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GENERAL PURPOSE TECHNOLOGY, REVOLUTIONARY TECHNOLOGY, AND TECHNOLOGICAL MATURITY

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Abstract:

An important inference of the theoretical literature on the development of general purpose technologies is that public investment in their development is necessary if economic growth is to be sustained. The theoretical results are broadly consistent with the empirical generalization that the public sector, particularly military and defense related research, technology development and procurement, has played an important role in the development of most of the general purpose technologies in which the United States is presently globally competitive. These sources are, however, unlikely to play such an important role in the development of new general purpose technologies in the immediate future. Nor is the private sector, burdened by impatient capital, likely to become an important source of new general purpose technology.

Key Words:

General purpose technology, revolutionary technology, technological maturity, basic research, application technology, private sector, public sector, military, defense, procurement

JELClassification: 03 & 04

In spite of substantial research elucidating the concepts of general purpose technology, revolutionary technology, and technological maturity the several concepts and the relations among them need further clarification. The purpose of this paper is to advance this body of work by investigating the financing of the research and technology development (R&D) that is the source of the invention and innovation of General Purpose Technologies (GPTs), an aspect of the GPT literature that has received inadequate attention.[1]

Recent theoretical work has shown that public investment in early stage general purpose technology development has, like basic research, important spillover effects in the form of application technologies (Bresnahan and Trajtenberg 1989, 1993, 1995; Carlaw, and Lipsey 2006; and Lipsey, Carlaw and Bekar 2005). In a decentralized economy this results in innovation that is “too little” and “too late.”[2] These theoretical results are consistent with the empirical generalization that the public sector has played an important role in the development of most of the general purpose technologies in which the United States is presently internationally competitive (Ruttan 2001, 2006).

In this paper I also give particular attention to the neglected issue of technological maturity. I argue that public investment in the development and diffusion of new revolutionary general purpose technologies is necessary to sustain economic growth in

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[1] In this paper I draw substantially on Ruttan (2001 and 2006). I am indebted to Richard G. Lipsey, Kenneth Carlaw, Clifford T. Bekar, Thomas Misa and Richard R. Nelson for comments on an earlier draft of this paper. I have also benefited from reviews of Ruttan (2006) by Jurgen Brauer (2007) and Richard Lipsey (2007).

[2] It has been recognized by economists at least since the publication of Richard Nelson’s now classic article, “The Simple Economics of Basic Scientific Research” (1959) that “basic research generates substantial positive external economies. Private profit opportunities alone are not likely to draw as large a quantity of resources into basic research as is socially desirable” (1959: 302). It is only since the early 1990s, however, that evidence has accumulated that the private sector also lacks the incentives to invest optimal amounts in applied research—particularly “early stage” applied research and technology development.

the United States. In the absence of the development of new general purpose technologies the maturing of older general purpose technologies will result in the dampening of productivity growth. In the absence of the growth dividends released by productivity growth, conventional macroeconomic policy will be inadequate to sustain economic growth.

General Purpose Technology

The term general purpose technology, sometimes general purpose engine (David 1990: 355), enabling technologies (Lipsey, Bekar, and Carlaw 1998: 30), or macro-technology (Mokyr 2002: 29-31), emerged in the literature on the economics of technical change in the late 1980s and early 1990s, in part because of concern about the inadequacy of aggregate or total productivity—sometimes referred to as a measure of our ignorance (Abramovitz 1956)—as an indicator of the contribution of technical change to output.[3]

In a series of seminal papers Bresnahan and Trajtenberg addressed the problem of how to establish “a link between the economic incentives for developing specific technologies and the process of growth” (1995: 84). They suggested that at any point in time a limited number of general purpose technologies, characterized by pervasive use across a wide range of sectors, account for a relatively large share of productivity growth. “As a GPT evolves and advances it spreads throughout the economy, bringing about and fostering generalized productivity gains” (1995: 84). Electric power and information

