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Postindustrial technology policy

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Abstract

Even without the possibility that reassessment of the nation's military posture might lead to declines in support for generation of new knowledge in the physical sciences and engineering, the growth of the service economy should suffice to occasion a fresh look at US technology policy. This paper reviews the reasons, with particular attention to services such as health care. It then sketches needs for a postindustrial, post-Cold War US technology policy. Those needs lie heavily in the direction of diffusion and learning.

Keywords: Services; Productivity; R&D

1. Introduction

There are four reasons for reassessing technology policy in the United States and by extension other high-income economies: (1) the end of the Cold War; (2) the continued expansion of service-producing sectors relative to manufacturing and other goods-producing industries; (3) the ongoing interpenetration of national economies through trade and investment, globalization for short; and (4) the remarkable efflorescence of knowledge in the biological sciences. This essay addresses the services in some depth, devotes less space to defense, still less to international trade and investment, and touches on the biological sciences only indirectly, in relation to health care. The focus throughout is the United States, where services account for more than three-quarters of employment and nearly as great a share of gross domestic product (GDP). Other countries, needless to say, are postindustrial too, notably those of Western Europe. Still, the United States seems in some respects more so. Thus the United States has been the prime incubator for new applications of information technology (IT) since the 1950s and 1960s, when large businesses first began to keep their books with the aid of mainframe computers. The United States has also, paradoxically, suffered more than most from lagging productivity growth and wage stagnation, phenomena linked in ways not fully understood with IT and the shift to services.

2. The new economy of services

More Americans now work in physicians' offices than in auto plants, in laundries and dry cleaners than in steel mills.[1] For reasons including rising affluence and productivity growth in goods-producing industries, agriculture as well as manufacturing, the service sector, i.e. the non-goods residual, continues to expand in the United States and in other high-income countries. Health care expenditures alone amount to some US$ 1.2 trillion annually in the United States, more than 13% of GDP.

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[1] This section, and several later parts of the paper, draw on Herzenberg et al. (1998).

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Health care is in many ways the exemplar of service production. The sector, like the service economy as a whole, is extraordinarily heterogeneous. In the United States, it includes low-wage businesses such as home health agencies and residential nursing facilities along with academic medical centers. Most nursing homes pay aides, who account for the bulk of payrolls and provide nearly all care, at or slightly above legal minimums, provide little if any training, and accept annual labor turnover rates of 100% or more. Total quality management and continuous improvement have hardly been heard of; regulated standards of care are widely flouted. Hospitals and clinics, for their part, including those that operate at the forefront of medical art and science, seem generally to underinvest in IT (Keystone Research Center, 1997) and to be unenlightened if not backward in their applications of information systems (Keystone Research Center, 1998, pp. 82–92).

Other service businesses, including nursing homes, make little use of IT and telecommunications. It is true that automated ordering and inventory management has been a pillar of the competitive strategies of retailers such as Wal–Mart, that corporations are reorganizing their purchasing departments to take advantage of the Internet and intranets, and that electronic medical records will at some point replace, for most residents of high-income countries, scattered files of often-misplaced paper records. But the larger point is that production of services differs systematically from production of goods in ways that have little or nothing to do with IT.

The most fundamental difference is that goods, notably manufactured goods, are designed and developed in advance of production. Their attributes are predetermined. Services, with minor exceptions, are co-conceived and co-produced by workers and customers, typically at the place and time of delivery. These differences have significance for trade, for technology policy, and for innovation, especially the incremental innovation that arguably contributes the most to economic performance. (Given that output and hence productivity in many services can be difficult to measure, it is often useful to speak, more generally if less precisely, of economic performance, or simply performance, rather than productivity.) Given that product development and production processes differ so greatly between manufacturing and the services, the growth of the service economy may also be contributing to realignment between disciplinary specialties in engineering and the economic sectors with which many of these disciplines co-evolved over the past century or so.

2.1. The service economy

From the Civil War into the 1960s, manufacturing served as armature for the US economy and locus of technology development. Organized R&D combined with practical know-how to spawn pathbreaking innovations in primary metals, electrical and mechanical equipment, chemical products, and consumer goods. Manufacturing firms set the patterns not only in R&D and technology development but in management, marketing, and wages.

Even so, output of services has exceeded output of manufactures for as long as the US government has collected the relevant statistics (which is since the Civil War). Manufacturing never reached 30% of US employment (Fig. 1), has recently fallen below 15%, and will continue to shrink relative to services. (Because productivity growth in most services has lagged, at least as measured by the official statistics, the output share of services trails the employment share slightly.) Although goods-producing firms have been unbundling and outsourcing activities ranging from cafeteria services to R&D (e.g. in the steel industry) and relying more heavily on temporary workers counted as service employees to staff their factories, reengineering and restructuring explain only a small portion of the growth of service employment and output. As Fig. 1 shows, services substitute in large measure for agriculture rather than manufacturing over generational time spans.

