," American Enterprise Institute, conference paper, October 3, 1994. For a nice summary of the growth accounting and return on investment literature, see Gregory

called “new growth theory” emphasizes that the rate of economic growth is driven by the total stock of human capital--the collection of knowledge or innovative "ideas" held at any one time by people in businesses, universities, and governments. Essentially, this approach contends that new ideas are the root source of growth because they lead to technological innovation and hence to productivity improvements. Thus, if too few resources are dedicated to education and scientific research and development (both for the purpose of increasing the stock of human capital or new ideas), then the rate of economic growth will be lower than it otherwise could have been.⁵

In the short run, a 1 or 2 percent reduction in the overall growth rate may not appear significant. But compounded over generations, it could be the difference between the standard of living merely doubling or surging five-fold over a hundred year period. For countries with similar standards of living today, small differences in the rate of growth could lead to very different economic outcomes in the future. In addition, once an economy sets out on a high-growth or low-growth path, studies by economic historians and theorists of increasing marginal returns suggest that either high growth and low growth may be self-reinforcing over time.⁶ To take just one example, Argentina and the United States had roughly similar levels of economic performance during the 1860's. So a relatively poorer country might do better now to invest in more higher education and R&D rather than mass industrialization.

Finally, a recent review of efforts to measure the rates of return on investments in new technology found that the private rates of return to firms performing R&D often vary between 20

Tassey, *Technology and Economic Growth: Implications for Federal Policy* (Washington DC: U.S. Department of Commerce, Technology Administration, October, 1995).

⁵ Paul M. Romer, “Increasing Returns and Long-Run Growth,” *Journal of Political Economy* 94, no. 4 (October, 1986), pp. 1002-37, and “Endogenous Technological Change,” (1990) *Journal of Political Economy*, 98(5), pp. S71-S102.

⁶ W. Brian Arthur, “Self-Reinforcing Mechanisms in Economics,” *Working Papers* 111, (Stanford, CA., Center for Economic Policy Research, 1987); and “Positive Feedbacks in Economics,” *Scientific American* 262, no. 2, February, 1990, page 92.

to 30 percent in a variety of industries. For comparison, note that the average rate of return to investment in the business sector as a whole is thought to be in the neighborhood of 10 percent. Estimated rates of return from R&D to society as a whole, due to beneficial spillovers from an initial R&D investment to consumers and to other firms, vary from 20 percent to well over 100 percent in a variety of industries, with an average somewhere close to 50 percent.⁷ The channels of diffusion of the spillovers vary considerably and their effects on productivity growth are sizable. These results also suggest the likelihood of a substantial underinvestment by private firms in R&D activities because they cannot internalize the significant returns that spillover to others, including to competitors.

In sum, despite enormous disparity of methods, these different bodies of work all acknowledge that there is a strong link between advances in knowledge, technical progress, and long-term growth in productivity and GDP. There is also a general consensus that high rates of investment in broad-based R&D across a wide technical frontier are essential, and that modern technical infrastructure and a skilled, technically competent work force are *sine qua non* complements to achieving sustained rates of productivity advance.

There is, however, great controversy over how to attain that investment and by whom. There is no consensus about what the proper balance of investment ought to be between industry, government, and academia. There is no agreement about whether government's role should include direct R&D dollars or be limited to investment incentives for private R&D spending (as with R&D tax credits). There is no agreement about whether public funding should be limited to cases of private market failure (as when social returns to R&D spending exceed private ones causing under-investment by private market actors), or should include a focus on fulfilling

⁷ M. Ishaq Nadiri, "Innovations and Technological Spillovers," National Bureau of Economic Research, *Working Paper* No. 4423, August 1993.

government missions (e.g., defense) and social needs (e.g., health). There is, consequently, broad disagreement about the composition of investment, whether public or private.

There is also substantial contention, highly contingent on chosen time-frame, over whether new technologies are net labor-displacing or job-creating—although the balance of evidence suggests that over the long-term new technologies are capital saving, complement labor, and thus create jobs.⁸ In general, economists presume that new technology will generate more jobs than it eliminates, as it leads to new products and services, lower prices, and expanded markets. Unfortunately, there may be prolonged lags between job losses and new job creation, and the new jobs may not be appropriate for those displaced by technological change. (For example, the Industrial Revolution eventually produced a large and unprecedented middle-class, but only after creating huge inequalities – and tremendous resistance to change—during its first half-century). The consensus answer to the time lag problem—and it is the Clinton Administration’s answer as well—is that the compensating demand effects which offset job loss from technological change come more quickly when overall economic growth is strong and when markets for both labor and capital are flexible. Government can help by avoiding recessions and making workers more adaptable through improvements in education and training.