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[3] I was first sensitized to the concept of general purpose technology in a now classic article by Paul David (1990). David had discussed the concept at an OECD Seminar in June 1989. The seminal paper containing a formal growth theory analysis of GPTs was Bresnahan and Trajtenberg (1989; see also Bresnahan and Trajtenberg 1992 and 1995). Bresnahan (2001) presents a richer discussion of the invention of new general purpose technologies and the co-invention of application technologies. For a critical review of both the “appreciative” and the “formal” GPT literature see Lipsey, Carlaw, and Bekar (2005: 372-384).

technology have been regarded as the prototypic general purpose technologies (Jovanovic and Rosseau 2005).[4]

The distinguishing features of a general purpose technology include: (1) *Pervasiveness:* A GPT should have an impact on technical change and productivity growth across a large number of industries; (2) *Improvement:* A GPT should experience continuous improvement leading to sustained productivity growth and cost reductions in its own industry; (3) *Innovation spawning:* A GPT should lead to product and process innovation in application sectors (Bresnahan and Trajtenberg 1995; Jovaovic and Rousseau 2005).

Bresnahan and Trajtenberg characterize the endogenous growth models of the type introduced by Romer (1986) and Lucas (1988) as “flat”—they do not allow for specific technologies in each sector or explicit interactions between sectors. In their several papers Brenahan and Trajtenberg introduce a model drawing on a stylized history of semiconductor technology that includes the GPT and several application sectors that also engage in innovative activity. The key technical assumptions are generality of purpose and innovational complementarities. “Our model is a stylized set of related industries with highly decentralized technical progress centered around the GPT” (p. 86). These translate in a world of imperfect appropriability in two distinct externalities: the “vertical” externality between the GPT and each application sector, and the “horizontal”

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[4] Between the early 1920s and the early 1960s the electric power industry was the major driver of productivity growth in the United States (Gordon 2004: 22-49, 172-217). Since the early 1980s the computer and microprocessor technologies have emerged as the major drivers of technical change and productivity growth in the United States economy (Jorgenson 2001). Other important industrial general purpose technologies of the 20th century include the internal combustion engine, nuclear power, the internet and the space communication and earth observing technologies. In the area of biological technology plant breeding and vaccines are general purpose technologies. Biotechnology seems poised to be the important general purpose technology of the first several decades of the 21st century (Lipsey, Bekar and Carlaw 1988; Ruttan 2001: 368-422; Ruttan 2006).

one across application sectors" (Bresnahan and Trajtenberg 1995: 88). This results in a divergence between the social optimum and the decentralized Nash equilibrium because of the complementarities between the two conventional externalities and the positive feedbacks that are generated (p. 93).

Analysis of the Bresnahan-Trajtenberg model suggests that in a decentralized economy "arms-length market transactions between the GPT and its users may result in 'too little and too late' innovation" **(**1995: 83). "Any arms-length market mechanism under innovational complementarities necessarily entails private returns that fall short of social returns for either upstream or downstream innovations under *all* plausible pricing rules" (p. 94). Thus, in the Bresnahan-Trajtenberg model the concept of public good is extended from advances in knowledge in the basic sciences to technology development.[5]

In an iconoclastic paper Kenneth Carlaw and Richard Lipsey (2006; see also Lipsey, Carlaw and Bekar 2005: 440-467) called attention to the empirically infeasible assumptions employed in earlier GPT growth modeling literature. In their paper they presented an alternative three equation model in which they incorporated a GPT arising out of basic research and spillovers from basic research to application sectors as drivers of economic growth. In the three-sector model resources are allocated to maximize consumption output in each current period by equating the expected marginal increases in consumption from a unit of resources allocated to each sector. "The competitive equilibrium output is different in each period and the equilibrium never settles into a stationary equilibrium. This enables us to focus on the historical path dependent process

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[5] The Bresnahan-Trajtenberg innovations were reconsidered (Lipsey, Bekar and Carlaw 1998a: 15-54; 1998b: 193-218) and modeled more formally (Helpman and Trajtenerg 1998a: 55-84; 1998b: 85-120) in a book edited by Elhanen and Helpman (1998).

of knowledge accumulation and variable pattern of growth driven by a variable rate of innovation" (Carlaw and Lipsey 2006: 158).