Service workers in the United States earn less than their counterparts in manufacturing. Fig. 2 shows the trend for production workers (70% of total employment); managerial and supervisory employees also earn less on average in the services. Although the gap has narrowed since the 1980s, the growth of the services has contributed to what is perhaps the central phenomenon of the past two decades in the US economy: stagnation and decline in real wages, coupled with growing wage inequality. These are widespread if not pervasive phenomena: real wages for physicians have fallen along with those for nurses' aides. Nearly all groups have been affected — blacks and Hispanics

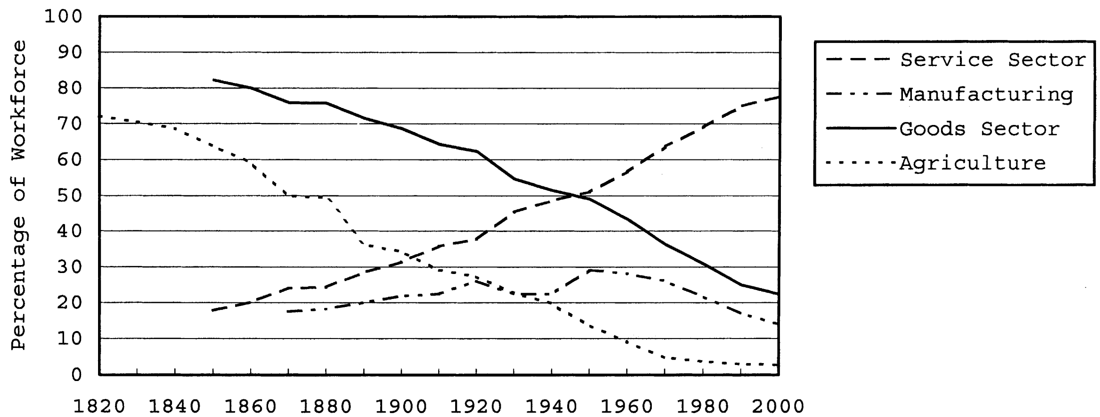

Fig. 1. Growth of the US service economy. Note: the goods sector consists of manufacturing, construction, agriculture, and mining. The service sector includes the rest of the economy. Sources: U.S. Department of Commerce, Bureau of the Census, September 1975, Historical Statistics of the United States, Colonial Times to 1970, Part 1 (US GPO, Washington, DC), p. 138; U.S. Department of Labor, Bureau of Labor Statistics, Current Employment Statistics Survey and Current Population Survey.

more than whites, men more than women, those with low levels of educational attainment more than those with high. There is more inequality in services than in manufacturing and more in both sectors today than at the end of 1970s (Herzenberg et al., 1998, pp. 26–29, 178–179). Pay began to recover in the second half of the 1990s, as Fig. 2 shows, but not until 1998 did real wages for service workers return to levels reached in the 1970s; manufacturing wages remain below their 1978 peak. (Some of the post-1995 gains could vanish in the next recession.) Although recent increases in the minimum wage raised the bottom tiers somewhat, there is little sign otherwise that increases in wage inequality will abate or reverse.

The reasons for these trends are complicated, but technological change is part of the explanation, along with declining union coverage, deregulation, and wage-based competition as in nursing homes. Production processes for many services are difficult or impossible to automate or convert to self-service, yet often require less in the way of specialized knowledge and skill than in the past. Millions of clerical and

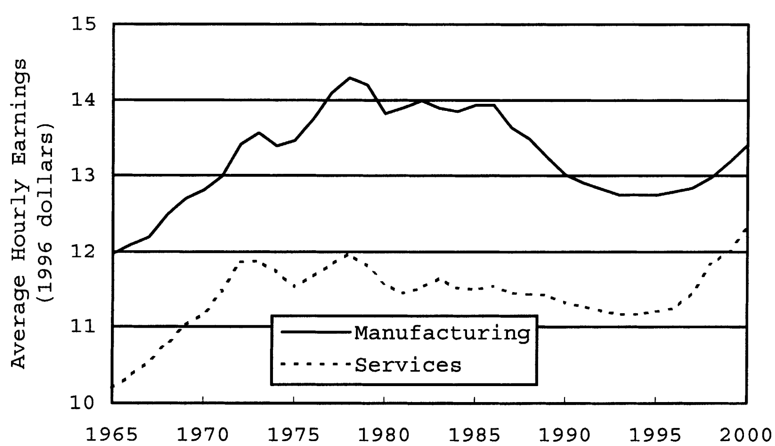

Fig. 2. Real wages in US manufacturing and services. Notes: production workers and nonsupervisory employees only. Deflated using CPI-U-X1. 2000 first 8 months. Source: U.S. Department of Labor, Bureau of Labor Statistics, stats.bls.gov.

administrative workers, as well as middle managers, have seen experience-based skills — both "hard" (navigating proprietary IT systems) and "soft" (knowing who to call to resolve a problem in a large, hierarchical organization) — devalued as software becomes more standardized and organizations delayer and disperse authority. Banks and insurance companies that once had 100 or more specialized software packages, many of them old, idiosyncratic, and non-intuitive, are replacing some and linking others through intranets as they reorganize under rubrics such as business process reengineering. The reengineered systems are easier to learn, reducing incentives for employers to pay high wages to retain experienced workers.