Although there is basic agreement that the vast bulk of social benefits from technology flow from its application and widespread diffusion, terribly unsettled is the character of the links between production and use—whether, that is, an economy the size of the US needs to be a leading-edge producer in order to reap the full benefits from use. Technology policy proponents typically argue that the initial establishment of a dominant position in markets for an advanced technology can lock in control of a long stream of follow-on product and process innovations,

⁸ Richard M. Cyert and David C. Mowery, editors, *Technology and Employment: Innovation and Growth in the U.S. Economy* (Washington, D.C., National Academy Press, 1987); Paul Krugman, “Technology’s Revenge,” *Wilson Quarterly*, Autumn 1994, pp. 57-64; David R. Howell, “The Skills Myth,” *The American*

making market entry much harder for technology "followers." This means that a temporary market advantage can turn into a more enduring technological advantage. A more conventional argument holds that it might actually be to the economic advantage of manufacturers to be *second* rather than first—to absorb the spillovers from investments made initially by competitors (foreign or domestic) and thus start production further along the technological learning curve.

Such issues are likely to remain unsettled given the state of the economics art. At the moment, and for the foreseeable future, there is absolutely no right answer, no algorithm or formula that can identify the best balance of choices and optimize the economic returns. Where one stands is ultimately a normative judgment about the role of government, the virtue of certain ends and the relative efficacy of different means. In that spirit, the current debate pits both conservatives, who oppose an aggressive technology policy as too interventionist, and liberals, who think government should intervene to serve different ends, against so-called moderates, economic nationalists and self-interested industry trade associations who favor it.

But, in light of the probable central role technical progress plays in long-term economic performance, it is surely worth asking how apposite those political positions really are. If technical progress is less important than consensus indicates, then aggressive technology policy risks mis-allocation of resources and lower short-term growth. But far more is at stake if the technical progress is central to economic performance and hands-off prescriptions are followed. We risk a significant sacrifice of opportunities for long-term national economic growth and productivity advance. We risk, that is, precisely what we are now experiencing. *In short, where technology policy is concerned, the hands-off approach is radical for it risks the most; the only prudent approach is to err on the side of government involvement in the sponsorship of new technologies.*

Prospect, Number 18, Summer 1994 pp. 81-89; "Technology and Unemployment," *The Economist*, February 11, 1995, pp. 21-23.

And on that score, there is surely cause for long-term concern in the US. Both Europe and Japan project significant increases in civilian R&D over the next few years, with Japan proposing to double R&D spending between 1995 and the year 2000. US spending, particularly Federal spending, may be headed in the opposite direction. Some Congressional proposals are estimated to cut R&D spending by 30 percent over the next seven years. The United States could enter the next century spending less than its major competitors—less in absolute dollars as well as in percentage of GDP—for the first time in the postwar era.⁹

MARKETS AND TECHNOLOGY

The public debate on technology policy is typically truncated into the issue of picking winners and losers. From there it is easy to conclude, on the one hand, that markets do that most effectively, and on the other that porkbarrel politics is more likely to support the losers anyway. Notice how that neat two-step operates: It first eliminates from the realm of technology policy everything for which government is institutionally well-suited, from infrastructure building and investment incentives to support of skills training. It then notes that what is left is, of course, institutionally more appropriate for the market. Q.E.D. notice, too, how the argument is legitimated simultaneously by our ancient faith in markets and our recent cynicism about politics.

Even accepting the critic's definition of the issue, there are limiting cases in which the reductionist conclusion about picking winners and losers is not defensible. The most important such limiting case is the development of new technologies—for which markets are not entirely adequate institutions. As previously noted, empirical evidence suggests that as a result of spillovers of all kinds, the social returns to R&D spending on new technologies far exceed the

⁹ U.S. Department of Commerce, *Building the American Dream*, August, 1996.

private returns—perhaps by as much as 50 to 100%.¹⁰ Appropriability problems lead to over-investment in some technologies and under-investment in others relative to the social optimum.¹¹

But markets also deal inadequately with technological progress because of the highly contingent nature of innovation. Innovation is marked by broad uncertainty.¹² Differently positioned firms evaluate the attendant risks differently, apply different capabilities to their technological effort, receive different signals from customers in response, and go down different development paths. In essence, technology development is a path dependent process of learning.¹³ Technical progress involves insights that coalesce only in conjunction with experience in development, production, and use. Advances are driven through cumulative learning-by-doing in production, and learning-by-using in consumption.¹⁴ Rather than being preordained by scientific logic, technology development is contingent—contingent upon the actions of developers, producers, and users as they perform their respective roles, interact, and accrue different kinds of know-how over time.

