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From "Mission-Oriented" to
"Diffusion-Oriented" Paradigm:
New Trend of U.S. Industrial Technology Policy

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Abstract

As the post-World War II history shows, several "diffusion-oriented" countries, Japan and Germany in particular, have performed better economically than some "mission-oriented" countries, like France and the U.K. As the leading "mission-oriented," innovator and "first mover" country with three decades' economic and technological dominance and impressive "spin-off" achievements, the U.S. has been eclipsed in its traditional competitive advantage by many "smart followers" which have strong technical resources and complementary assets, and could rapidly assimilate innovator's technical advances and compete away innovator's economic rewards. To revive, the U.S. Federal government is undergoing a structural transition in its industrial technology policy toward "diffusion-oriented" paradigm. This new trend also reflects the growing skepticism and even disillusionment about the conventional "spin-off" rationale. In "diffusion-oriented" policy framework, U.S. Federal government active participation in "generic" and "precompetitive" technology is a rather novel strategic movement in this country. However, there still are some delicate issues involved in, especially, "precompetitive" cooperative industrial R&D remaining to be solved.

From "Mission-Oriented" to "Diffusion-Oriented" Paradigm: New Trend of U.S. Industrial Technology Policy

"Mission-Oriented" vs. "Diffusion-Oriented" Policies

In technology policy, the U.S., the U.K. and France could be described as "mission-oriented" countries, as compared with "diffusion-oriented" ones, such as Germany, Sweden and Switzerland, while Japan is a hybrid between both.¹

Mission-oriented policy attempts to generate and exploit radical innovation. Its ideal is to create entirely new industries based on new technologies. So it tends to compete in the early phase of technology life cycle, and emphasize "heroic" efforts in "big science and technology," or major programs. These programs, mostly defense and aerospace-related, are highly sophisticated and normally put more emphasis on performance than on cost. It is expected that, in addition to accomplishing the designated missions, the large-scale, high-end technological achievements can somehow lead to many smaller-scale, "less than high-end" applications. More specifically, through government R&D contracts or procurements of high-performance products, the contractors can upgrade technical capabilities, accumulate production experience, and drive down the cost. They then seek commercial applications. By this "spin-off" or "trickle-down"² process to civilian industry, it is hoped that the government initial costly investment can ultimately be justified.

By contrast, diffusion-oriented policy concentrates on acquisition, diffusion and assimilation of technology in industry. It attempts to increase value-added for existing products by improving quality, increasing efficiency or entering niche markets, rather than to create brand new industries. Moreover, especially in Japan, lower cost and lower risk fields are normally first targeted, and then used as stepping stones to accumulate experience and economic profits for competing in the next higher-end products. So incremental innovation is emphasized, and there are few large scale programs initiated by government mission agencies aimed at radical technological advancement. Though moving toward earlier phases of

technology life cycle is also pursued, the key notion of this policy is to be a "smart follower" first, instead of a "first mover" who risks the most. This is so-called "trickle-up." It also turned out that, in some fields, notably microelectronics, civilian technology thus cultivated could be largely used for military applications. This is the opposite of "spin-off," and may well be called "spin-on."

Comparatively speaking, "market-pull" plays a greater role in diffusion-oriented policy than in mission-oriented policy. In the latter case, government designated missions create initial markets, and "technology-push" then supports further "spin-off" or "trickle-down" activities, if any. In terms of innovation pattern, mission-oriented policy tends to focus more on product innovation (e.g., performance of key functional parameters), whereas diffusion-oriented policy tends to emphasize more process innovation (e.g., efficient manufacturing).³

It is also worth noting that the mission-oriented policy of the U.S., the U.K. and France is connected to their national security policy seeking greater degree of technological self-reliance. These three countries' defense R&D expenditures as a share of total GNP are much higher than those of diffusion-oriented countries. As a result, the non-defense R&D shares in GNP of the U.S., the U.K. and France have constantly been lower than those of Japan and Germany for the past three decades. In the mid-1980s the ratio of the former to the latter in GNP percentage was about two thirds.⁴

As the post-war history shows, the mission-oriented France and U.K. have been less successful economically than the diffusion-oriented Japan and Germany. The large military efforts in the former countries have apparently not led to particularly favorable positions on civilian markets of high technology. However, the U.S. was an exception at least until the 1970s when its international competitiveness of some industries began to erode significantly.