Service firms have also created many millions of new but poorly paying, dead-end "McJobs" — not only in fast foods but in other parts of retailing (which alone employs over than 22 million Americans, some 3 million more than all of manufacturing) and business services (e.g. janitorial, security, data entry, telemarketing). Thus, department stores facing stiff competition from both discount and specialty outlets have transformed non-professional positions that once called for product knowledge (e.g. of home appliances) and offered decent wages and benefits into low-paying, high-turnover positions that call for little more than ringing up sales. Needless to say, there are many high-wage service workers: webmasters and accountants, airline pilots and insurance agents. But on the whole there are not enough "good" jobs in the United States, those in which workers without high-level or specialized skills can earn a decent wage and take the first steps on an upward mobility path.

In part simply because so many service jobs pay so poorly, policymakers have often tried to wish them away, seeking in vain to create or preserve manufacturing employment through trade or technology policies. Some have looked to education for remedies, though rarely asking why employers should be willing to pay higher wages to retail clerks or nurses' aides with another year or two of schooling. But the most common response to the rise of the services has been neglect.

2.2. Taking the services seriously

Disregard of services is nothing new. From the beginnings of economic analysis, services have been overlooked or labeled as unproductive if not parasitic. Economic thinking developed in considerable part in reaction to mercantilism, the view that nations could only become wealthy and powerful by exporting more than they imported, thereby accumulating gold or other, second-best, mediums of exchange. Even the opponents of mercantilism accepted, typically without much consideration, that services, by reason of intangibility, could not contribute to growth in the stock of wealth. Transient and immaterial, services could be neither stored nor traded; by the same token, they were "unproductive." Such perspectives have been remarkably persistent.

Adam Smith's attitude toward the services, as expressed in *The Wealth of Nations*, still finds echoes today, even though his starting point — personal servants employed by England's upper classes — almost guaranteed a circumscribed perspective. Smith (1887) wrote:

> The labour of the menial servant, on the contrary [the comparison is with "the labour of the manufacturer"], does not fix or realize itself in any particular subject or vendible commodity. His services generally perish in the very instant of their performance, and seldom leave any trace or value behind them, for which an equal quantity of service could afterwards be procured.

He went on to note that the same could be said of the services provided by army and navy, as well as "churchmen, lawyers, physicians, men of letters of all kinds; players, buffoons, musicians, opera-singers, opera-dancers, & c."

> Like the declamation of the actor, the harangue of the orator, or the tune of the musician, the work of all of them perishes in the very instant of its production.

Smith termed their activities "unproductive labour," in contrast to the work of farmers and manufacturers.[2] Writing at a time when corn, cloth, and colonial

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[2] As Alfred Marshall (1920) explained it:

> Thus the Mercantilists who regarded the precious metals, partly because they were imperishable, as wealth in a fuller sense than anything else, regarded as unproductive or "sterile" all labour that was not directed to producing goods for exportation in exchange for gold and silver. Adam Smith ... still considered that agricultural labour was more productive than any other.

silver were among the predominant sources of wealth, preoccupied by trade among nations, and looking to pin-making for his famous explication of the division of labor, Smith gave no more than the briefest account of how services were actually produced.

For those who followed, technological innovation in the design and production of manufactured goods seemed more or less self-evidently the driving force for the first and second industrial revolutions, the latter directly based on the old science of chemistry and the new sciences of electricity and magnetism. Services for which technology was plainly central seem to have been regarded as *sui generis* (telegraphy) or subsidiary (transportation). Was it not manufacturing firms that built ships to carry goods or lay undersea cables? Was not it only natural to put steam engines in ships once such engines had been proven in stationary and railway service? And what were wholesaling and retailing for but to get goods to customers? Even today, it is not that common to view health care, much less education, as industries to be analyzed like others in terms of their production processes.

Only in the 1960s, with the pioneering work of Victor Fuchs (1968), did services begin to get serious analysis. Few economists followed his lead. Sociologists and political scientists paid more attention, with Daniel Bell's (1973) *The Coming of Post-Industrial Society* particularly influential in turning attention toward the service-producing residual. Considerable effort had already gone toward estimating the size of the information-based portion of economies, and more was to follow.[3] But this did not translate into attention to the services more generally. Neglect by analysts, moreover, has been matched by neglect in the popular and business press: *Fortune* magazine did not include service firms in its *Fortune 500* list until 1995.