The contingent nature of technical progress means that neither innovators nor the private capital markets that fund them are fully capable of accurately evaluating the risks involved.

¹⁰ In addition to Nadiri, *op. cit.*, See Martin Neil Baily and Alok K. Chakrabarti, *Innovation and the Productivity Crisis* (Washington, D.C., Brookings Institution, 1988), Edwin Mansfield “Social Returns from R&D: Findings, Methods, and Limitations, *Research and Technology Management* (November-December, 1991); and Zvi Griliches, (1992) “The Search for R&D Spillovers,” *Scandinavian Journal of Economics*, vol. 94, supplement, pp. 29-47.

¹¹ For a concise summary, see Linda R. Cohen and Roger G. Noll, et.al., *The Technology Pork Barrel*, (Washington, D.C.: Brookings, 1991) at p.18-22; and Richard R. Nelson, ed., *Government and Technical Progress*, (NY: Pergamon Press, 1982), p.2-5 and 480-481.

¹² See the discussion in Christopher Freeman, *The Economics of Industrial Innovation*, (Cambridge, Ma: MIT Press, 1982) at Part Two.

¹³ On the concept of path-dependence, see W. Brian Arthur, "Competing Technologies and Lock-in by Historical Events: The Dynamics of Allocation Under Increasing Returns," *CEPR Publication #43*, (Stanford: Center for Economic Policy Research, September 1985).

¹⁴ The concepts of learning-by-doing and by-using are drawn from Nathan Rosenberg, *Inside the Black Box: Technology and Economics*, (Cambridge University Press, Cambridge, MA, 1982), who elaborates the

Perfect information is impossible given the uncertainties. Private capital markets and innovators alike must misallocate their investment and effort. Some bets will pay off big; some not at all. There will always be, and there must always be, winners and losers—but they can only be positively identified in the revealing gaze of hindsight.

This is as true for private as public investment. Look at the track record of venture funds and private companies. For every Macintosh there are normally several Lisa's. For every IBM there are several GE's and Westinghouses whose technological bets on mainframe computers failed to pay off. For every Intel there are assorted, now-defunct Molecros and AMEs. For every winner in a venture portfolio, there are untold losers that get nowhere near the publicity.

Indeed, there is absolutely no evidence beyond the economist's leap of faith that private investment is any more capable than public investment of separating the winners from the losers before the fact. Both face the same uncertainties. Each must place bets. Neither can avoid the certainty of losers. Each can cover enough points to be assured of some winners. The major difference, of course, is that private losers exit the market, while publicly-backed losers are held to the higher standard of wasting taxpayers' money.

In short, winners and losers are an inevitable byproduct of the process of innovation. Picking winners and losers is the wrong metaphor to characterize the socially useful and necessary activity of government in supporting that process. Government is actually placing bets on our collective future. And from the public standpoint, the magnitude of the potential social gains are sufficiently large to provide a comfortable margin for error in choosing among technologies to back.¹⁵

classic statement by Kenneth Arrow, "The Economic Implications of Learning by Doing," Review of Economic Studies, June, 1962, p.155-173.

THE LIMITED CASE IN FAVOR

The case against aggressive technology policy thus falls short of damning a significant government role in support of new technology development. But the failure of the case against does not by itself justify government support. Two related rationales accomplish that, one political and the other economic. First, the government is a significant consumer of technology in its own right as it goes about providing for our common needs. In areas ranging from national defense to infrastructure, like any other large customer the government must open our wallet to get the technology it needs. Very often that means sponsoring research and procurement that launch new industrial capabilities.

As a consumer, the government's demands are usually determined through the political process rather than the market. Those who acknowledge all of the flaws of politics but none of the market are extremely leery of this. They dismiss it by labeling it porkbarrel politics.¹⁶ As a process in its own right, American politics may fail to satisfy the economist's dream of perfect efficiency, but the government can hardly fail to respond to constituents' demands. That it does so has actually had little bearing on the quality of the technology that eventually results.