They note that a major accomplishment of their work, in contrast to other endogenous growth models, is that "a balanced equilibrium growth path is never reached which makes it easier to allow for behavior which is more realistic but also more complex" (p. 173). They conclude the article by listing a series of feasible improvements that could be made to more closely approximate the behavior of GPTs.[6] Lipsey and his colleagues insist that as a GPT matures it approaches an upper limit on efficiency gains (Lipsey, Carlaw and Clifford 2005: 434-439).

An exceedingly important inference from the Carlaw-Lipsey as well as the Bresnahan-Trajtenberg work that has received inadequate attention in the science and technology policy literature is that public investment in the development of general purpose technologies is necessary to achieve an efficient allocation of research and development resources. Carlaw and Lipsey conclude that the efficient allocation of resources to R&D could either be assumed to be done by a social planner or by the private sector subsidized by a government that taxes agents in the consumption and application sectors to pay for the fundamental research. Both proposals, as well as the Bresnahan- Trajtenberg results, are broadly consistent with the empirical generalization that during much of the twentieth century the public sector has played an important role in the development and/or diffusion of most of the general purpose technologies in which

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[6] A number of the improvements they suggest in the article are discussed in greater detail in Chapter 15, "Formal Models of GPT-Driven Sustained Growth: Extensions and Applications" in Lipsey, Carlaw and Bekar (2005: 458-496). The inverted time sequence between the article and the book is due to publication lag. The article was first presented to a conference in 2001. After being rejected several times it was finally published in 2006.

the United States has been globally competitive (Ruttan 2001: 602; Ruttan 2006: 159-190).

Radical Technical Change

The major general purpose technologies that have become important sources of application technologies have typically represented radical advances in science and/or technology.[7] The criterion for technological revolution is that the leading edge of technological progress be based on the development of a new system. “The technological revolution has occurred … when the new system is accepted by even a minority of the relevant community as a foundation for new normal practice” (Constant 1980: 19).

But where do the ideas that lead to the design of new systems come from? Historians of science and technology, and scientists and engineers themselves, have traditionally sought to interpret advances in scientific and engineering knowledge internally—in terms of the motives of individual scientists and engineers or in terms of the culture of scientific and engineering societies and communities—rather than in terms of changes or differences in social, political or economic environments. Internalist interpretations have, however, become considerably less compelling as advances in scientific and engineering knowledge have increasingly emerged from large government and industrial laboratories and from publicly supported grant and contract research carried out by private firms and research university laboratories (Ruttan, 2001: 534-599).

During the 1960s through the 1980s economists developed a series of new theoretical insights and models of the process of technical innovation. In the 1960s and

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[7] Radical advances in technology tend to be discontinuous events that, in recent history, have largely emerged from corporate, government or university laboratories. “There is no way in which nylon could have emerged from improving the production process in rayon plants or the woolen industry. Nor could nuclear power have emerged from incremental improvements to coal or oil-fired power stations” (Freeman and Perez 1988: 46).