2.3. Technology in the services

Not surprisingly, the services have until recently been close to invisible in discussions of innovation, just as "technology," except for IT, has been absent, or nearly so, in most discussions of service industries.[4] Thus, readers of the 1987 and earlier editions of *Science & Engineering Indicators*, the primary US government compilation of R&D statistics, would have encountered figures indicating that nonmanufacturing firms (those in service industries plus construction, mining, and agriculture) accounted for only 3–4% of industrial R&D — a few billion dollars annually. More recently, the National Science Foundation (NSF) has made large upward revisions in its reports of nonmanufacturing R&D based on improved surveys and reclassification of some firms from manufacturing to nonmanufacturing. As Fig. 3 suggests, the revisions amount to a jump from one trend line to another; the true share of nonmanufacturing R&D has no doubt been increasing gradually over many years.

Relatively little is known concerning the sectoral composition of services R&D. Moreover, the limited information available raises as many questions as it resolves. For example, NSF puts 1998 R&D by the wholesale and retail trade sector at US$ 11.3 billion, a figure that is large in absolute terms, slightly more than one-quarter of all nonmanufacturing R&D, and some 40% greater than reported for the preceding year (U.S. National Science Foundation, 2000). (Other major nonmanufacturing R&D sectors include computer and data processing services and R&D services themselves.) Do firms in the trade sector actually spend an order of magnitude more on R&D than FIRE (finance, insurance, and real estate), for which NSF reports 1998 R&D spending of US$ 1.6 billion? Are the rapid growth and very large total reported for the trade sector associated with electronic commerce? Do firms such as Amazon.com report as R&D expenditures of a sort that large banks, credit card issuers, and insurance companies in the FIRE sector do not? These are among the many uncertainties concerning technical activity in the services. They provide another illustration of inattention to service industries for reasons that are largely historical. When NSF began its estimates in 1953, it put total business-funded

[3] For a concise survey of thinking during the 1970s and 1980s, see Block (1990), who notes that there has never been any consistent view of postindustrialism, in particular, as to whether "information" in some sense should be taken as central, or whether postindustrial economies are simply those in which service-producing activities have come to overshadow goods-producing sectors.

[4] There has been more work on innovation and services in Europe than in the United States. See, for example, Metcalfe and Miles (2000), as well as the many papers and reports of the SI4S Project (1998).

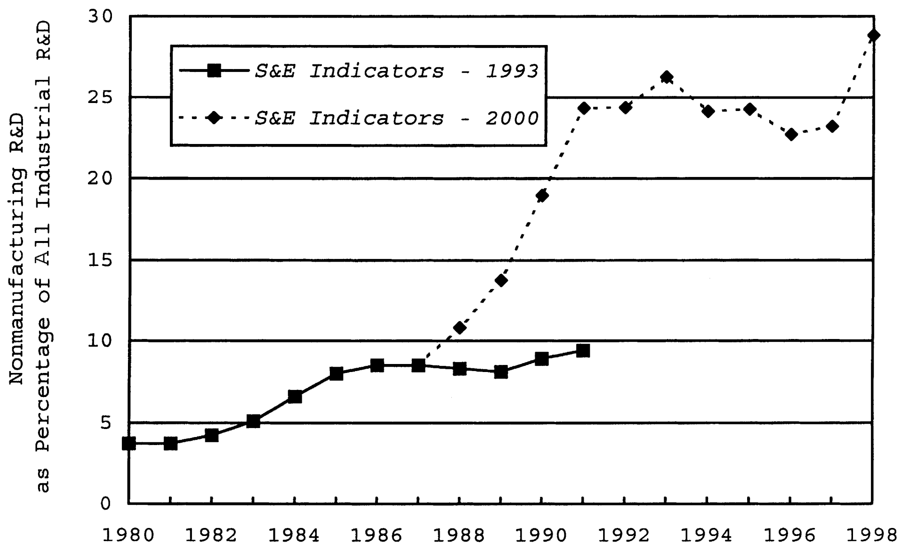


Fig. 3. Nonmanufacturing R&D as a share of all US INDUSTRIAL R&D. Note: R&D conducted by business firms; all source of funds. Sources: U.S. National Science Board/National Science Foundation, 1993, Science & Engineering Indicators — 1993 (US GPO, Washington, DC), Appendix table 4–34, p. 374; U.S. National Science Board/National Science Foundation, 2000, Science & Engineering Indicators — 2000 (US GPO, Washington, DC), Appendix table 2–52, p. A-93; 1998 from Research and Development in Industry: 1998 (Early Release Tables), www.nsf.gov/sbe/srs/srs00408, Table E-2.

R&D at only US$ 2.2 billion; the agency would have found little reason to look carefully at service firms.