U.S. Policy Principles and "Spin-off" Achievements

Based on a general consensus that government involvement in science and technology is to overcome market failures, especially low appropriability and capital market imperfections, that cause

underinvestment in R&D, U.S. government traditionally only supports fundamental scientific research, just as all other developed countries do, and well-defined mission-oriented technological programs in which government has a strong and direct procurement interest. One of the very few exceptions in the history is the early agricultural R&D and extension program.

Because of lack of knowledge about commercial potential and reluctance to induce uneven distribution of benefits, Federal government basically follows free-market principles and leaves civilian technology development to private industry. Though some policy initiatives designed to expand Federal government role have been proposed for the past three decades, few of them were enacted or lasted beyond the initiating administrations' term of office.⁵ So in the arena of industrial technology policy, the U.S. has a cumulation of mission-oriented programs, but lacks a comprehensive and strategically-oriented approach as compared with Japan and many West European countries. Besides, U.S. Federal government does not "pick winners" or purposefully nurture "national champions." This is a big policy distinction between the U.S. and many European countries as well as Japan.

During the three decades following World War II, U.S. "spin-off" achievements based on a number of mission-oriented programs were fairly impressive. Well-known examples include jet engines (for high-performance fighters and bombers), computers (for plotting missile trajectories), semiconductors (for missile guidance systems), numerical control (NC) systems (for carving out aircraft structural parts), lasers (for tank range finders and beam weapons), and time sharing, digital communications and computer graphs (for air defense system).⁶

As a matter of fact, the impacts of some U.S. "spin-off" cases, most notably semiconductors and computers, are extremely far-reaching. They have triggered "technological paradigm" change, and created a new constellation of basic technological artifacts and heuristics or intellectual principles which dictate the working protocols.⁷ They have also induced "technology system" change, and brought about a range of technological and innovative activities

clustering around them. What is more, they have been affecting not merely one industry or group of industries, but spilling over to the entire economy, including working practices and life styles. That is, they have even caused "techno-economic paradigm" shift, and led the way to a modern "information society."⁸

Genetic engineering and high temperature superconductivity are two recent cases which may have some potential similar to semiconductors and computers. Though both came from basic research, rather than from mission-oriented programs, they are also of U.S. origin, and Federal government is the major sponsor.

By any measure (if possible), U.S. "spin-off" achievements in the early post-war era were unmatched by any other country. In fact, U.S. "spin-off" contribution is by no means confined to its territory. Many other countries could also benefit from U.S. pioneering progress.

Measurement and Patterns of "Spin-off"

Despite some apparent and great "spin-off" cases, it is, however, very difficult to quantify or measure rather accurately the "spin-off" impacts, even only in economic terms. Many issues involved also concern the fundamental difficulties in assessing technological innovation. In general, it may be easier to take account of "first order" cost saving or price increase resulting from incremental process innovation, but it is difficult to consider "second order," long-term and indirect effects, and it is nearly impossible to assess brand new products, some of which may even lead to new industries. Because U.S. modern military R&D normally puts much more emphasis on performance than on cost, tends to contribute more to product than to process innovation, and has created new civilian markets and even new industries in several cases, the economic impacts of "spin-off" are thus very difficult to measure.

When opportunity cost is taken into account, the challenge of evaluating cost-effectiveness becomes even more insurmountable. For example, the defense technology programs could be compared with R&D sponsored by the National Science Foundation, by other Federal agencies, or by commercial companies. They could also be

assessed against a system differently managed. And there could even be investments of different weights along the spectrum of basic research, applied research, development, engineering, testing and validation. In fact, many standards and criteria could be used.⁹ Certainly, it can be argued that it is inappropriate to consider cost of "spin-off" because the cost should be charged against the targeted missions. But when the investment is very big and "spin-off" becomes one reason to justify part of the investment, then the consideration of "spin-off" cost, however difficult in quantitative terms, makes some sense.

For strategic implications, it may also be useful to understand "spin-off" patterns. In this regard, there have been some studies of important cases.¹⁰ For instance, in semiconductors and computers, though the Department of Defense (DOD) supported relevant research, the key technological progress did not take place under DOD's direct sponsorship of R&D contract. Instead, DOD's assured procurements of high performance products at virtually any prices induced some firms to invest their own R&D resources, and they achieved great success. In the case of jet engine, the commercial aircraft could utilize rather directly the products developed for military purposes. In nuclear power and satellite communications, the defense needs created a technological infrastructure and support systems, like abundant nuclear technical data, space launch vehicles, etc. The civilian industry therefore could grow economically at the margins of the military efforts.¹¹ Still, some programs were technically conservative and mainly focused on exploiting the existing state-of-the-art rather than tried to generate significant scientific and technological advances. But they accelerated the progress by overcoming the resistance to technological change through demonstration. As an example, the use of computers in highly visible space programs was said to have greatly increased the acceptance of computers by the business world. Finally, as the early history of semiconductors shows, the practice of mission agencies (mainly DOD and NASA) to establish a competitive market encouraged and supported many small innovative firms. Some of them later took over some conservative established firms' leading

position and rejuvenated the industry.¹² Though the cases discussed here are neither exhaustive nor necessarily representative, they exhibit the variety and complexity of "spin-off" patterns.