1970s they focused their attention on the development of the theory of induced technical change which emphasized the role of economic forces—changes in demand and changes in relative factor prices—on the rate and direction of technical change (Smookler 1966; Hayami and Ruttan 1970; Nordhaus 1973; Binswanger and Ruttan 1978). In the late 1970s, stimulated by the work of Nelson and Winter (1982), attention shifted to evolutionary models inspired by a revival of interest in Joseph Schumpeter's work on the role of innovation and the entrepreneur in the process of economic development (Nelson and Winter 1982; Ziman 2000). Beginning in the late 1980s these theories were supplemented by the development of historically grounded "path dependent" models of technical change trajectories (Arthur 1989; David 1990). Each has contributed substantial insight into the processes involved in the generation and choice of new technology. But they did not address the sources of revolutionary new general purpose technologies.[8]

In a landmark book on the history of the turbojet revolution Edward Constant (1980) advanced the concept of *presumptive anomaly* as a source of radical advances in technology. "Presumptive anomaly occurs in technology, not when the conventional system fails in any absolute sense, but when assumptions derived from science indicate either under some future condition the conventional system will fail (or function badly) or that a radically different technology will do a better job" (Constant 1980: 15; see also Constant 2000: 227).[9]

Thus, in the case of the turbojet, insight derived from aeronautics in the1920s created a presumption among a few aircraft engineers that over the longer term,

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[8] In the next several paragraphs I draw directly on Ruttan (2001: 100-116 and Ruttan 2006: 13-14). For an early and exceedingly rich review and critique of economists' models of the sources of invention and innovation see Nelson and Winter (1977).

[9] Rosenberg (1969) had discussed somewhat similar concepts under the rubrics of "technical imbalance" and "bottlenecks."

fundamental constraints would be encountered in the performance of the piston-propeller system of aircraft propulsion. Another example was the realization by Marvin Kelly, director of research at Bell Telephone Laboratories, that the heat generated by vacuum tubes would become a constraint on the development of rapid telephone switching technology. A more contemporary example is the realization, because of the impact of carbon dioxide emission on global temperature, that efficient alternatives to carbon based fuels must be found if economic growth is to be sustained (Ruttan 2001: 515-521; National Research Council and National Academy of Engineering 2004; Pacala and Socolow 2004).

It is not necessary that the insight that gives rise to a presumption of anomaly be derived from science. Advances in engineering, agronomic or medical knowledge may also give rise to presumptive anomaly.[10] When a radically new technology is initially envisaged it will almost certainly be judged to be less efficient than the system it is designed to replace. Furthermore, a radical new general purpose technology will generally, over time, do much more than perform existing functions more efficiently. As emphasized in the previous section it will also give rise to the proliferation and further evolution of new application technologies—it will "fertilize" technical and institutional innovation. Thus, the electronic digital computer and the transistor gave rise to the evolution of entirely new communication technologies. This process was in turn reinforced by the further evolution of computer and microprocessor technology.

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[10] The knowledge employed by the Wright brothers and other early aircraft designers drew almost entirely on craft and engineering knowledge and practice. The technology of early flight owed "practically nothing to the relatively primitive state of the science of fluid dynamics" (Anderson 2002: 45). For other examples see Rosenberg (1982: 142).

Technological Maturity

A good deal of attention has been given to the lag between the introduction of a new general purpose technology and its impact on productivity growth. Paul David (1990) called attention to the similarity in the long lags between the invention of the dynamo and of the computer and their impact on productivity growth. In both cases the lag was in the range of 40 years. In the late 1980s Robert Solow commented famously, "You can see the computer age everywhere except in the productivity statistics" (Solow 1987: 36).[11]

In contrast, only limited attention, since the early work of Kondratev, Burns and Kuznets in the 1930s, has been given to the issue of technological maturity. Important recent exceptions include Freeman and Louca (2001: 66-97), Metcalfe (2001), Perez (2003); and Lipsey, Bekar and Carlaw (2005). Bresnahan and Trajtenberg (1992: 31) make a brief comment to the effect that as a GPT matures the innovation complementarities among the GPT and application technologies and among application technologies will tend to decline, heralding a decline in the role of the GPT as an "engine of growth." In my work I have followed the practice of engineers and other technologists in defining technological maturity in terms of the incremental cost of achieving critical performance indicators. For example, in the cases of both piston-propeller and jet aircraft, technical maturity has been traditionally defined in terms of how fast and how high an aircraft could fly. After experiencing rapid or even explosive development along an initial trajectory, technologies have often experienced a period of technical maturity or stagnation. In some cases, as in aircraft, renewed development has occurred along a new