Table 1 indicates that more than half of US scientists and engineers now work in the nonmanufacturing sector (not necessarily in R&D). Little is known about their job responsibilities, but employers probably value their generalized skills in quantitative methods and reasoning (mathematical modeling, statistics, data analysis, or simply sensitivity to numbers and practiced rigor in thinking) as much or more than specialized disciplinary training. Product and process design in service firms does not draw nearly so directly as in manufacturing on knowledge of the engineering sciences (e.g. solid and fluid mechanics, electrical circuit analysis). On the other hand, back-office processing in financial services takes place in settings not unlike assembly lines. Do engineers design facilities for processing checks and credit card statements using similar principles and techniques, e.g. those of industrial engineering? Such questions have only begun to be addressed. While literally hundreds of studies of auto assembly lines have been published, there

Table 1
US employment of scientists and engineers (S/E's)[a]

	All S/E's (thousands)	S/E's in manufacturing (thousands)	S/E's in nonmanufacturing (thousands)	S/E's in nonmanufacturing as percentage of total (%)
1980	1366	747	621	45.5
1986	1642	926	775	47.2
1990	1962	929	1030	52.5
1993	2010	875	1136	56.5

[a] Notes: 1993 is the last year available; NSF no longer reports data in this form. Figures exclude government employees. Sources: 1980, 1986 — U.S. National Science Board/National Science Foundation, 1993, Science & Engineering Indicators — 1993 (US GPO, Washington, DC), Appendix table 3–1, pp. 301–306; 1990, 1993 — U.S. National Science Board/National Science Foundation, 1996, Science & Engineering Indicators — 1996 (US GPO, Washington, DC), Appendix table 3–9, appendix p. 7.

are probably not a dozen accounts of back offices in financial services.

2.4. Product and process

Technology need not be closely associated with the formal tools of engineering and science. As Fuchs (1968, pp. 111–112) observed:

> The principal technological changes in beauty shops ... have had a significant impact on productivity ....
>
> [N]umerous minor technological improvements have resulted in making an improved service available at a much lower price.
>
> Some, such as reductions in the time required to dry hair, increased productivity in much the same way that reduction in process time improved productivity in manufacturing ....

Although every industry, axiomatically, differs, as does every technology, beauty shops and medical practice provide equally valid illustrations of the generic process of service production, which we label the "interpretive model." (For a full discussion, including implications for performance improvement, see Herzenberg et al., 1998, pp. 85–106.) Briefly, the service provider engages in a reciprocal dialog with the customer, eliciting responses (hair styling preferences, symptoms of illness) and adjusting the services provided accordingly. The physician takes a medical history, perhaps orders specialized tests, develops a tentative diagnosis, plans a course of treatment. Depending on the patient's reaction, further detective work may follow, perhaps a change in diagnosis and an altered treatment regimen. The goal, not always achieved, is to bring diagnosis and treatment into congruence through mutual adjustment.

The work of nurses' aides — in calming, say, a patient with Alzheimer's — involves similar interpretive processes. So does that of auto mechanics, sales personnel, and teachers. Each third-grade arithmetic lesson is a little different; so is each selection and fitting of a business suit and each home mortgage — though not, in any meaningful sense, each fast-food pizza.

In the contrasting "engineering model," found in manufacturing and other goods-producing industries, product attributes are determined in advance of production and specified in complete detail, typically by blueprints, process sheets, or the equivalent, now likely to be digital. This is true not only for mass-produced goods, such as microprocessors or auto tires, but for items produced in lots of one or a handful, such as highways or communications satellites. Production follows a predetermined design. Workers have little latitude to deviate from that design until they encounter undetected errors in the plans and specifications (of which there are always a few).

Some services — fast foods, commodity banking products — fit the engineering model. But these account for a minor share of total service output. Although goods-producing and service-producing industries draw on a common knowledge base, ranging from the accepted theories and empirical findings of science to the heuristics and rules-of-thumb of technical practice, the processes by which knowledge is transformed into economic outputs differ systematically.

3. The heritage of the cold war

The dominant patterns for science and technology (S&T) policy in the United States stem from the 1950s, when war in Korea drove home the need for sustainable superiority not only in nuclear weaponry but in conventional military equipment. [5] By the end of that decade, the US "national system of innovation" was firmly established. Although R&D spending has increased greatly since, neither agency structure nor policies have altered very much. This is the system that the United States will have to change to create a post-Cold War, postindustrial technology policy.

Cold War defense policies year after year pumped large sums of money into the physical sciences and engineering, into the design and development of weapons systems, and into procurement of those weapons. The sums dwarfed expenditures by all other countries except the Soviet Union. They generated a great deal of new knowledge in a broad range of disciplines, including tools and methods now used worldwide in technical analysis and design.

The end of the Cold War and the subsequent crumbling of Russian military power have as yet had little

[5] Parts of this section are based on Alic (1998).

effect on defense-related R&D spending or on the technologies embodied in US weapons systems. Despite the experiences of the 1991 Persian Gulf War and recent fighting in the Balkans, and much talk of "revolution in military affairs" and unconventional warfare, including "information warfare" and even "postmodern war," the United States has not seriously debated requirements for national security in the coming decades, much less translated such understanding into technological needs. Most of the adjustments to this point have taken the form of reductions in unit purchases of long-planned systems such as the F-22 fighter, which was conceived in the early 1980s to counter anticipated improvements in Soviet aircraft.