It is quite possible that politics does effectively what the market does not, namely aggregate enough to get the market's attention of the demand of numerous dispersed customers (citizens) who would otherwise have no other way of expressing their collective influence over technological development. In that way, a broader portfolio of socially useful technologies is undoubtedly explored and screened than the market would ever normally permit. In reality, those who see this process as porkbarrel are ultimately lamenting not the economic inefficiency, but the lack of expert direction.

¹⁵ Gene M. Grossman, "Promoting New Industrial Activities: A Survey of Recent Arguments and Evidence," *OECD Economic Studies*, Spring, 1990, #14, p.87-125.

¹⁶ Cohen and Noll, *op. cit.*, are illustrative.

Leaving aside such political rationales, the pure economic case in favor of public support to new technologies must rest on the disproportionate importance of some industries to economic well-being in ways that can only be captured through local production. Industries may be strategic for economic welfare in at least three ways. They may contribute a major share of the technological progress that, as argued before, is central to long-term growth. Or, they may provide a higher return to factors of production than could be earned elsewhere in the economy. Or they may provide externalities like technological spillovers that broadly benefit the rest of the economy.¹⁷

Technology-intensive (or science-based) industries—i.e., high tech—fit the bill under all three columns. As primary suppliers of producer goods (and service inputs), high-tech industries are primary carriers of technological progress. High-tech industries also fund a disproportionate amount of industrial R&D, offering innovations that pervasively spillover to the economy as a whole.¹⁸ At the moment, high-technology industries account for only about 20% of the nation's manufacturing output and 24% of its manufacturing value-added, but nearly 60% of its private industrial R&D. High-technology industries are also high-productivity industries that pay higher compensation than other manufacturing industries. By the early 1990s, value-added per worker in all high-technology industries was one-third higher than the average for all manufacturing and two-thirds higher if only production workers are included. These differentials are significant and persistent.¹⁹

¹⁷ The latter two ideas originated in the so-called new trade theory literature, see, e.g., Paul R. Krugman, ed., *Strategic Trade and the New International Economics*, (Boston, Mass.: MIT Press, 1986).

¹⁸ This and the following data are drawn from Laura Tyson, *Who's Bashing Whom: Trade Conflicts in High Technology Industries*, (Washington D.C.: IIE, 1992).

¹⁹ See, e.g., William T. Dickens and Kevin Lang, "Why It Matters What We Trade: A Case for Active Trade Policy," in William T. Dickens, Laura D'Andrea Tyson, and John Zysman, eds., *The Dynamics of Trade and Employment*, (Cambridge Ma.: Ballinger, 1989).

In short, production of a dollars worth of silicon chips really is more important than that of potato chips for many principal determinants of economic well-being like wages, skill formation, productivity, investment, and R&D. Equally important, many of the economic benefits that high-tech industries provide appear to be “local” externalities that require domestic production to enjoy. While some technology is footloose, i.e., embodied in products, blueprints, or open technical fora like published research, much other technology is, as argued earlier, generated only in development and production. That kind of technical knowledge accumulates in specialized local assets like labor pools and supplier networks. It is embodied in them and does not diffuse easily.

When US PC assemblers go to Taiwan for design and development of notebook computers, when US disc drive assemblers go to Singapore for process and volume manufacturing, when IBM moves microsystem development out of the US to Japan, they are seeking access to precisely such specialized local assets—in this case, embodying know-how in components and micro-systems' design, integration and manufacturing. Such local capabilities are the probable basis for product differentiation and new technology generation. They help to attract footloose technological know-how originating abroad, and ensure that it can be exploited domestically. In other words, technological progress is intimately bound with local capabilities. Unless they exist, an economy has no enduring potential for operating at the technological frontier, with all that implies for maintaining national well-being.

This localization of technology's economic benefits is strongly reinforced by the imperfect nature of technological competition. Modern high technology markets are characterized by extreme scale economies, oligopoly, persistent entry barriers, and thus, strong first mover advantages. Firms or nations that establish initial advantage—whether through private competence or government support—can enjoy those advantages long enough for the

economic benefits to accrue locally rather than abroad. This was the case with Japan's concerted efforts to dominate semiconductor memory and display technologies, and with Europe's Airbus.

