Private Technological Capabilities as Products of National Innovation Systems: Four Ways of Looking at the State[1]

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Both the real world of science and technology and our conceptualization of it are changing in ways that raise the prominence of corporations. In the real world, private sources are funding an increasing share of measured R&D. In the United States, for instance, 68.4% of all R&D funding was supplied by the industrial sector in 2000, while the government share was just 26.3%. (State governments, universities, foundations, and other non-profits make up the remaining 5.3%.) The ratio of private to public is the inverse of that of 1965, when the government share peaked. Similar trends are apparent across the OECD; the government share of all OECD R&D funding in 1998 was but 30.7%, compared to 45% in 1981.[2]

These figures probably underestimate the true ratio, since unmeasured research and innovation is substantial and almost entirely located in the private sector, particularly in small

[1] This paper was originally prepared for a conference on "The Corporation as a Political and Social Institution" at the Hagley Museum and Library in February, 2000, which was supported by the Alfred P. Sloan Foundation. Comments by the participants at the conference and by David Guston and an anonymous reviewer at *SPP* are gratefully acknowledged.

and medium-sized firms that make no formal accounting for R&D.[3] Moreover, the trend in favor of the private sector has accelerated lately. U.S. industrial R&D spending grew by about 50% in real terms in the second half of the 1990s, while growth in U.S. government support added up to only about 10% in that period. The U.S. venture capital market (which funds many of the small innovative firms alluded to above) boomed in these years as well, peaking in 2000 with investments of over $90 billion (substantially more than federal government R&D funding in that year).[4] Again, similar (although perhaps not quite as dramatic) stories could be told about other industrialized countries.

To be sure, this period was unusual. As the data for 2001 and 2002 are tabulated, the differential in growth rates will surely narrow, and quite possibly may be reversed. Any such reversal, however, is likely to be a minor deviation in the larger historical pattern. Absent an impetus for change much more dramatic even than the present "war" on terrorism, the private sector's dominant role in the process of technological innovation will be a fact of life for decades to come. This fact hardly means that science and technology policy will wither away. It does mean that scholars of science and technology policy need to continue to reconceptualize "policy" and to think harder about the mechanisms through which the public sector influences private decisions.

This paper draws on recent work in political science[5] to make a contribution to this effort. I argue that the state shapes the private sector's capacity to carry out technological innovation in four major ways, drawing illustrative examples primarily from U.S. history . The state can be

[2] National Science Board (NSB), *Science and Engineering Indicators 2002* (Arlington, VA: National Science Foundation, 2002), ch.4, section 1, and appendix table 4-44.
[3] Lewis M. Branscomb and Richard Florida, "Challenges to Technology Policy in a Changing World Economy,"in Lewis M. Branscomb and James H. Keller, eds., *Investing in Innovation* (Cambridge: MIT Press, 1998), 24-26.
[4]NSB*, op. cit.,* appendix tables 4-5 and 6-19.

thought of as a group of organizations, a taxing and spending monopoly, a set of rules, and a normative order.[6] Each conception of the state highlights different sources of leverage through which policy-makers may alter the direction or pace of technological innovation in the private sector. Analysts must bear all of these in mind simultaneously in order to build a full picture of science and technology policy.

Innovation Systems and the State

The field of science and technology policy studies has already moved quite a distance in its thinking about the role of the state. Early work in the field concentrated heavily on public funding of R&D, especially in the areas of national defense, space, atomic energy, and university science. This emphasis reflected government's dominance of national R&D budgets and the public problems most salient at the height of the Cold War. It also served the purposes of advocates of these spending programs, who played an important part in the founding of the field. The linear model of innovation, in which government, academia, and industry each had well-defined roles, gave these analyst-advocates a clear message to bring to Washington and other national capitals.

The linear model always had its critics, but not until economic competitiveness issues came to the fore in science and technology policy (first in Europe, then in the U.S.) was it supplanted by the model of innovation as an institutional system. In such a system, innovation is perceived to occur in diverse settings -- on the factory floor as well as in the scientific laboratory -- and involves flows of information across many organizational boundaries, flows that are

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[5] Political science was once a primary disciplinary reference point for science and technology policy studies, epitomized by the late Don K. Price (who blended in more than a dash of practical experience as well). A range of other disciplines have taken over this role in recent years, while political science has faded almost out of the picture.

governed by institutions, including laws, policies, and customs. Bengt-Ake Lundvall, one of the progenitors of the model and his collaborators emphasized two-way interactions between producers and users of new technologies in the innovation process.[7] The innovation system model opened up a range of potential roles for the state, from manager of the overall system to participant in it.