US military R&D increased seven-fold in nominal dollars, and almost as impressively in real terms (a factor of 5.5)) during the 1950s, with the most rapid rate of increase in the second half of the decade as the lessons of the Korean War sank in. Outnumbered allied forces, equipped in many cases with equipment from World War II, had been badly mauled. More so even than the Soviet Union's nuclear tests, the Korean experience set the United States on the road to a high-technology military. Defense R&D (properly RDT&E, for research, development, test, and evaluation) rose from 4.8% of defense expenditures in 1955 to 12.4% in 1960 and has remained high ever since. (On the change in perceptions and attitude toward R&D as a result of the Korean War, see Blanpied (1995)).

World War II had of course been a turning point in military technologies and the military-civilian relationship. Postwar planners sought better jet engines for high-performance fighters and bombers, faster computers for plotting missile trajectories, semiconductors for the guidance systems in those missiles. In the United States, the Department of Defense (DoD) picked up most of the tab for creating a knowledge base, for training people, for building organizational know-how. Universities structured programs in engineering and the physical sciences around DoD dollars. The Pentagon spent large sums on research to guard against even the remotest possibilities of technological surprise. For example, by intensively studying both prospective designs for quiet submarines and techniques for finding and tracking submarines underwater — efforts that ranged from basic research in oceanography to development of towed sonic arrays — the United States sought to insure against both the danger of a Soviet breakthrough in quiet submarines and in methods for tracking and targeting US submarines.[6]

Defense spending contributed not only through R&D but procurement, and not only in the form of artifacts like the integrated circuit and the predecessors of the Internet but through development of engineering methods, as well as experience-based learning, including learning how to do R&D. In particular, many now-common analytical techniques, in recent years generally implemented through computerized numerical analysis, emerged from DoD-funded work in universities, defense contractors, and the government's own laboratories. Examples range from methods for antenna design to computational fluid dynamics and aircraft structural integrity (e.g. mathematical models for predicting crack growth). In the case of integrated circuits, the Pentagon supported development of computer-aided design tools as it became clear that chips would soon incorporate so many circuit elements that computer assistance would be indispensable. The pioneering text *Introduction to VLSI Systems* by Mead and Conway (1980) pulled together, codified, and extended chip design know-how developed with many contributions from DoD-supported projects; both authors had longstanding ties with defense agencies. As Japanese firms came to dominate markets for memory chips, which depended on mastery of manufacturing processes, US chipmakers shifted to design-intensive products such as microprocessors and logic. Able to hire engineers conversant in the latest design techniques, American firms could quickly reshape their competitive strategies.

Of course, most of DoD's R&D dollars went to defense contractors for the design and development of weapons, both the prosaic (a new assault rifle to replace the M1 of World War II) and the heroic if not foolhardy (the Dyna–Soar space plane,

[6] This is one of many instances in which defense research had serendipitous outcomes, here baseline data on global climate change stemming from long-term monitoring of ocean temperatures. The military was "willing to support almost anything that helped characterize the environment in which they operated" (Weart, 1997).

intended to skip along the Earth's outer atmosphere). Today, although the Cold War is over and potential US adversaries weak, the United States continues to fund military R&D as if it faced superpower rivals. Fiscal 2000 RDT&E, at US$ 37 billion — roughly half of all federal R&D spending — represents about 13% of the defense budget. Procurement is only US$ 10-plus billion higher. In effect, the United States is planning new high-technology weapons systems as if the Cold War was still underway — the F-22 and Joint Strike Fighter (JSF), the Navy's F/A-18E/F and next-generation attack submarine. Not only is there little indication that procurement funds for all these systems will be available, no convincing arguments have been put forward that future national security threats call for so many different systems of such sophistication at such costs. As the congressionally mandated National Defense Panel put it with respect to tactical aircraft (National Defense Panel, 1997),

> ... the Panel questions the total number of planned aircraft buys and the appropriate mix of systems in 2010–2020. [T]he services must demonstrate how these two systems [the JSF and the F/A-18E/F], and the F-22, can operate effectively in the 2010–2020 environment, which will be characterized by new challenges to our power projection capability.

Recent debates, finally, seem virtual replays of those three decades ago concerning, say, the B-1 bomber (which had its genesis still earlier in the aborted B-70, proposed as a replacement for the B-52). In the mid-1990s, as the Air Force struggled to balance the budgetary claims of the B-2 against those of the F-22, that service's leaders argued for both against the Navy's assertion that the United States should instead buy three new aircraft carriers. After the Air Force settled its internal debate in favor of the F-22, the bomber faction began to push for a B-X: "A new, manned long-range combat aircraft costing less than half the price of the B-2" (Fulgum, 1997). Critics meanwhile asked in vain for some convincing explanation of the need for such systems.