Recent Technology Policies

Under the Reagan administration, integration of economics and science and technology was generally emphasized with a view to enhancing industrial competitiveness.¹³ Without an explicit and coherent agenda, the underlying technology policy may well be deduced from the budget decisions.

Along with the military build-up, defense R&D funding (only a very small fraction of which was for basic research) was increased from 50% of total Federal R&D investment in 1980 to nearly 70% in 1988.¹⁴ In 1989 U.S. defense R&D spending, \$46.3 billion, accounted for one third of national R&D spending, \$134.2 billion, and was estimated to be five times all the other OECD countries' total defense R&D spending, \$9.3 billion. In the same year, U.S. non-defense R&D investment was \$87.9 billion, less than all the other OECD countries' \$117.1 billion.¹⁵

In addition, under the Reagan administration, a number of very costly "mega programs," such as National Aerospace Plane, Space Station and Strategic Defense Initiative (SDI), were promoted. Some "spin-off" arguments, like "Oriental Express," were also raised by proponents.

In the meantime, DOD became more active in developing technology with broader application potential. In fact, this was not in consistency with the administration's initial ideology similar to the logic of the Mansfield Amendment (passed in 1969) that restricts DOD's technological activities to those areas directly concerned with military needs. But the obvious importance of increased defense expenditures to the economy, which was losing its international competitiveness, led the administration to have DOD do something for the civilian industry.¹⁶ Under this new philosophy of pragmatism, several programs, such as the Very High Speed Integrated Circuits (VHSIC) Program and the Strategic Computing Program, included rather explicit non-military intention. Moreover, in 1987 DOD

started to underwrite the Semiconductor Manufacturing and Materials Research Consortium (SEMATECH), an initiative of the civilian Semiconductor Industry Association. In 1988 DOD even sponsored the research in high-definition television (HDTV). On the whole, the Reagan administration relied more on mission-oriented, mainly defense-related, programs than ever before in implementing its technology policy.

In the Bush administration, the first technology policy statement¹⁷ was published in September 26, 1990, and delivered to the U.S. Congress. In this document, some advanced technological fields, namely, robotics, high performance computing, semiconductors, superconductivity, and advanced imaging technologies, are targeted as also falling into Federal R&D responsibilities and demanding multi-agency efforts. Some others, like biotechnology, alternative energy and transportation, are also identified as requiring Federal government strong support.¹⁸ However, this technology policy statement mentions little about major mission-oriented programs explicitly. Instead, it devotes a significant part of its content to diffusion-oriented measures, including transfer of Federally funded technology, commercial applications of defense and space R&D results, and government participation in precompetitive research on generic technologies that have the potential to contribute to a broad range of government and commercial applications. This low key treatment of major mission-oriented programs in the Bush administration is in rather sharp contrast with the Reagan administration's seeming "addiction" to highly visible programs. If this distinction is purposeful, then it would be prudent to say that the U.S. industrial technology policy is undergoing a structural change. The traditional "mission-oriented" paradigm is on the wane. The "diffusion-oriented" paradigm is gaining momentum. And one driving force behind this new trend seems to be the growing criticism against the traditional "spin-off" rationale.

Skepticism toward "Spin-off" Rationale

In recent years, there have emerged many negative opinions (though some of them not really new given the long-existing issues) challenging the "conventional wisdom" of "spin-off."¹⁹ One argument contends that there has been a tendency toward diverging design requirements of military missions and civilian applications. This leads to diminishing commercial returns and even "distortion" of commercial technology development. Some apparent examples include "stealth technology" for military fighters and bombers, radiation-resistant semiconductors for nuclear weapons, and supersonic military aircraft. The former two have few commercial applications. For the last one, so far only subsonic aircraft is needed by civilian airlines. Another somewhat controversial case is the NC machine tools sponsored by the Air Force. The military requirements were evaluated to be far more advanced than what the civilian user industry needed and could afford. The technological efforts were thus not cost-effective in a commercial sense. It could even be argued that these efforts were "misled" by the military.