Empirical research inspired by the system model suggested that in practice the state's role was strongly constrained by historical forces. Deeply inscribed patterns of industrialization, international conflict, political development, and the like channeled policy activity into patterns that strongly differentiated countries from one another.[8] Change tended to be slow and incremental. Scholars adopting this approach generally assumed that the nation was the most powerful and policy-relevant unit of analysis, although many recognized that national systems of innovation were increasingly interacting as a result of globalization and that there were significant regional variations within nations as well.

In recent years, Loet Leydesdorff and Henry Etzkowitz have advanced the concept of the "triple helix of innovation."[9] Academic, industry, and government form the strands of the helix, which are seen to be interwoven and constantly reconfiguring one another in a process of "endless transition." The concept also embraces interactions among multiple levels of

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[6] This typology draws most heavily on Stephen D. Krasner, "Approaches to the State: Alternative Conceptions and Historical Dynamics," *Comparative Politics* 16:223-246 (1984).

[7] E.S. Andersen and Bengt-Ake Lundvall, "Small National Systems of Innovation Facing Technological Revolutions: An Analytical Framework," in Christopher Freeman and Lundvall, eds., *Small Countries Facing the Technological Revolution* (London: Pinter, 1988); Bent Dalum, Bjorn Johnson, and Bengt-Ake Lundvall, "Public Policy in the Learning Society," in Lundvall, ed., *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning* (London: Pinter, 1992), 296-317.

[8] Henry Ergas, "Does Technology Policy Matter?," in Bruce R. Guile and Harvey Brooks, eds., *Technology and Global Industry* (Washington: National Academy Press, 1987), 191-245; Richard R. Nelson and Nathan Rosenberg, eds., *National Innovation Systems* (New York: Oxford University Press, 1993).

[9] Loet Leydesdorff and Henry Etzkowitz, "The Triple Helix of Innovation: An Introduction," *Science and Public Policy* 25:358-364 (1998); Henry Etzkowitz and Loet Leydesdorff, "The Dynamics of Innovation: From National Systems and 'Mode 2' to a Triple Helix of University-Industry-Government Relations," *Research Policy* 29:109-123 (2000).

governance, from the local to the global. The triple helix is a valuable metaphorical device for critiquing the government-dominated systems that still prevail in many transitional and developing countries. It also suggests that there is more malleability in the national systems of innovation of industrialized countries than the received wisdom presumes.

The triple helix model goes too far, however, in its equation of the state with academia and industry and of the national level with other levels of governance. In the future, the state may indeed "decline" as lower-level forces hollow it out and higher-level forces bring about global governance. So far, though, reports of its death are highly exaggerated; the promised "transformation," as Eugene B. Skolnikoff has put it, has been "elusive."[10] The much-vaunted deregulation of the past quarter-century, for instance, has produced, in the words of Stephen Vogel, both "freer markets" and "more rules."[11] Decline in some dimensions is matched by increased importance of others. These cross-currents make it all the more important for students of the governance of science and technology to have a fully developed conception of the state.

The State as Organization

One way to see the state is as an organization (or collection of organizations) that participates in markets just like firms. This organization may have a different revenue source and authority structure than the firm, but these distinctive features are more or less irrelevant in interactions mediated by the market. The capacities of firms to innovate are shaped by this state in much the same way that they are shaped by other firms: as customer, insurer, supplier, and competitor.

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[10] Martin Van Creveld, *The Rise and Decline of the State* (New York: Cambridge University Press, 1999); Eugene B. Skolnikoff, *The Elusive Transformation: Science, Technology, and the Evolution of International Politics* (Princeton: Princeton University Press, 1993).
[11] Stephen K. Vogel, *Freer Markets, More Rules* (Ithaca, NY: Cornell University Press, 1996).

