Public Policies and the Emergence of High-Technology Sectors

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Executive Summary

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1. **Introduction**

The maturation of "high-technology sectors" has been perhaps the major transformative force of the U.S. economy and society over last decade. Biotechnology and the Internet represent two undeniable examples; nanotechnology may be waiting in the wings.

Public policy has been a critical sustenance underlying these sectors. Though no one would argue that American public policy invented and consciously charted the entire course, pivotal moments are nevertheless clear, when a prescient policy community engaged an incipient technological transformation productively. The ability of a national technology policy to grasp such moments is essential to a healthy innovation system.

When, how and in what form public policy consciousness manifested itself in the U.S. toward two emerging high technologies -- the Internet and nanotechnology -- is the main question addressed in this report. The core of the research is presented in historical case studies of each. The cases are preceded by an overview of the public policy discussion of "high technology policy" in U.S. over the last several decades, and followed by conclusions about the design of public policies toward high technology sectors.

2. Public Policy Toward High Technology in the U.S.

The assertion that there is an overall "high technology policy" in the U.S. would prompt quick dispute in American policy circles. Indeed, history suggests that the American approach to high technology sectors is more ad hoc and entrepreneurial than conceptual or deliberate. On the other hand, U.S. success in developing high technology sectors argues at least as strongly that an implicit technology policy has been a constant component of American policy.

In the 30 – 40 years following World War II American science and technology policy established its "traditional" pattern. The prototype was laid in the Bush Report, "Science: the Endless Frontier," which emphasized public support of science, and left technology largely to the private sector. Beyond this, the era was dominated by large government programs – defense, space, atomic energy and health -- dedicated to the fulfillment of particular government "missions," and thus not seen as a coherent high technology policy.

The traditional policy paradigm established institutions, competencies and approaches critical to the subsequent development of high-technology sectors. Most of the publicly funded R&D were actually performed in the private sector, thus augmenting the capabilities of companies, universities, and research institutes. A technical "establishment" became highly interconnected, via the movement of funds, cooperative projects and mobile career paths for technical professionals. A "culture" of entrepreneurship emerged, based competitive bidding, peer review, and a "project mentality" -- which tended to foster excellence, initiative and flexibility in the face of often-varying funding patterns. DARPA (Defense Advanced Research Projects Agency) and the NIH (National Institutes of Health) deserve special credit

By the mid-1980s, the "competitiveness crisis" prompted questions about the adequacy of traditional science and technology policy. A new argument suggested that a national interest in technology development for economic purposes could be discerned, and that the government should push it forward. By the end of the decade, events bespoke a resolution of the debate. In 1988 the

Advanced Technology Program (ATP) was. In 1990 the Bush White House issued a Technology Policy Statement endorsing government support of the development of "generic" technologies in their "pre-competitive" phase. And a host of programs, both Federal and state, focused on technology commercialization.

The policy innovations of the 1980s also left a curious countervailing legacy: antipathy for new government "programs." This made the concept of "technology "initiatives" attractive. Technology initiatives date to the formation of the Federal Research Internet Coordinating Committee (FRICC) in 1988. By the end of the Clinton-Gore years, the science and technology policy community had become comfortable with – even habituated to – the use of interagency technology initiatives.

Looked at as an instrument of U.S. high technology policy, initiatives exhibit four main features: a) they are designed to appeal to a broad constituency, both technically and politically; b) they typically target technical fields that are broad and enabling rather than technologies of specific or limited scope; c) they presume a limited government role – research and coordination less than specific programmatic objectives – coupled with the recognition that private sector technology development is the desired next step; and d) they bespeak a "bottom-up" approach to technology policy in which the motivation tends to arise from the scientific and engineering community rather than "top down."

3. The Internet

The Internet is without question one of the outstanding successes of U.S. investment in technology. The Internet economy (broadly defined to be companies ranging from Internet infrastructure to electronic commerce) now employs over 3 million people and has revenues of over $800 billion. Its impacts on education, government, and society at large have been profound. The Internet would not have been possible without sustained investments by the U.S. Federal government over a more than 30-year period.