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[11] As recently as the mid 1990s most economists were convinced of the validity of the" Solow paradox." Since then, a consensus gradually emerged to the effect that the information technology is clearly visible in the productivity statistics (Jorgenson 2002: 57).

trajectory only after substantial public investment. In other cases alternative paths of technology development have failed to emerge.[12]

A formal model of the innovation cycle was first advanced by Robert Evenson and Yoav Kislev (1975: 140-141). They modeled scientific and technical research as widening the variance in the distribution of traits in genetic material. They traced the history of sugarcane variety development through three innovation cycles beginning in the middle of the 19th century. As each cycle reached maturity the productivity of research directed to the development of new technical varieties declined. In the first two cases, however, advances in biological knowledge opened up opportunities for a new round of technology development. Within each stage increasingly large increments in breeding effort were required to develop new higher yielding varieties.

As noted above aircraft propulsion was an example in which a mature technological trajectory, the piston-propeller system, was followed by the development of a radical new propulsion system, the turbojet. The mature piston–propeller technology was epitomized by the Douglas DC-3 introduced in 1935. The scientific and technical foundations for transition to a jet propulsion trajectory were well underway by the late 1940s. The British-built de Haviland Comet initiated the first scheduled commercial jet air service between London and Johannesburg in 1952. The Boeing 747, introduced in 1969, epitomized the mature wide bodied commercial jet transport.

The technology of electric power generation from coal fired power plants reached technical maturity between the late 1950s and the early 1960s. With boiler-turbine units in the 1000 megawatt range, the technological frontier was limited by the ability of boilers to withstand higher temperatures and pressure. The frontier was pushed out during

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[12] The examples discussed in this section are discussed in greater detail in Ruttan (2006).

the 1950s by incremental advances, particularly in metallurgy, and with the development of high temperature alloys (Gordon 2004: 177).

It would be premature to argue that the computer-semiconductor technology is reaching maturity. However, there are several indicators that suggest approaching maturity. The inability of Seymour Cray to find a buyer for his most advanced supercomputer in the mid-1990s, the consolidation of the personal computer industry since the mid-2000s, and growing concern about the sustainability of the productivity gains in computer chip technology as described by Moore's law are suggestive. Even if advances in computer power as measured by Moore's law should slow substantially, rapid advances on application technology could be expected to continue for at least a decade or so (Carlaw, Lipsey, and Webb 2007: section 4.5).

A Future for General Purpose Technology?

It cannot be emphasized too strongly that if either scientific and technical constraints or institutional and cultural constraints should dampen the emergence of new general purpose technologies over the next several decades the effect would surely be a slowing of productivity growth in the United States economy. Endless novelty in the elaboration of application technologies can hardly be enough to sustain a high rate of productivity growth over the long run. What are the prospects for new general purpose technologies? The answer to this question requires an answer to several additional questions.

The Private Sector

The *first* question is, can the private sector be relied on as a source of revolutionary new general purpose technologies? As noted above a large share of the gains from new general purpose technologies are captured by the developers of application technologies (see also Nelson 1959; Markiewicz and Mowery 2003). Furthermore, most of the major general purpose technologies that have emerged during the twentieth century have required several decades of public support, often in the form of military R&D and defense related procurement, to reach the threshold of military or commercial viability (Lipsey, Bakar and Carlaw 1998; Ruttan 2001, 2006). Decision makers in the private sector almost never have access to the patient capital implied by a twenty year, or even a ten year, time horizon (National Research Council 2000: 233-235).