The state as customer is the most familiar and most important of these relationships. Firms have often found that public tasks provide the "killer applications" that launch important technological innovations. Jet aircraft and electronic computers, for instance, were supplied to military organizations before they found civilian uses. Thomas Watson, Sr., the founder of IBM, famously stated that the market for computers was limited to a few big government customers, although his son (who was also his namesake and successor) proved him wrong. Public customers, in turn, sometimes serve as "lead users" that assist firms in refining and improving new technologies. Military procurement, particularly during wartime, illustrates this sort of relationship, in which the customer's influence extends deep into the innovation and production processes.[12]

The influence of the state as customer may be so pervasive as to shape the organizational structure and strategic decisions of firms. Diversified firms, for example, have sometimes established divisions specifically to serve government organizations; more specialized state-oriented firms found that they were unable to adapt to non-governmental customers; still others maintained their distance from state organizations in order not to have to change their strategy and structure to serve these organizations. Such decisions have important consequences for technological innovation. Whether new technologies can be "spun off" from government to non-government uses and whether the firms that have developed the technologies do the spinning off

[12] Kenneth Flamm, *Targeting the Computer: Government Support and International Competition* (Washington: Brookings, 1987); Allen Kaufman, "In the Procurement Officer We Trust: Constitutional Norms, Air Force Procurement, and Industrial Organization, 1938-1947," manuscript, 1997; Jonathan Zeitlin, "Flexibility and Mass Production at War: Aircraft Manufacture in Britain, the U.S., and Germany, 1939-1945," *Technology and Culture* 36:46-79 (1995). In many cases, of course, the public customer also subsidized, protected, or otherwise helped its supplier firms. These activities fall elsewhere in my typology; their coincidence in some, but not all, cases emphasizes the point that these ways of looking at the state are complementary, not exclusive.

(or whether new entrants supplant them), for instance, seem to be related to firms' adaptations to government organizations as customers.[13]

Government organizations as insurers exert a somewhat weaker gravitational pull on firms' technological capabilities than as customers. The insurer may encourage innovation by sharing in the risk taken by consumers of new products, or it may refuse to do so and have the opposite effect. U.S. government health insurance plans, for instance, have generally been unwilling to cover experimental medical treatments (although in practice many claims to such treatments probably slip through). On the other hand, these plans have been willing to pay high prices for such treatments once they are proven. The latter effect seems to have been the stronger one, helping U.S. pharmaceutical and medical device firms to be among the world's most innovative and profitable. While health coverage is the biggest element of the U.S. government's insurance portfolio, crop insurance, mortgage insurance, and disaster assistance might also be cited as potential influences on private innovative behavior.[14]

Government organizations, in the U.S. context at least, have less often been competitors or suppliers than customers or insurers. One exception was the Tennessee Valley Authority (TVA) of the 1930s, which was intended to serve as a "yardstick" for private power producers and to spur innovation among electric appliance manufacturers and fertilizer makers. Its "business model" of high-volume, low-cost electricity and electricity-using devices helped to prompt a response in kind from these competitors, which ultimately forced the TVA itself out of

[13] John A. Alic, *et. al*, *Beyond Spinoff: Military and Commercial Technologies in a Changing World* (Boston: Harvard Business School Press, 1992); Ergas, *op. cit.*

[14] U.S. Congress, Office of Technology Assessment (OTA), *Pharmaceutical R&D* (Washington: GPO, 1993), 232-233; Rebecca Henderson, Luigi Orsenigo, and Gary P. Pisano, "The Pharmaceutical Industry and the Revolution in Molecular Biology: Interactions Among Scientific, Institutional, and Organizational Change," in David C. Mowery and Richard R. Nelson, eds., *Sources of Industrial Leadership* (New York: Cambridge University Press, 1999), 267-311; David A. Moss, *When All Else Fails: Government As the Ultimate Risk Manager* (Cambridge: Harvard University Press, 2002).

some of these markets. The TVA's later role as a lead user of nuclear power plants might also have been intended as an example for private utilities, one that might better have been ignored.[15]

Government organizations may supply technological ideas as well as products and services to businesses, although given the imperfections in the market for ideas, this relationship fits rather uncomfortably in this category in my typology (but better here than elsewhere). Cooperative research and development agreements (CRADA) in recent years, for example, have put pricetags on the know-how of U.S. government organizations, like the Department of Energy's national laboratories, and built formal inter-organizational relationships between these organizations and industrial partners. Twenty-first century firms may produce more environmentally-friendly vehicles and extreme ultraviolet lithography equipment as a result of CRADAs.[16]

The State as Fisc

Although the state may sometimes appear to be just another participant in the market, appearances are deceptive. The state has at least two crucial monopolies. One is its monopoly on legitimate force, which, among other things, allows it to impose taxes. The other is its monopoly on the means of exchange; unlike firms, the state can print money and spend it. The state's power to tax and spend has important consequences for the innovative capacities of firms within its jurisdiction. The fiscal state can create markets for innovations where none would have existed otherwise, subsidize or penalize specific firms, groups of firms, or organizations