The Internet's development can be divided into four periods:

- pre-1969, when the ARPANET was developed;
- 1969-1983, when networking expanded and the inter-networking protocols were developed;
- 1983-1993, when the Internet expanded but before being widely used by the general public; and
- 1993 to the present, when the World Wide Web and web browsers contributed to the rapid global expansion of the Internet.

Throughout these periods the Federal role changed considerably moving from defense to civilian agencies. The purpose of support changed from advancing computer science and enabling defense communications, to providing computing infrastructure for researchers, to providing broad economic benefits. And leadership for Internet policy passed from a small group of computer scientists to the Congress and the White House.

Packet switching and the development of the ARPANET were two major antecedents to the Internet. The first paper on packet switching theory was published in July 1961, and the ARPANET -- the first major packet switched network – followed toward the end of the decade as the key systems innovation. The Network Control Protocol, developed in 1970, enabled communication among hosts via a common data format.

DARPA provided the main support for this work. It explored networking and communication concepts, looked for economies in computer purchases, and promoted computer networking as a way to share resources. Although the assertion is sometimes made that the ARPANET was created to provide communications to survive nuclear war, this was only true for work on packet switching, not ARPANET. During this stage there was little high level (Congressional or Presidential) interest; however, the Cold War did generate strong support for defense related research, and DARPA had ample funding and autonomy in pursuing projects that interested it.

During the early 1970s, several developments dramatically expanded ARPANET's uses. File transfer protocols were developed, email became the most popular use, and the communications industry's attention was piqued. Kahn and Cerf are widely credited with developing protocols that created the Internet. DOD adopted a standard for these protocols in 1980. Meanwhile, the scientific and business community outside of DARPA began developing intense interest in networking, prompting the genesis of the domain name system. Still, no coherent policy community addressing the wider implications of the Internet had coalesced.

The 1983-1993 period is key in the expansion of the Internet, when it evolved from a network among a small number of computers into a phenomenon that attracted the attention of the highest levels of government. By the beginning of 1983, when the ARPANET was officially converted to the TCP/IP protocol, the key technologies for the Internet were in place. As the ARPANET became a production, rather than a research network, DARPA began to lose interest. Other organizations -- the Department of Energy, NASA, corporate and grassroots groups – had been developing their own networks since the late 1970s.

NSF took a crucial role. The Computer Science Network (CSNET) began as a dial-up network that enabled researchers at universities were not connected to the ARPANET to get on a network at low-cost. This established the precedent of non-metered connections between networks and resulted in a great expansion of the number of people who were connected. In 1985, a program of supercomputer centers was launched, and in 1986 NSFNET, the first large-scale network, was connected to the ARPANET. Through NSF's clear indication that its seed money would not continue indefinitely, the privatization and commercialization of the Internet inevitable. By the mid-1980s, sufficient interest in the use of Internet in the research, educational and defense communities that it was possible to establish businesses making equipment for the Internet.

Around the same time the Internet began to attract higher level policy visibility. In 1986, Senator Gore introduced the Supercomputer Network Study Act. This contributed to an active interest in networking in the Office of Science and Technology Policy. Studies and reports proliferated from other agencies. By 1988, Federal agencies were beginning to cooperate on computer networking, most notably in the FRICC. They were successful in large part due to the phone company's pricing policies, which gave large discounts for large volumes, and thus provided a financial incentive for the agencies to work together to share networking. The FRICC also put together an interagency initiative that became known as the High Performance Computing and Communications (HPCC) initiative in 1991. Subsequent legislation set funding targets for the agencies, including DARPA, NSF, DOE, NASA, Commerce, and EPA, required a program plan, and established an advisory committee.