Another argument claims that, mainly caused by the rapidly increasing unit cost, most military procurements of high-tech systems demand only small volumes. This contributes little to the manufacturing productivity which is now one of the U.S. industry's serious weaknesses.

A third argument maintains that the present contracting system does not encourage cost consciousness which is crucial in commercial competition. The main reason is that, though cost-plus-fixed-fee and cost-plus-incentive-fee contract types have been largely replaced by firm-fixed-price and fixed-price-incentive contract types during the past four decades, there are still many schemes to accommodate cost overruns. So cost-plus contract is in effect still widely used.²⁰

A fourth argument asserts that the restriction of communication of classified information and the "isolated" system of defense R&D, even within a firm, for accounting purposes constitute serious barriers to technology sharing and diffusion.

A fifth argument points out that DOD's principle to separate R&D contracts and production contracts in order to encourage

competition in both areas in effect retards the incorporation of manufacturability into development phase. As a result, the final products, even after adaptation, are normally too expensive for the civilian markets, if any.

Finally, a sixth argument says that DOD's another principle to force its R&D contractors to share DOD sponsored R&D results with DOD indicated other firms in order to ensure multiple supply sources makes some high-tech firms to decline to bid on defense projects for fear of losing their proprietary information and advantage in civilian markets. In these cases both "spin-off" and "spin-on" are retarded.

The Strategic Defense Initiative (SDI) is a case in point. It marks the highest point of embracing high technology as a solution to major problems of national security in the post-war U.S. In this program, a "super" system, comprising ground and space facilities, of unprecedented technological complexity will be developed, integrated and managed. Its ultimate feasibility will depend on many big scientific and technical advances still remaining to be done. So far the potential "spin-off" benefits have been largely ruled out as a convincing factor to justify SDI's astronomic budget.²¹ But DOD's initial vehement advocacy for boost phase defense using directed-energy weapons (the really novel part of SDI as compared with the old "ballistic missile defense") and many features of its systems design have proven rather unfounded. DOD's reaction to some outside studies has also revealed its inappropriate self-defense ignoring even some fundamental natural rules.²² In fact, since 1984 when SDI was announced by President Reagan, the R&D foci for boost phase defense have fluctuated greatly--from chemical laser, to ground-based laser (using relay space mirrors), free-electron laser and, finally, space-based rockets (relying on kinetic energy, the most traditional killing mechanism).²³ These facts seem to exhibit DOD's proclivity to endorsing grandiose programs even with insufficient justification for their main missions.

New Policy Arena: Generic and Precompetitive Technology

As indicated in the recent technology policy statement, "generic" and "precompetitive" technology is a critical field where

Federal government will play an increasingly important role.²⁴ In fact, the passage of the National Cooperative Research Act in 1984, which eliminated treble-damage penalty and thus largely reduced firms' fear of antitrust violations in joint R&D, has already paved the way. And the previously mentioned DOD's expanding role in non-defense technology is also more or less in this line.

Generic technology means a concept, component or process, or the further investigation of scientific phenomena, that has the potential to be applied to a broad range of products or processes. Precompetitive technology covers R&D activities up to the stage where technical uncertainties are sufficiently identified to permit assessment of commercial potential and prior to development of application-specific prototypes.²⁵ By these definitions, it is evident that investment in generic and precompetitive technology is aimed at diffusion as one of its main missions. Therefore, this strategy may as well be categorized into the framework of "diffusion-oriented" policy.

Through active support of generic and precompetitive technology, U.S. government will in effect expand its R&D activities beyond its traditionally "legitimate" domain--science and "academic engineering," and cover more "downstream" R&D. The new criteria for government involvement now rest on the distinctions between public good-natured, non-proprietary R&D and application-specific, proprietary R&D, rather than on the distinctions mainly between science and technology. In other words, this new perspective turns the attention from the properties of R&D activities to the usage of R&D results. Policy formulation could therefore be more closely linked to the industry needs.