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[15] David M. Hart, *Forged Consensus: Science, Technology, and Economic Policy in the United States, 1921-1953* (Princeton: Princeton University Press, 1998), 68-71; Gregory B. Field, "'Electricity for All': The Electric Home and Farm Authority and the Politics of Mass Consumption," *Business History Review* 64:32-60 (1990); Ronald C. Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home* (Berkeley: University of California Press, 1996).
[16] Christopher T. Hill and J. David Roessner, "New Directions in Federal Laboratory Partnerships with Industry," *Science and Public Policy* 25:297-304 (1998).

involved in science and technology, and regulate the availability of funds that might be used to make investments in innovation.

Excessive taxation, of course, can crush all forms of business activity, including innovative activity. For my purposes, however, the scale of taxation is less interesting than the taxing authority's ability to privilege some business activities over others. Tax relief may provide incentives for particular firms to put money into R&D or plant and equipment, for instance, and to locate that spending in particular places. The same accounting conventions that lead small enterprises to be overlooked in surveys of R&D spending, for instance, also allow large firms to take fuller advantage of the research and experimentation (R&E) tax credit. Tax breaks may also be targeted to induce quite specific innovations. The U.S. "orphan drugs" act, for example, induces firms to develop therapies to treat maladies that strike groups too small to constitute a market without government intervention. Genzyme, Biogen, and a number of other new biotechnology firms have grown up in the shelter of this legislation.[17]

In addition, U.S. law exempts from taxation the distribution of privately accrued fortunes to the "independent sector" of universities and charitable foundations. Thus, the entrepreneurs of one technological generation may, if they so choose, reinvest their gains in building up later generations. They have often done so, donating academic science and engineering facilities, providing research grants, and endowing professorships. The Howard Hughes Medical Institute, for instance, is one of the biggest funders of biomedical research in the United States. The Bill and Melinda Gates Foundation, similarly, is investing in vaccine research and guaranteeing the

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[17] U. S. Congress, Office of Technology Assessment, *The Effectiveness of Research and Experimentation Tax Credits* (Washington: GPO, 1993); OTA, *Pharmaceutical R&D*, 1993, *op. cit.*

market for immunizations in developing countries in an effort to jumpstart private innovative activity in this previously neglected area.[18]

Direct government subsidies (including "soft" loans and the like) are a more precise tool for fostering the development of specific technologies than tax breaks, and such policies are sometimes enacted even when the state is not the main customer for the end product. The Airbus consortium, which has benefited from generous government "launch aid," for instance, has brought contemporary Europe into the large civilian aircraft industry. The withdrawal of U.S. government subsidies for Boeing's supersonic transport (SST), by contrast, ended the SST development effort, probably to Boeing's benefit if one considers the experience of the Concorde. The state's shaping of business through the subsidy mechanism is likely to be less profound than when the state is the lead user of new technology. Subsidy programs often aim to leave recipients to the market in the end, playing the role of midwife but not nursemaid. Even if this transition is in fact effected, however, previously-subsidized firms may nonetheless be different than they would have been if they had evolved without the state's help. They might have adopted particular bureaucratic practices, for instance, or be considered to have special public responsibilities.[19]

Finally, the post-World War II state has been characterized by macroeconomic regulatory capabilities associated with John Maynard Keynes. By manipulating the state budget, interest rates, and exchange rates, Keynesian policy intends to stabilize the growth of aggregate demand, thereby assuring firms that their investments will not go unrewarded. Investments in technological innovation were among those that Keynesians had in mind. These hopes have

[18] Daniel J. Kevles, "Foundations, Universities, and Trends in Support for the Physical and Biological Sciences, 1900-1992," *Daedalus* 121(4):192-235 (1992); United Nations Development Program, *Human Development Report 2001* (New York: Oxford University Press, 2001), 102.

largely been realized, even though the business cycle has not been entirely eliminated. The mindset of those who fund R&D in firms, the technology community's business confidence, if you will, is thus in part a product of the fiscal state.[20]

The State as a System of Rules

The organizational state participates in high-technology markets, and the fiscal state funds, directly or indirectly, R&D and related activities. A third way of looking at the state focuses on its role in establishing and enforcing the rules under which market participants engage one another.[21] This arrangement, in which a player is also the umpire, may not seem entirely fair, and sometimes it is not. Like excessive taxation, collusion between privileged enterprises and legal authorities may destroy private incentives for innovation. Yet, the lack of a system of rules may be even more stifling. In between the extremes, where most states operate, the details of the rules and the nature of compliance with them shape the innovative activities of firms.