At this point still primarily as a tool for researchers, the Internet was beginning to be recognized for its potential to be a new national information infrastructure. Externally, other key developments were taking place that would expand the use of the Internet to society at large. The development of the World Wide Web (WWW) began in 1989 at CERN, Europe's high-energy physics facility, and was released in 1991.

With the release of the graphical web browser, Internet usage quickly took off. In 1993, the Clinton-Gore Administration made it clear that it considered the Internet to be basis for a new national information infrastructure. Commercial networks expanded so rapidly that in April 1995, NSF ceased its support for the NSFNET backbone. Innovation has continued at a rapid pace, with its locus largely in the private sector. Many of these innovations still benefit directly or indirectly from federally sponsored research and development, but government sponsorship has receded in importance.

The overall policy environment established by the Federal government, however, does appear to be important. This is conducive to entrepreneurship and supportive of the relatively free development of electronic commerce. U.S. telecommunications policy, based on flat rate pricing for local telephone calls, has allowed individuals to connect to the Internet through dial-up services much more cheaply than in many other countries. And there still is an active Federal R&D effort in computing and networking, focused in the Next Generation Internet Initiative, a multi-agency Federal program of Internet research.

As the Internet continues to evolve, standards processes are critical in determining its shape. Over time the Internet Engineering Task Force (IETF) has emerged as the main engineering and standards body. In the beginning, and until the early 1990s, U.S. research and education institutions dominated the IETF. However, the majority of participants are now from companies, and it has become much more international

The widespread deployment of the World Wide Web has brought with it a new community that is not primarily concerned with networking. A new coordination organization was formed, the World Wide Web Consortium (W3C) to take on the responsibility for evolving the various protocols and standards associated with the Web.

The following general observations may thus be made about the Internet's development:

- Given its origin as a research tool and the large government role, the Internet is an atypical case of technology development
- It is the result of sustained investment over many years, not a single initiative
- The factors leading to success in its development changed substantially over time
- Policy development has been bottom-up
- Many people were slow to realize the Internet's importance
- Although Federal investment was vital, commercial developments have assumed equal importance

4. The U.S. National Nanotechnology Initiative

On February 7, 2000, President Clinton's budget proposed a National Nanotechnology Initiative (NNI), recommending an 83% increase in federal funding for research and development (R&D) on nanotechnology in a single year, from $270 million in FY 2000 to $495 million in FY 2001. Six federal agencies would share this funding.

In the U.S. political system, Congress does not always accept a President's budget proposals, particularly when a different political party controls the

Congress. However, Congress did in fact provide most, though not all, of the FY 2001 nanotechnology funding requested by President Clinton – a total of $418 million, an increase of 55 percent over the previous year. Nanotechnology (which we define here to include the fields of nanoscience and nanoengineering)* was thus accepted as a priority by both the Congress and the Administration.

The sense of excitement and opportunity about what we now call nanotechnology dates back to a specific event – a December 29, 1959 talk by Caltech physicist Richard Feynman, which President Clinton cited in his program announcement. If Feynman was the visionary, K. Eric Drexler is seen by many as the principal "evangelist," promoting the new technology and its applications over the subsequent 40 years.

Dramatic technical advances in the 1980s and early to mid-1990s turned nanotechnology from a dream into a real possibility. Some of the underlying research was funded by the government, notably through DARPA. Over the course of this research, a growing number of scientists and engineers were convinced that nanotechnology had become a serious and important field of research. Nevertheless, there is little evidence to show that scientific and technical societies or industry groups organized to encourage the federal government to make nanotechnology research a national priority. Rather, the push for a national nanotechnology initiative came from within the federal government itself, led by policy entrepreneurs, first in federal research agencies and later in the White House.