The local and national concentration of technological benefits and the imperfect nature of high tech markets mean that high-tech competition can take on an inherently beggar-thy-neighbor caste. A bigger national share of global high-tech output can mean a bigger national share of good jobs and a higher level of economic well-being. That is why technology-intensive industries are a principle source of constant trade friction between the US and its competitors. And that is why aggressive technology policy that aims at sponsoring the development and launch of new technology industries may be a necessity for the US.

WHAT WORKS AND WHAT DOES NOT

Theoretical justifications for an explicit government role in supporting the development of new technologies, must be judged against the actual track record. How effective has the government been in the technology stakes?

Federal support to new technology crystallized after World War II around national defense, the development of nuclear energy, and later, space exploration. The spending model was premised on belief that pouring in investments in science at the front end of the development pipelines would produce technology out the other end. Military spending thus supported the enormous development costs of relevant new technologies.

Initial applications were developed for, and procured by the military, and later would diffuse—'spin-off'—into commercial use.²⁰ In this way, US defense spending promoted the

²⁰ For a fuller elaboration of the successes and failures of this technology development model, see the Chapter by Jay Stowsky in Wayne Sandholz, Michael Borrus, et.al., *The Highest Stakes: The Economic Foundations of the Next Security System*, (NY: Oxford University Press, 1992).

rapid development of a host of military technologies that eventually found widespread success in commercial markets, including, among many others, jet aircraft and engines, silicon chips, computers and operating systems, complex machine tools, data networks, data compression, optoelectronics, and advanced ceramic and composite materials.

In these cases, government underwrote the relevant basic science research at universities and labs, direct R&D contracts accelerated the development of the technology, and defense procurement at premium prices constituted a highly effective initial launch market. Very often, the military funded different technological approaches to the same goals, in effect prudently spreading its bets under conditions of uncertainty. The successful approaches were judged according to strict cost/performance criteria, and then were launched through procurement and strongly supported. A variety of mechanisms, ranging from patent pooling and hardware leasing (e.g., machine tool pools) to loan guarantees for building production facilities, helped to lower entry costs, diffused technology widely among competitors, and set the stage for commercial market penetration.

Aspects of the full-blown support model were adapted for government investment in other sectors, notably for public health (and broadly for generic science research via the National Science Foundation). Massive government funding of biomedical research, and for training research scientists, followed World War II successes in developing gammaglobulins and other pharmaceuticals.²¹ Commercial winners have ranged from treatment regimes, drugs, and medical equipment to biotechnology. Peer review of research proposals and results, dedicated peer-run institutions like NIH, and strong links to the practitioner community, all help to ensure market viability and diffusion of innovation.

²¹ See the chapter by Henry G. Grabowski and John M. Vernon, in Nelson, *op. cit.*

The overall key to the successful cases seems to have been the successful launch and diffusion of a technology development path—a trajectory—whose characteristics strongly coincided with the requirements of the commercial marketplace. Thus, when the military pushed silicon chips toward high reliability, miniaturization, high performance, and low costs, it was helping to create a trajectory that the commercial computer industry could ride. Similarly, when it turned to the national community of scientists and engineers in their roles as users to define the characteristics for the ARPANet, the Defense Department was launching a data networking trajectory which would also meet that community's commercial needs as the ARPANet metamorphosed into today's Internet.

In that sense, the US government's direct R&D sponsorship has probably been less important for commercial success than its procurement and indirect support, for the latter policies acted to launch the fledgling technologies and diffuse them into widespread use. Although some of the winners generally credit their parallel civilian R&D efforts for the relevant technological advances, they all acknowledge the benefit of procurement, of know-how spilling over from defense R&D, of defense funding of graduate education and research in the relevant technical disciplines, of funding of prototype systems that demonstrated the efficacy of new technologies, and of the variety of other mechanisms which supported diffusion and use.

It is important to note that this strategy of public support was not a simple stepchild of the technological successes of World War II. For example, government support to aeronautics predates the War, beginning in earnest with the creation of NASA's precursor, the National Advisory Commission on Aeronautics (NACA). NACA was a vital source of the R&D and testing during the 1920s and 30s that led to the modern passenger airliner.²² Of course, that was back in the days when we were willing to be public risk-takers, before the ideological purity set in, when we acted rather than believe we shouldn't.