One fundamental set of rules distinguishes between domestic and international trade. By expanding the scope of the market, Adam Smith tells us, states may deepen the division of labor and thus enhance private technological capabilities. The exceptionally large market of the continental U.S., for example, gave its manufacturing firms a technological leg up in the nineteenth and early twentieth centuries on their counterparts abroad. The post-World War II closing of the technological gap by leading European and Asian firms, in turn, owed much to the free trade policies of the *pax americana*, which expanded the scope of their markets. Under

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[19] Laura D'Andrea Tyson, *Who's Bashing Whom: Trade Conflict in High-Technology Industries* (Washington: International Institute of Economics, 1992); Mel Horwitch, *Clipped Wings: The American SST Conflict* (Cambridge: MIT Press, 1982).
[20] Hart, *op. cit.*, 145-174.
[21] In many cases, these rules may be conceived of as solutions to collective action problems that would otherwise cause markets to fail. Some subsidies and tax incentives may be also thought of in this way. This class of problems

some conditions, trade restrictions may more effectively cultivate firms' technological capabilities than openness. If, on the one hand, American firms a century ago had access to the world's largest customs union, so too did they benefit from tariffs designed to limit the degree to which their foreign competitors shared this resource. Domestic trade protection and aggressive exporting have been essential ingredients in the recipe for Japanese manufacturers' rise to global leadership.[22]

Another fundamental set of rules establishes property rights and particularly, for my purposes, intellectual property rights (IPR). As with trade restrictions, the state must strike a balance in this area if it is to effectively foster innovative businesses. Too loose an IPR regime will deter private investment in new products and processes out of fear of free-riding; too strict a regime will lead to endemic litigation. In their high-tech heydays, General Electric (1920s and '30s), IBM (1960s and '70s), and Microsoft (1990s and 2000s) all faced bitter complaints that their imitative capabilities suppressed otherwise competitive entrepreneurs who were unable to protect their innovations from these giants; on the other hand, aviation, automobiles, and radio were all plagued in their early years by patent deadlocks. Survey research has shown that the pharmaceutical industry relies most heavily of all industries upon IPR. Nor surprisingly, changes in the U.S. IPR regime around 1980, such as the Bayh-Dole Act (which expanded the scope of universities' IPR) and the *Chakrabarty* decision (which authorized patents on genetically engineered life forms), contributed significantly to a restructuring of the innovation

has spawned a very large political science literature, beginning with Mancur Olson, *The Logic of Collective Action* (Cambridge: Harvard University Press, 1965).

[22] Richard R. Nelson and Gavin Wright, "The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective," *Journal of Economic Literature* 30:1931-1964 (1992); Chalmers Johnson, *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925-1975* (Palo Alto: Stanford University Press, 1982).

process in this industry, including the strengthening of academic-industry relationships, the emergence of new firms, and the reorganization of old ones.[23]

Financial regulations comprise a third item on this list of essential rules. By regulating the mechanisms by which firms raise capital, the state structures their capacity for taking risks, including technological risks. For example, the U.S. venture capital sector, which has fostered an array of high-technology industries (and new technology-based competitors in mature industries as well), first boomed only when banking and securities regulations were altered to permit a very high-risk component in financial service firms' portfolios. The close relationships between Japanese main banks and large industrial firms, similarly, allowed those firms to make major investments in innovation when they might not have been able to make under another nation's rules.[24]

A state is not really a state without trade, property, and financial rules. But the regulatory state typically extends far beyond these minima. Codes of conduct or, in the American lexicon, fair trade practices, for example, may place limits on cooperation among competitors and on mergers and acquisitions (and other practices). These limits may significantly affect firms' technological capabilities. For example, the merger wave at the turn of the twentieth century in the U.S., which was provoked in part by an antitrust policy that outlawed market sharing agreements, set the stage for the establishment of central corporate research laboratories by dominant high-technology firms in the ensuing decades. The tightening of antitrust enforcement in the 1930s and 1940s and the imposition of compulsory patent licensing as a remedy for