Four specific aspects of policy development process were particularly important in the case of the nanotechnology initiative:

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* The essence of nanotechnology is the ability to work at the molecular level, atom by atom, to create large structures with fundamentally new molecular organization…. Nanotechnology is concerned with materials and systems whose structures and components exhibit novel and

- Mid-level agency experts became interested in nanotechnology, began talking to colleagues in other agencies, and then talked to White House staff, supplying ideas about nanotechnology policy.
- Staff-level policy entrepreneurs at the White House were receptive to ideas for new initiatives
- Presidential endorsement was critical persuading Congress to provide money for the new initiative.
- Policy entrepreneurs launched an interagency effort through a process, partly informal and partly formal, in which it is politically "safe", effective, and useful for people from different agencies to work together to forge multi-agency R&D initiatives.

The first policy entrepreneurs were mid-level specialists within federal agencies, notably at NSF, DOC and DARPA. An informal group was established, bringing together those who shared a genuine intellectual interest in nantotechnology, a belief that it could contribute to their agencies' missions, and an agenda of increasing research budgets through cooperation. In 1997 a workshop was held to review the status of the technology and government programs abroad, and in 1998 the head of the NSF was persuaded to testify to Congress about the importance of nanotechnology.

The next step for the policy entrepreneurs was to approach White House staffers with the suggestion of nanotechnology as a national initiative. The interest that White House staff – themselves policy entrepreneurs -- showed in nanotechnology did not result from a desire to please key political constituencies or to distribute benefits to particular industries. Rather, the potential benefits for U.S. economic competitiveness, as well as benefits for other important areas such as health loomed largest. The staff understood that if they were to recommend a nanotechnology initiative, the benefits would be long-term, not immediate. Fortunately, President Clinton and Vice President Gore liked long-term

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significantly improved physical, chemical, and biological properties, phenomena, and processes investments. So did the President's new Science Advisor and OSTP Director, Neal Lane – formerly the NSF Director who had earlier listened sympathetically to the staff's arguments in favor of nanotechnology.

In September 1998, the White House's science and technology coordinating body, the National Science and Technology Council (NSTC), created a formal interagency working group to study nanotechnology policy – a step again sought by the agency policy entrepreneurs. The group received the title of Interagency Working Group on Nanoscience, Engineering, and Technology (IWGN). NSF, DOC, OSTP and OMB had representatives, as did the National Institutes of Health (NIH), NASA, and the Departments of Defense, Energy, Transportation, and the Treasury. The creation of the working group did not guarantee that the Clinton Administration would indeed propose a formal nanotechnology initiative, but it provided a formal mechanism for studying the topic, increasing familiarity about the technology, and making recommendations.

In late 1998, the IWGN began to put together the detailed plans and program rationale that OMB and other senior officials in the White House demand of a potential Presidential initiative. In addition, the working group needed to find out how the larger U.S. research community would respond to the possibility of a large-scale, expensive nanotechnology initiative. At a workshop in January 1999, officials saw the research community respond enthusiastically to the idea of greater federal funding in this field. Armed with this background nanotechnology emerged from the formal annual budget process listing R&D priorities as number one among the top ten.

In the fall of 1999, President Clinton and Vice President Gore accepted staff recommendations that the FY 2001 budget should contain a formal National

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due to their nanoscale size.

Nanotechnology Initiative. Much of it would build on existing nanotechnology research activities in the agencies, but the budget would propose a significant increase in funding and make nanotechnology a formal Presidential priority. Beyond specific funding requests, the Administration released detailed reports and an implementation plan, which were used to explain the program to Congress.

In the United States, it is not enough for a President to propose a new initiative. For a new policy initiative to succeed, advocates must build a coalition and persuade Congress to provide the funding. In the case of nanotechnology, two factors complicated these efforts. First, this initiative came out of the Executive branch – not from a strong industry coalition or even from a coalition of scientific and technical societies. Second, 2000 was a presidential election year, and the Republicans who controlled Congress were not disposed to endorse a program that might conceivably help Vice President Gore as he ran for the Presidency.

That the Clinton Administration successfully overcame these problems is due to the following factors: a) early briefing of members of Congress and Congressional staff; b) the endorsement of technical groups that appeared non-partisan; c) the relatively non-partisan character of R&D initiatives generally; d) a well-crafted program design; e) program funding that would flow to many constituencies; f) no organized opposition, and g) a budget surplus that allowed President Clinton to propose funding increases.