The failure of the United States to conduct a meaningful reevaluation of its security needs, even though no conceivable adversary could, without many years of build-up and many years of inaction by the United States and its allies, field forces remotely comparable in their technological capabilities, reflects oft-noted failures in defense planning, intra- and inter-service rivalries, and disagreements between and among high-ranking military officers and civilian officials. On the other hand, there are almost certainly emerging needs, as yet poorly defined, given a world of peacekeeping missions, small-scale conflicts, and non-conventional warfare. These threats — info-warfare, bio-warfare, terrorists possessing weapons of mass destruction — are getting lip service and limited funds, while the bulk of acquisition dollars go for weapons that reflect missions inherited from the past.

The eventual outcomes matter for more than national and international security, and not only because the Internet, even though its military roots are in the 1960s, demonstrates that spinoff still takes place (as does commercialization of Global Positioning Satellite receivers, to take another highly visible example). DoD continues to put more than US$ 4 billion annually into basic and applied research; one-third of those funds flow to universities. DoD spending on development and procurement, furthermore, continues to contribute to the evolution of the computer-assisted engineering methods mentioned above, and more generally to informal technical knowledge. These parts of the technology base have not been carefully studied, but a glance at current engineering textbooks — or at the desks and computer terminals of working engineers, including those at a far remove from defense — should be enough to suggest their significance. For half a century, DoD and other parts of the "national security state" (e.g. the Atomic Energy Commission and its successors, the National Aeronautics and Space Administration) supported much of the technical knowledge base for the United States and indeed the world. Defense no longer dominates US S&T policies as it did in the 1950s. Yet it remains a primary force. There is much more for defense to gain in the short term from commercial technology than for commercial industries to gain from military technology. On the other hand, commercial industries have gained a great deal over the long-term from military support for generic technical methods such as those of computer-assisted engineering. Once the United States does rethink its defense posture and acquisition policies, the impacts on technology and science will ripple through the economy, perhaps with considerable force.

4. International trade and investment

There are three proximate reasons why analysts, policymakers, and the media have devoted so much more attention to manufacturing than to the far larger service sector. Two have already been noted: manufacturing has long been a source of well-paying jobs for those with less than average levels of schooling; and manufacturing firms have traditionally been considered the major performers of R&D and wellsprings of technological innovation. The third reason: international trade flows consist largely of goods. While the United States runs a substantial positive balance in "invisibles" (Table 2), that surplus has not been nearly enough to offset the deficit in goods, nor will it be in the foreseeable future. Although cross-border trade in some services has been expanding rapidly with globalization, reduced communications costs, and advances in IT, and although production of goods and services interdepend in numerous ways, a great many service products, including those that account for the bulk of GDP in the United States and its major trading partners, are non-tradable or only lightly traded. The reasons, again, are inherent in processes of production and thus unlikely to change dramatically. Those services that can be neither shipped to be held in inventory until sold nor delivered remotely in real time will not be greatly affected by further advances in telecommunications and IT. Telemedicine, for example, while a boon to those who might otherwise be deprived of expert medical consultation, is unlikely in the foreseeable future to substitute for more than a few percent of health care services. Nor can anyone realistically expect the Internet to deliver high-quality educational services absent considerably greater understanding of how people actually learn; information transmittal is no substitute, especially for acquisition of procedural, as opposed to declarative, knowledge (Alic, 1997).

Table 2
US International trade balance, 1999[a]

	Balance (exports − imports)
Goods	US$ 346 billion
Services	US$ 81 billion
Travel and transportation	6.8
Royalties and license fees	23.2
Other private services	49.9
Government/military transfers and expenditures	0.8

[a] Notes: parentheses indicate deficit. "Travel" consists of spending by residents of foreign countries temporarily in the United States (e.g. for food, lodging, and domestic travel) or by US residents temporarily abroad; "transportation" includes both passenger fares and freight charges. "Royalties and license fees" includes franchising fees, licenses for use of patents and other intellectual property, and charges for transfers of technology and know-how. "Other private services" includes telecommunications, construction, movies and television programming, legal services, accounting, insurance, advertising, education, and health care. Source: U.S. Department of Commerce, International Trade Administration, www.ita.doc.gov/td/industry/otea/usfth/tabcon.html.

The services trade accounts also exhibit peculiarities, some of them suggested by the notes to Table 2, which limit the significance of several categories. For example, intracorporate transfers predominate in "royalties and license fees," making up as much as three-quarters of both exports and imports. Multinationals price such transfers for internal financial reasons (e.g. to minimize global tax bills); reported figures may not reflect market values (and markets are in any case thin for many such transactions). Intracorporate transfers likewise make up a substantial share (about 30% on the export side and 40% for US imports) of "other private services." Nor is the nature of "trade" always self-evident. Exports of US educational services, more than US$ 9 billion annually, consist chiefly of that portion of the living expenses and tuition payments of foreign nationals attending schools in the United States estimated to be paid from foreign sources.[7]

With product and process placing fundamental limits on the growth of trade, direct foreign investment will remain the primary route to overseas sales by service firms. We estimate that some 90% of US service jobs are at present effectively insulated from the international economy (Herzenberg et al., 1998, p. 16). While 10% of US service output is a big number, around half of manufacturing output, the

[7] In this and other cases, governments estimate exports and imports of services based on surveys that vary considerably in accuracy and coverage. Many of the estimates, at least for the United States, appear to err on the low side. Although official figures probably understate both the total volume of services trade and the positive US balance, more accurate estimates would not raise the totals to levels approaching those for goods.