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[23] Richard C. Levin, *et al.*, "Appropriating the Returns from Industrial R&D," *Brookings Papers on Economic Activity* 1987, no. 3, 783-820; Henderson, *et al.*, *op. cit.*

[24] Hart, *op. cit.*, 164-172; Lewis M. Branscomb and Philip E. Auerswald, *Taking Technical Risks: How Innovators, Executives, and Investors Manage High-tech Risks* (Cambridge: MIT Press, 2001); Johnson, *op. cit.*

violations of antitrust law helped to strengthen the technological capabilities of smaller and weaker firms in the post-World War II era.[25]

Many other forms of regulation have also influence firms' technological capabilities. Price regulation in the U.S. aviation industry between the 1930s and the 1970s, for instance, created incentives for rapid technological change, particularly in luxury features, since these features became the primary basis for airline competition. In the telephone industry, over roughly the same period, a regulatory regime of price regulation combined with monopoly to limit the pace of diffusion of such innovations as digital switching and fiberoptic transmission, even as it fostered basic research at Bell Labs. The rules governing labor relations affect the pace and direction of private technological innovation, too, as when firms seek to substitute capital for labor to ward off unions that threatened their control and cost structure.[26]

More recently, environmental, safety, and health regulations have changed the innovation investment calculus within companies. In some cases, regulations have forced the development and diffusion of new technologies, and in others, they have frozen the "best available control technology" (as many U.S. environmental laws put it) in place. A major rationale for the most recent wave of "market-conforming" regulations, such as tradable emissions permits, is that this regulatory structure creates greater incentives for businesses, particularly the heaviest polluters, to undertake technological innovation. Similar arguments are now being offered for the development of a global climate change control regime.[27]

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[25] David C. Mowery, " The U.S. National Innovation System: Origins and Prospects for Change," *Research Policy*, 21:125-144 (1992); Hart, *op. cit.*, 84-96.
[26] Richard H.K. Vietor, *Contrived Competition: Regulation and Deregulation in America* (Cambridge: Belknap, 1994); Kenneth Flamm, "Technological Advances and Costs: Computers vs. Communications," in Flamm and Robert W. Crandall, eds., *Changing the Rules* (Washington: Brookings, 1989), 13-61
[27] Robert N. Stavins, "What Can We Learn from the Grand Policy Experiment? Lessons from SO2 Allowance Trading," *Journal of Economic Perspectives* vol. 12, no. 3 (Summer, 1998), 69-88.

The regulatory state infiltrates the mindset of actual and would-be innovators more profoundly than does the fiscal state. In a well-functioning regulatory state, the threat of enforcement, rather than enforcement itself, deters smuggling, infringement of property rights, and non-compliance. Indeed, compliance may come to seem natural, even in areas in which the initial intervention by the regulatory state provoked shock. The threat of enforcement may be reinforced as well by the moral sentiment of citizens both inside and outside of business. The process of deploying new technologies on the shopfloor, for instance, involves consultation with and adaptation to the workforce in some settings for legal, business, *and* normative reasons, while in other settings all three of these motivations may be absent. The regulatory state thus helps to erect and maintain a set of norms that exercises an influence on the process of technological change.[28]

The State as Normative Order

The regulatory state, of course, hardly inspires universal devotion among businessmen. Yet the moral sentiments that do attach to it, however modest, point toward the fourth way of looking at the state, which is as a set of shared beliefs and experiences. This state is typically taken for granted, second nature. Its impact on industrial innovation is subtle but significant. Nationalism, liberalism, socialism, and plenty of other -isms (not to mention a bundle of less well-articulated elements of political culture) motivate and channel the energy and attention of corporate scientists, engineers, and managers.

The most powerful of these norms is nationalism. Even the academic scientific community, which maintains a powerful counter-norm of internationalism, has been riven

[28] Jeffrey Keefe, "Do Unions Hinder Technological Change?," in Lawrence Mishel and Paul B. Voos, eds., *Unions and Economic Competitiveness* (Armonk, NY: M.E. Sharpe, 1992), 109-141.

regularly by nationalist sentiment. The fervor with which professors served their nations' militaries in World War I, for instance, stunned the community's idealists. Close collaboration between the national security apparatus and high-technology companies has been even more common than military-academic collaboration. To be sure, money changes hands in these relationships (hopefully from state to business and not the other way around), but they are sealed by shared beliefs. IBM engineers who worked with the U.S. National Security Agency undoubtedly wanted to safeguard national secrets and break Soviet codes as well as get paid and stay at the cutting edge of technology.