In fact, some of the most grand and most successful experiments in public support to commercial technology occurred back then. The two worth a brief look are the creation of RCA and, the granddaddy of public programs, the Agriculture Extension System. RCA grew out of Woodrow Wilson's concern that British dominance of radio technology would limit America's commercial rise, and was created to establish a commercial US presence in radio.²³ With the guarantee of Navy contracts providing R&D funding, the launch market and lure, RCA was formed as a patent-pooling consortium among the Navy, GE and eventually AT&T, Westinghouse and United Fruit. Since commercial interests were involved from the start with the avowed aim of developing and diffusing radio technology, the result of public sponsorship was an explicit and successful commercial technology trajectory.

However, the most elaborate, and arguably most successful US program of public support to commercial innovation is in agriculture. The Agriculture Research and Extension System is comprised of a network of interdependent institutions that stretch from the Federal to local level, including land-grant colleges, the state experiment stations, and research and extension services.²⁴ Dating from the Morrill Act in 1862, the evolving system has provided focused education and training, long-term R&D, and widespread diffusion of new technology to America's farms. Although not without controversy—e.g., its neglect of organic farming methods—it is still widely credited with a major role in making American agriculture the world's most productive.

While such successes are suggestive, there is as much to learn from the failures. The defense-energy-space nexus provides robust examples that range from outright flops like the supersonic transport (SST), synfuel plants, and the fast breeder reactor, to more complex and

²² For the full story, see the chapter by David Mowery and Nathan Rosenberg in Nelson, *op. cit.*

²³ For details see Eric Barnouw's classic history of broadcasting, *A history of broadcasting in the United States*, (New York: Oxford University Press, 1966)

ambiguous cases like the development of numerical control for machine tools or of the Space Shuttle or photovoltaics. For example, the Air Force sponsored the development of numerical control technology for machine tools to build advanced aircraft. The programming language proved too complex for general commercial use. Diffusion was slow and civilian application costly. The resulting technological development path produced only a commercially vulnerable US industry that was squeezed by Japanese competitors from the low end and German firms from the high.

Similarly, the more visible failures moved down technology trajectories that were commercially unacceptable for a variety of reasons.²⁵ The commercial market was aiming at short-haul and wide-bodies rather than supersonic speeds. The fast breeder reactor and synfuel programs were too horrendously expensive relative to commercial alternatives, particularly after the oil shocks abated. In each case there were problems of both conception and execution. Performance objectives were narrowly construed and alternative technological paths were not sufficiently explored. Demonstrations and pilots proceeded despite experimental evidence of failure. In some cases like photovoltaics, political considerations killed development prematurely.

CLINTON'S PILOT PROJECTS

Public support to technology thus runs into trouble mostly when it pushes down development paths that diverge from commercial market cost/performance requirements, particularly when it over-specifies an exotic technical solution in the form of a particular

²⁴For an evaluation, see the chapter by R.E. Evenson in Nelson, *op. cit.*

²⁵ For details, see the relevant chapters in Cohen and Noll, *op. cit.*

product.²⁶ *This is not so much a problem of technology development, as it is a failure to be sensitive to the requirements of commercial market diffusion.* And those requirements—like manufacturability or customer-defined cost/performance—don't seem so hard to build in to future programs, particularly if the public risk is shared jointly with private investment (as it has been with more recent forays into industrial policy like Sematech, the semiconductor industry's manufacturing technology program).

Thus, by the time the Clinton Administration's technology investment projects were launched early in 1993, policy designers were able to draw on two wells of relevant experience to create programs which they hoped would be both effective and economically-efficient. Clinton technology officials consciously attempted to prevent new instances of "government failure," the public sector analog of the market failures these projects were trying to correct. They built several programmatic features into the projects to ensure that they would provide government support without dampening market signals: To avoid backing the wrong technologies, the Clinton technology initiatives relied on industry to co-design the research agenda for each project. This ensured that project awards would target technologies that were also thought likely to be commercially-viable once technical bottlenecks were overcome.

Similarly, investments were made in an array of technical fields to ensure that the champions of any particular technology or industry did not exercise undue influence. The programs also required grant applicants to compete in teams (e.g., defense and commercial firms, universities and/or government labs) for a finite flow of federal funds. The competitions were to be judged on technical and economic criteria by a panel of government technical experts or other independent peer-review process. As part of the competitive process, applicants were typically

²⁶Even in those cases there are likely to be important technical spillovers, especially when generic research is funded as part of the program.

required to provide evidence that the technology at hand could be commercially sustained within five years, without further federal funding.