This does not mean that the private sector cannot, under the right conditions, be a source of general purpose technologies. When Marvin Kelly, director of research at Bell Laboratories, decided in the mid-1930s that vacuum tubes would become an obstacle to the efficient operation of telephone switchboards, he turned to William Shockley, a recent MIT physics Ph.D. recipient, to initiate a program to explore the potential of solid state physics in communication technology development.

During the first several decades after World War II, transient circumstances such as limited international competition and a favorable regulatory environment conspired to enable a number of United States research intensive firms to take a long-run perspective on returns to basic research. Lewis Branscomb and colleagues at the Harvard Kennedy School of Public Affairs note, however, that by the late 1990s many of the older research-intensive firms had almost completely withdrawn from the conduct of basic research and even from early-stage technology development (Branscomb and Aserwald 2002: 1). I find it difficult to anticipate that in the United States the private sector will, without substantial additional public support, become an important source of new general purpose technologies over the next several decades.

Public Sector

A *second* issue is, could a more aggressive policy of public support for commercially-oriented R&D become an important source of new general purpose technology?[13] I have argued in *Technology, Growth and Development* (Ruttan 2001: 368-422) that molecular biology and biotechnology has become the major new general purpose technology of the early decades of the 21st century.

For more than three decades the molecular genetics and biotechnology research leading to the development of commercial biotechnology products in the pharmaceutical and agricultural industries was funded almost entirely by the Rockefeller Foundation, the National Science Foundation, the National Institutes of Health and the National Energy Laboratories—largely at government and university laboratories. When the pharmaceutical and agricultural industries decided to enter the field they found it necessary to make very substantial grants and contracts to university laboratories to obtain a "window" on the advances in the biological sciences and in the techniques of biotechnology that were underway in university laboratories (Ruttan 2001: 368-422).

It is possible that a combination of concerns about environmental and energy security could induce sufficient public support for the development of alternative energy sources—sources other than carbon based fossil fuels. Modest efforts have been made since the mid-1970s to explore renewable energy technologies. Considerable progress has been made in moving down the learning curves for photo-voltaic and wind turbine technologies (Alic, Mowery and Rubin 2003: 3). The Bush administration has placed major emphasis on the potential of hydrogen technology to provide a pollution free

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[13] This issue was addressed in considerable detail forty years ago by Nelson, Pack and Kalachek (1967). It was revived in the mid- and late-1980s. For a review see Ruttan (2001: 575-583).

substitute for carbon based fuels by the second half of the century (National Research Council and National Academy of Engineering 2004; Pacala and Socolo 2004). It would require major sustained public support for alternative-energy R&D, including redirection of programs at the national laboratories managed by the Department of Energy, to create the productive opportunities for investment in alternative-energy technology development (Committee on Prospering in the Global Economy of the 21st Century).[14]

It is possible that a combination of scientific and technical advances currently being pursued by public and private laboratories in the area of nanotechnology (or more aptly molecular technology) are already opening up powerful new GPTs. Lipsey, Carlaw and Bekar insist that a key characteristic of nanotechnology is its potential capacity to fundamentally alter all materials production by manipulating matter at the molecular level" (2005: 214-216; see also Drexler 1986). At the time this paper was written a clear view of the particular products that are under development was not available. My own judgment is that it will be at least a decade, possibly two, before application technologies based on nanotechnology, will begin to have a measurable impact on growth of aggregate output and productivity (Lane and Kalil 1995; Singer et al. 1995; Beribe 2006; Kuzma and VerHage 2006).