By the time Congress and President Clinton finished the FY 2001 appropriations (spending) laws, federal nanotechnology programs had received a total of $418 million, an increase of 55 percent over the previous year. This was not everything the President had requested, but still a substantial increase above the FY 2000 level. Support for nanotechnology funding had not been a contentious issue in the Congress. While some partisans of nanotechnology, as well as other critics, have argued that it may hold dangers, but so far they have not had a significant effect. An though no one can predict exactly how the new President will treat this field, it is likely that nanotechnology has now truly become a national R&D priority.

While the U.S. Government has made nanotechnology a priority for government R&D, this is not to say that the *nation as a whole* has made nanotechnology *applications* a national priority. As nanotechnology research produces new discoveries and inventions, American companies (and others) will try to commercialize these results and sell products based on them. But will the public accept these products? Will some people try to regulate the industry and its products? Whether its many applications become successful commercial industries will depend on factors far beyond R&D policy.

5. Conclusions

U.S. public policies toward high technology have evolved considerably over time. The early rubric, "public support for science; private technology development," appears to have been superseded by national research "initiatives" in support of broad technical fields underlying high technology sectors. The Clinton-Gore National Nanotechnology Initiative, endorsed by the Congress for FY 2001, is the latest manifestation of this evolution.

National technology initiatives take many of their characteristics from the larger U.S. policy process. They are broad-based, drawing on many constituencies. They cross agency and sectoral barriers. They arise from a "bottom up" process, in which policy entrepreneurship in the technical agencies, the Congress and the White House play an important role. And they cast the government in the role of supporting research and cooperation more than executing a programmatic function. Nanotechnology and the Internet have both benefited from the use of such initiatives, though in strikingly different ways.

The Internet is without question one of the outstanding successes of American technology. It would not have been possible without sustained investments by the U.S. government over more than 30 years. But given the highly unusual characteristics of the Internet, and its relationship to public policy, generalizations from this case to other technologies are difficult.

If Federal investment has been vital to the Internet, the role of commercial and other private developments cannot be underestimated. Neither sector, however, can be credited with anticipating the Internet's significance. The fact that many prominent institutions were slow to catch on underscores the difficulty that traditional top-down decision-making has in reliably identifying important emerging technologies.

Although its conceptual base has been developing since the late 1950s, nanotechnology only emerged recently as an official national priority, in the National Nanotechnology Initiative of the Clinton-Gore Administration. The political recognition of nanotechnology's importance that accompanied Congressional approval of large budget increases can be traced to the following factors:

- visionaries and "evangelists" for the technology.
- growing interest in the scientific and engineering communities
- policy entrepreneurs
- a broad political coalition in favor of the initiative.
- few organized opponents
- nanotechnology's use as an enabling technology to many areas of science and engineering

- a U.S. budget surplus
- belief that nanotechnology could help right an imbalance between growing funding for health research and flat support for physics, chemistry, engineering, etc.
- support from the U.S. semiconductor industry
- solid belief that R&D is a valuable investment in long-term economic growth and competitiveness.

It is important to note that these factors combine both the technical and the political. And that they came together at an auspicious moment. It is also clear that success in developing a consensus for nanotechnology as a national priority combined a long-term, broadly based, bottom-up movement within the policy community with leadership that extended to the highest levels of government.

If most participants in the American policy process would grant that its focus has moved considerably toward support for emerging technologies of economic importance, few would characterize this as a deliberate "high technology policy. What is strongly endorsed, however, is the idea of broad public support for the infrastructure of science, technology and its commercialization. The exact form that laws, institutions, funding patterns, programs and initiatives toward this objective may take is a question that most are happy to leave to the traditional U.S. technology policy process: ad hoc, entrepreneurial, diverse, open and contentious.