To prevent the subsidies from making grant recipients lazy (reducing the efficiency-inducing effects of competition), private sector participants were required to cover a minimum of roughly 50 percent of the project's costs. That is, although they were subsidized, they were also required to risk their own money. To prevent the creation of technology pork barrels, government program managers were committed at the outset to rigorous program evaluations and could typically make only time-limited grants. Technical milestones and other performance metrics were established up front. It was also felt that the 50 percent matching requirement would make private sector partners anxious to quickly abandon technological approaches that were not working.

After four years, the various Clinton technology initiatives have demonstrated progress. They have fostered new industry-led R&D partnerships in a number of technical fields and have encouraged defense and commercial firms to work together on the commercial development of a number of military-relevant technologies. By playing midwife to consortia or teams of companies, universities and national labs, these initiatives appear to be facilitating more rapid technology transfer and innovation, though at a small scale. In some cases, the government's involvement appears to have helped R&D performers, both public and private, to overcome the “collective action” problems that otherwise prevent them from exploiting potentially significant economic and technological opportunities. Indeed, many recipients of the awards—and even some teams that failed to win—report that the programs have facilitated beneficial organizational relationships that would not have existed had the programs not existed.

Significantly, the features these programs incorporated to avoid government failure also appear to have worked. It is too early to judge the effect of time-limited grants, but other

features of these programs—government-industry cost-sharing, competitive selection, and the requirement that applicants be made up of industry-led teams—have combined to render these efforts nearly free of political pork.

Ironically, the very success of those features has had the paradoxical effect of reducing opportunities for supporters to cultivate stable political constituencies for continuing (never mind expanding) these programs. Compare the dismal political fortunes of the Commerce Department's Advanced Technology Program (geared toward promoting private-sector competitiveness and economic growth) and the Pentagon's Technology Reinvestment Project (geared toward promoting the commercial development of technologies with both civilian and military applications) with those of three other Clinton-era technology initiatives: The National Flat Panel Display Initiative and the so-called "Clean Car" program have survived Congressional scrutiny so far, down-sized but intact, due to the focused efforts of their specific and, therefore, readily-organized industrial constituencies. More tellingly, the Commerce Department's Manufacturing Extension Partnership (MEP), which had fortuitously placed more than 40 manufacturing extension centers in over 30 states (read: at least that many congressional districts), is actually being expanded by the Republican-led Congress.

Equally significant, however, the Clinton projects suffer—on the analysis in the last section—from two very telling deficiencies. One is the lack of programmatic objectives that are tied to clearly-defined government missions as opposed to more amorphous goals like "competitiveness" and "growth" which most Americans assume to be primarily the responsibility of the private sector. The other is their significant lack of scale and scope. They spread limited resources across too many small projects that are too focused on R&D and not tied to diffusion through procurement. The latter failing is largely a consequence of President Clinton's political inability to defend a sizable, as opposed to severely truncated, "investment" program in the political debate over deficit reduction early in his first term.

THE NEW REALITY

Difficult as it will continue to be to create political and budgetary support to enlarge technology policy efforts in scale and scope to the point they would have significant impacts in launching new technology industries, this would be a most inopportune moment for the United States to rely blindly on the invisible hand. Up until the 1980s, when the absolute lead US industry enjoyed in most high technology sectors began to evaporate, the federal government could be quite certain that the domestic economy would enjoy the lion's share of the broad social gains generated by its sponsorship of new technology industries. As the strongest and most advanced economy, the US was in all cases the launch market for the new technologies fostered by public spending. US industry typically commercialized and produced the innovations at home, and then exported abroad. Initial and leading customers—those who shaped the new technology's initial development and its path of diffusion—were also typically domestically-based. Local R&D, production, and advanced use, meant that most of the spillovers that generated the broad social benefits would occur within US borders.

During the last decade, however, several trends converged to challenge the easy identity between federal R&D and localized spillovers. Foreign competitors caught up and in some cases surpassed US producers. Foreign governments followed the US lead to sponsor high and rising levels of R&D spending, Foreign markets became effective launch markets for new technologies invented there, as Europe's Airbus proved in pioneering fly-by-wire and other aeronautical innovations. Lead times for spillover from US defense spending collapsed as foreign producers caught up with US innovation. And as international competition intensified, so did the costs and risks of private R&D spending, so much so that even US firms chose to spread them across global markets by producing abroad and finding foreign partners.