In fact, this strategic perspective, with a little modification, could also accommodate the present "spin-off" dilemma. That is, government should support the development of generic and "dual use" technology which can benefit both military and civilian industries.²⁶ This argument is grounded on the fact that "dual use" technology tends to be at the generic stage rather than at the final application stage, and many modern critical technologies utilized for military applications have their origin in civilian sector. Microelectronics is a typical example. The U.S. military has shown

deep concern over its dependence upon Japanese. And this is the main explicit reason for DOD to endorse SEMATECH's semiconductor manufacturing technology.²⁷

So far, among others, a broad field of manufacturing technology has been identified as needing government crucial support.²⁸ This is a response to a widely perceived structural shortcoming in U.S. competitiveness. That is, in manufacturing productivity, process innovation, concurrent engineering (i.e., simultaneous design of products and production processes), etc., there is ample evidence that the U.S. has been surpassed by, especially, Japan in many industries, despite that U.S. capabilities in science and "big technology" are still generally superior to the rest of the world.

Some Issues about Precompetitive R&D

In practice, strictly speaking, there are some delicate differences between generic technology and precompetitive technology. Generic technology is conceptually broad and ambiguous, but strategically appealing. This would give government more room for policy and implementation maneuvers. On the contrary, precompetitive technology is more specific.

Precompetitive technology emphatically implies that it can be shared among "potential competitors," hopefully without reducing the financial incentives for individual firms to develop and market commercial products and processes based upon it. So it is associated with cooperative R&D strategy.

As a long tradition in the U.S., government, mainly through the Federal Trade Commission, vigilantly guards against anti-competitive activities if they cannot be justified by other entailed potential benefit to the society. However, in the face of Japanese challenge which is believed to be partly rooted in a series of its national cooperative R&D programs (most notably the VLSI program), U.S.--like many European countries and EEC--virtually adjusted its stand, exemplified legislatively by the enactment of National Cooperative Research Act as indicated above. But to avoid anti-trust violation, cooperative R&D should be pre-competitive (or even pro-

competitive), not anti-competitive. Nevertheless, the boundaries are fairly fuzzy.

For the partners in the joint projects, they may not do "competitive R&D" from the perspective of their relations. But they quite definitely will do "competitive R&D" from the standpoint of their relations with other firms. Controversies may thus arise, and fairness may become a serious issue if government underwrites financially some private cooperative projects. In this regard, some experience outside the U.S. renders some lessons.

In "precompetitive" ESPRIT, EEC management in reality applies the following "workable" definition to justify their decisions: So long as firms cooperate in R&D, they must be working on precompetitive stages. Besides, the term "precompetitive" is also used as a protection against possible anti-competitive charges from other concerned EEC departments.²⁹ In U.K.'s "precompetitive" Alvey program, it was found that many projects were "competitive." But no big controversies have happened.³⁰ In Finland, the national "precompetitive" joint R&D projects are expected to be as "competitive" against foreign countries as possible.³¹ In Japan, "precompetitive" technology in the national information programs is the technology of common interest to the participant competitors.³²

Therefore, in these countries and EEC, "precompetitive" technology seems to be a term mainly to legitimize government and EEC support for industrial joint R&D. Its potentially detrimental "anti-competitive" character is overwhelmed by strong "competitive" mood against foreign competitors (in the case of EEC, mainly Japan and the U.S.). But this strategy may not be so easily applied in a country like the U.S., where government historically has played a regulatory rather than promotional role, where it is difficult to embrace most or all major players from relevant industries in joint projects because of lack of cooperative experience or rooted adversarial industrial climate, and where the firms outside the joint projects have a strong "legitimate" right to protest against the possible abuse of this policy design. Therefore, precompetitive technology may trigger much more debates in the U.S. than in many other countries, like Japan or European countries, as to how to assess

technical uncertainties and commercial potential, how to define application-general and application-specific R&D, and how to draw the "line" between precompetitive and competitive.

Concluding Remarks

In the early post-war era, the U.S., based on its economic and technological superiority, was the "first mover" to introduce most original, high value-added innovations to the domestic and world markets. It made heavy investment, took great risk, and captured high economic rewards. Potential "spin-off" was almost also to be applied first in the U.S. In this period, the U.S. led most other developed countries by a significant edge.

In recent years, however, the U.S. ability to appropriate its invested innovations has been severely eclipsed. Many countries have been catching up with large enough R&D and technical resources and could quickly assimilate other countries' innovations. The modern transportation and communications, and the emergence of many science-based technologies (science has the nature of public good--widely "consumed" by a large number of individuals and organizations and difficult for the "owner" to prevent others from "consuming" it) also facilitate more rapid technology transfer and diffusion. Despite some mechanisms, like patents and trade secrets, to limit the exploitation by others of an innovator's achievements, the lead time an innovator could enjoy has been largely shortened. "Smart followers" with strong complementary assets--including manufacturing, distribution, maintenance and service capabilities, and close relations with key customers--may easily compete away the innovator's "supernormal profits," and, based on their incremental improvements and higher efficiency, even defeat the innovator ultimately.³³ Therefore, the present scenario is very different from the past one and, in many respects, is to the disadvantage of the U.S. as an innovator and "first mover." Federal government traditional mission-oriented policy has thus been under scrutiny and criticism. If the recent White House technology policy statement is a correct message, then a departure from the old track is taking place: the U.S. is moving in the direction of diffusion-

oriented policy paradigm, in spite of the fact that many issues, such as those involved in "precompetitive" cooperative R&D, remain to be solved.