Patriotic sentiments need not be harnessed to national security to have an effect on industrial innovation. The project of nation-building, for instance through the development of energy, transportation, or communication systems, may mobilize the efforts of the corporate technical community. Companies like Bombardier and Nortel, which are centers of excellence in the Canadian national system of innovation, for example, have their roots in such a project. One would expect to find this pattern in developing countries in periods like the contemporary one, when innovation in the private sector is perceived to be a necessary element of any growth strategy. Technical elites in these countries, whether in the public or private sector, are quite likely to be ardent nation-builders.[29]

The conception of the state as normative order also embraces economic and political values other than nationalism. Individualism, for example, permeates the U.S. system of innovation, in which entrepreneurial spinoffs from large companies are a critical component. Fairchild, itself a spinoff from Bell Labs, was the spawning ground for some of Silicon Valley's most innovative new firms in the 1950s and 1960s. American culture's acceptance of risk-taking and failure enables entrepreneurs in the U.S. to start up new firms more easily than those in other countries. Such risk-taking occasionally finds expression even in larger firms. In societies in which risks are more fully socialized, bet-the-company efforts like the IBM 650 or the Boeing 747 would be even more difficult to carry off than they were in the U.S.

Economic individualism is not incompatible with the civic republicanism that has been prominent at times in U.S. history. The provision of new goods and services to all the people can be conceived of as a fulfillment of one's duty in this schema, and industrial innovation, therefore, a means of national service. Richard John, for example, finds traces of this ideological commitment in Theodore Vail's universal service strategy for AT&T. In the twentieth century, rights-based liberalism has overshadowed civic republicanism, and it too has had an influence on industrial innovation. The gay rights movement's deep involvement with AIDS drug development is one powerful example. The refusal of the movement's members to comply with conventional research protocols led to a significant restructuring of federal regulation of drug trials and approval and thus on the pharmaceutical industry.[30] The current debate over stem cells and therapeutic cloning in the U.S. is also best seen as a conflict of norms. Whether Advanced Cell Technology and other biotechnology firms will be allowed to continue to explore this particular frontier will depend on what ethical status is granted to embryos, a hotly contested matter in U.S. politics.

The state as a normative order is not monolithic. States usually encompass regional or ethnic variations as well as dissenting groups and individuals. The degree and extent of cultural variety may have implications for innovation in the private sector. Minority groups, for

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[29] Mark Elam, "National Imagination and Systems of Innovation," in Charles Edquist, ed., *Systems of Innovation* (London: Pinter, 1997), 157-173; Jorge Niosi, "Canada's National System of Innovation," *Science and Public Policy* 18:83-92 (1991).

instance, like Jews and overseas Chinese, have been disproportionately represented in the annals of industrial science and technology. Immigrants may bring new ideas and perspectives with them; contemporary Silicon Valley thrives as much on these newcomers as on good old American know-how.[31]

Conclusion

This quadripartite typology of the state as organization, fisc, system of rules, and normative order provides the basis for a systematic set of questions that might be posed in the analysis of science and technology policy. These questions lead toward a comprehensive causal understanding of the basis in public policy of the technological capabilities of the nation's private firms. The typology covers both intended and unintended interactions between the public and private sector that produce private technological capabilities. Indeed, its most significant value may be in teasing out the unintended effects of the state on the market and directing our attention to consider the simultaneous impact of several different (and typically uncoordinated) "policies" (if I may be allowed to invoke this inadequate term to cover all four "states" discussed above).

The typology also opens the way to a fuller incorporation of organizational, legal, and cultural variables into science and technology policy studies. Such variables are often taken for granted and left in the background. A more comprehensive conception of the state highlights their roles as constitutional elements in the development of corporate technological capabilities. It suggests that scholars of science and technology policy ought to participate in an even broader interdisciplinary dialogue than they have in the past.

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[30] Richard R. John, "Vail and Universal Service," paper presented at the Business History Conference, Chapel Hill, NC, March 7, 1999; Steven Epstein, *Impure Science: AIDS, Activism, and the Politics of Knowledge* (Berkeley: University of California Press, 1996).

[31] Annalee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge: Harvard University Press, 1994); Annalee Saxenian, "Silicon Valley's Immigrant Entrepreneurs," Public Policy Institute of California, June, 1999.