As a result, technologies pioneered in the US now flow rapidly across the national borders, sometimes to be commercialized, produced, and exploited more effectively there than in the US. Conversely, more and more innovations now originate abroad, but because foreign economies are rarely as open as the US, the reverse flow of innovation— into the US—has not fully materialized. Indeed there is a broad pattern of increased international technological specialization now visible—new technical skills arising in new places around the globe, especially in Asia, and not readily duplicated back in the US, but essential to commercialization of innovation.²⁷

The US can, thus, no longer take for granted the easy identification between federal technology sponsorship and generation of local spillovers that permit the social benefits to be captured within US borders. That connection has been significantly attenuated. This makes it all the more important for government to focus its own sponsorship in areas where spillovers are more likely than not to be generated and captured locally. On the analysis above, know-how developed through production and use and embedded in local assets like labor pools, supplier networks, and infrastructure, is less likely to diffuse readily across borders. Such specialized assets can be brought into being wherever government sponsorship develops the domestic market as the principal launch market for new technologies.

In the current era of tight budget constraints, this means that government must focus its scarce resources, not squander them in piecemeal sponsorship of small projects with at best modest impacts. It also means that the government cannot focus on the amorphous goal of directly supporting commercial competitiveness—for in most cases, the market dynamics of commercial industries are already developed and policy intervention is unlikely to alter them

²⁷ For evidence, see e.g. Daniele Archibugi and Jonathan Michie, “The Globalization of Technology: Myths and Realities,” *Cambridge Journal of Economics*, #19, 1995, and, Keith Pavitt and Parimal Patel, “The International Distribution and Determinants of Technological Activities,” *Oxford Review of Economic Policy*, #4, 1988, p.35-55.

significantly in ways that bring localized capabilities into being. Rather, federal sponsorship will launch local capabilities only by focusing on wholly new technological possibilities linked tightly to a government mission (so that the government becomes the initial launch market itself).

In short, civilian government missions would be used self-consciously as the creative first user to launch new technologies for which commercial markets have yet to develop (due to cost and risk factors). Aspects of this model are elaborated elsewhere in this volume, but the significant need is for sponsorship as comprehensive as that afforded by DOD to initial integrated circuit or jet engine technologies—from R&D and demonstration through procurement and explicit diffusion efforts. Two prime possibilities are environmental stewardship and infrastructure.

The environmental opportunity is to move beyond existing efforts aimed at regulating waste reduction and mandating clean-up. Sponsorship should instead be directed to replacing existing industrial production with technologies that generate no waste or pollution in the first place. In any of the areas government procures, from its fleets to its office supplies, it should favor industrial processes that boost pollution prevention, resource sustainability and efficient resource usage. Although the “clean-car” initiative appears to fall in this domain, it looks more like an exotic technical solution in the form of a specific product—that is, it looks more like past failures than successes. Rather, policy should set performance standards only, leaving it to the market to determine the most effective means of meeting those standards.

Similarly, there is an acknowledged need to rebuild much of the nation's eroding networks for transportation, power, sewage, and water, and to upgrade those for communications. Sponsorship of innovation to meet modern infrastructure needs would spur a host of new technologies from low-maintenance concretes to optical control systems. Emphasis would be on

seeding and then procuring new technological approaches that, while more costly up-front, held the promise of reducing total life-cycle costs in the future.

Even though public investment can help the economy to overcome chronic private underinvestment in basic research and launch new technological developments that have pervasive impacts—and even though such actions are critical to raising long-run living standards—US public support for government investments in these areas remains weak. To many Americans, the Clinton Administration's investments in technological innovation have appeared to benefit only the multibillion dollar corporations and high-tech professionals who are already doing well in the global, Information Age economy. Most middle-class voters, concerned about the impact of new computer-based technologies on their own jobs, uncertain and impatient about the economic future, see no evidence in their own lives of how these policies are actually working, let alone of how larger scale projects might work.

Nevertheless, public support persists in two areas where there seems still to be a broad consensus both about national needs and the legitimacy of government's role—national security and public health. It is possible that a set of TRP or ATP-like partnership programs of sufficient scale and comprehensiveness tied to these and other specific national needs—cleaning the environment, improving transportation and other infrastructure—might attract a broader, more stable constituency for government investments in technological progress. But the necessity of involving profit-seeking firms in the development of commercially-sustainable technologies means that the public is always likely to remain ambivalent about government's proper role.