In the late-1980s and early-1990s the federal government initiated several initiatives to support commercial technology development. Public-private cooperative agreements were designed to enhance the spin-off of technologies from national

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[14] Much of the research in molecular biology and genetic engineering leading to technical advances in the pharmaceutical and agricultural industries results in maintenance rather than productivity enhancing technology. Maintenance research and technology development is undertaken to maintain existing productivity levels. Thus, research to develop a rust resistant wheat variety is undertaken to prevent a decline in wheat yield. Research designed to develop a malaria vaccine is undertaken to protect health and to sustain rather than to enhance productivity. Similarly much of the research on alternatives to carbon based fuels is designed to generate environmental benefits rather than to reduce costs (Ruttan 1982: 60; Dalrymple 2004: 6-7).

laboratories (CRADAS). An Advanced Technology Program at the National Institute of Standards and Technology (NIST/ATP) provided financial support for public-private cooperative projects judged to have public goods dimensions or long-time horizons to achieve commercial viability. And a Small Business Innovation Research (SBIR) program was designed to support agency needs and to advance commercialization. These programs have been directed to the development of evolutionary or application technologies rather than radical general purpose technologies.

In spite of considerable technical success all have had great difficulty in achieving and maintaining political viability.[15] In spite of a number of promising initiatives I remain skeptical that public support, with the objective of commercial technology development, can be depended on to become an important source of new revolutionary general purpose technologies in the United States over the next several decades.[16]

Military and Defense Related Technology

The *third* question is, could military and defense-related support for science and technology development and procurement again become an important source of commercial technology development in the United States? During much of the twentieth century military and defense-related research, technology development and procurement have been major sources of technology development across a broad spectrum of industries that account for an important share of United States industrial production. The American and the global technological landscape would be vastly different today in the

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[15] In the 2006/2007 budget year the NIST Advanced Technology Program almost failed to have its funding extended by Congress. "The advanced technology program met its goals argue its supporters—and critics say that is why it needed to be killed" (Kinitsch 2006: 752). For greater detail see Berube (2007: 101-104).

[16] Richard G. Lipsey has noted that while in the United States much of the effective public support has been motivated by defense-related concerns while in Europe much of it has been motivated by concerns about economic growth (Lipsey 2007: 441).

absence of military and defense-related research, technology development and procurement.

At the beginning of the 21st century the United States was still the dominant producer of a broad range of capital- and skill-intensive defense-related systems. It still accounted for more than two-thirds of defense and defense-R&D spending by the North Atlantic Treaty Organization and Japan. But the absolute size of defense procurement had declined in real terms to less than half the 1985 Cold War peak (Flamm 1999). Furthermore, the share of output of the United States economy accounted for by the manufacturing sector had declined to less than 15 percent. Military and defense-related procurement had become a smaller share of an economic sector that itself accounted for a smaller share of national economic activity. Since at least the mid-1980s the role of defense and defense-related research, development and procurement has declined as a source of new GPTs and application technologies (Saal 2001).

It now seems clear that changes in the structure of the United States economy, in its defense industrial base, and in its military strategy will preclude the defense and defense-related agencies from playing a role in the generation of new revolutionary general purpose technologies comparable to the role that they played during much of the twentieth century (Ruttan 2006; Schmitt and Donnelly 2007).[17] Some close observers have argued that the major effect of the Iraq war has been to shift military priorities from big platform technologies toward the generation of more useful intelligence about the

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[17] John A. Alic, a leading student of defense and defense-related R&D and procurement has commented: "By the 1980s, the military had lost much of its ability to exploit the national system of innovation. As applications of technologies such as digital electronics exploded in the civilian economy, DOD increasingly was left to its own devices, ignored by innovators outside the specialized defense industry (Alic: 87).

political, economic and social developments that contribute to success in both combat and post combat operations (Kagan 2007: 30-51).

Conclusion

I conclude that when the history of United States technology development during the first half of the 21st century is eventually written it will focus on incremental or application technologies rather than on revolutionary general purpose technologies. It will also be written within the context of slower productivity growth than the relatively high rates that prevailed in the United States during the 1950s and 1960s and during the information technology bubble that began in the mid 1990s.[18] If I am correct this will have very important implications for the capacity of the United States to sustain a dominant position as an economic and military power.

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[18] The scenario assumed here is roughly similar to the "pessimistic" productivity and output projections developed by Jorgenson, Ho and Stiroh (2008: 18).

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