Notes

- 1 The typology of "mission-oriented" and "diffusion-oriented" technology policies is discussed in Ergas (1986).
- 2 The terms "trickle-up" and "trickle-down" are proposed in Branscomb (1989), pp. 5-6.
- 3 For the life cycle of product and process innovations, see Abernathy and Utterback (1978).
- 4 Nelson (1990), p. 125.
- 5 Roessner (1987), pp. 230-233.
- 6 See Mowery and Rosenberg (1982) for jet engine, Levin (1982) for semiconductors, Katz and Phillips (1982) for computers, Seidel (1987) for lasers, and National Research Council (1983) and Noble (1984) for machine tools.
- 7 For "technological paradigm" and "technological trajectory" (which follows a new "technological paradigm"), see Dosi (1982).
- 8 For "technology system" and "techno-economic paradigm," see Freeman and Perez (1986).
- 9 Ten standards used to evaluate the effects of defense R&D spending are identified in Carter (1989), pp. 4-6.
- 10 See also note 6.
- 11 For a brief discussion of these three "spin-off" patterns, see Carter (1989), pp. 6-8.
- 12 For defense and space programs' demonstration effect and stimulation of small innovative firms to enter the markets, see Schnee (1978).
- 13 See, for example, Lepkowski (1984) and Keyworth (1985). George A. Keyworth II was science advisor to President Reagan and director of the White House Office of Science and Technology Policy during 1981-1988.
- 14 Smith (1990), p. 133.
- 15 Carter (1989), pp. 3-4.
- 16 Smith (1990), pp. 143-145.
- 17 Bromley (1990). D. Allan Bromley is presently science advisor to President Bush and director of the White House Office of Science and Technology Policy.

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- 18 Bromley (1990), pp. 10-12.
- 19 The following arguments, except noted otherwise, are an integration of qualitative analysis and personal comments from several sources, including U.S. OTA (1989), pp. 129-158; an article interviewing Harvey Brook and Lewis Branscomb in *Technology Review*, August/September 1989, pp. 55-64; and the author's interview with a former French Minister of Industry and Research in Paris in January 1990.
- 20 Burnett and Scherer (1990), pp. 300-303.
- 21 See, for example, Council on Economic Priorities (1988), especially pp. 119-144.
- 22 This could be judged by reviewing the following documents: (1) the background paper *Directed Energy Missile Defense in Space* published by U.S. OTA in April 1984; (2) SDI Director General Abrahamson's "Department of Defense Comments on *Directed Energy Missile Defense in Space*" on May 8, 1984; (3) OTA's "Response to General Abrahamson's Comments on OTA's Background Paper" (date unknown); (4) the Defense Deputy Secretary Taft's letter to OTA Director Gibbons requesting the withdrawal of the background paper on June 4, 1984; and (5) the OTA Director's response to the above Defense Deputy Secretary's letter on July 13, 1984.
- 23 The boost phase defense R&D has been traced by Clausen and Brower (1987).
- 24 Bromley (1990), pp. 5 and 8.
- 25 Both definitions are from U.S. National Institute of Standards and Technology, published in *the Federal Register*, Vol. 55, No. 142, July 24, 1990.
- 26 See, for example, U.S. OTA (1989), pp. 33-38; and papers presented in the workshop "Dual Use Technologies: International Perspectives" held by Harvard University Kennedy School of Government on October 21-22, 1989 in Cambridge, MA.
- 27 U.S. OTA (1988), pp. 13-15.
- 28 U.S. OTA (1990).
- 29 Based on an interview in EEC in Brussels on Dec. 7, 1989.
- 30 Based on an interview with a group of researchers, who had done the interim evaluation of the Alvey program, in Manchester University on Dec. 11, 1989.
- 31 Based on an interview with the vice president of the Technical Center of Finland (VTT) in Helsinki on May 19, 1989.

32 Samuels (1987).

33 Teece (1986).

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