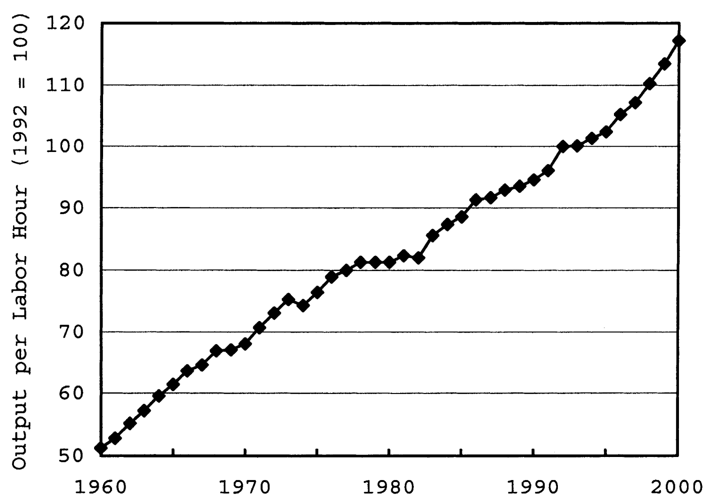
domestic forces influencing productivity and wages in services far outweigh the effects of globalization.

5. The productivity slowdown

Measured productivity growth in the United States, until it surged in the second half of the 1990s, had been low since the 1970s (Fig. 4). When productivity increases, pay tends to follow. Wage stagnation in the United States has multiple causes, but slow productivity growth is certainly one of them: although wages at the industry level depend on a wide range of factors, in the aggregate about 80% of US national income is distributed to individuals in the form of pay and benefits. Because technological innovation has long been known to be a major source of productivity increase, and because the slowdown coincided with successive waves of more-or-less obvious innovation in computers and IT, with more-or-less obvious efficiency gains for firms and their customers, the "productivity paradox" has occasioned a great deal of comment. So has the post-1995 upsurge.

5.1. *The slowdown*

Productivity growth declined throughout the industrial world around 1973, the time of the first oil shock. In the United States, the drop was especially pronounced and the subsequent recovery partial and halting. Before 1973, US labor productivity increased at around 3% annually; for two decades afterwards the rate averaged less than half that. Yet the US economy led others in nearly all applications of IT both before and after the slowdown began. During the 1960s, big companies transferred labor-intensive administrative tasks such as accounting, payrolls, and inventory control to big computers; in the 1970s, they adopted minicomputers for process control and technical calculations, while smaller firms moved business applications onto smaller machines. The 1980s saw the spread of desktop machines and distributed computing for office automation. Then came the Internet. Why did labor productivity rise at less than historical rates even as computers took over so many tasks that once required human labor — not only administrative "paperwork," but banking transactions,



Period	*Average Annual Rate of Growth*
1960-73	3.0 %
1973-95	1.4
1995-99	2.6

Fig. 4. US labor productivity. Notes: nonfarm business sector; 2000 charted at annual rate for first two quarters. Source: U.S. Department of Labor, Bureau of Labor Statistics, stats.bls.gov.

routing of trucks, point-of-sale scanning of retail prices? Many explanations have been offered; none has received broad acceptance.

During the 1980s, productivity growth in manufacturing returned toward its long-term average of 3–3.5% per year. Overall productivity did not. The sharp post-1995 increase likewise has been attributed in considerable part to manufacturing; indeed, Gordon (2000) traces it exclusively to the manufacture of computer hardware. To the extent that manufacturing is responsible for recent increases, lagging productivity in services remains an obstacle to improvements in economic performance, including wage increases.

Such conclusions hold even though productivity data are poor for many service industries. Both the aggregate series and that for manufacturing are considered reasonably reliable. The service sector overall makes up most of the difference between the two, and is presumably captured reasonably well. But for individual service industries, productivity can be very difficult to measure; for large parts of the service economy, the statistical agencies do not even try. And in some service industries for which figures are available — including health care, hotels, and grocery stores — measured productivity shows a decline. The difficulties are almost entirely a matter of valuing changes in output attributes over time: new or improved medical procedures, more variety on supermarket shelves, greater convenience in retail banking.

Yet if productivity data for individual service industries can be questioned, mismeasurement cannot account for the slowdown, at least in its entirety. To begin with, a number of services for which output is hardest to measure, including government (and hence public education) and non-profit health-care enterprises, are excluded from the nonfarm business series of Fig. 4, the usual focus of attention. Although existing statistical series probably understate the growth of output and hence productivity in a considerable number of services, no widespread deterioration in the ability to gage productivity coincided with the slowdown. Indeed, the statistical agencies would claim to have improved their output series for many services since the 1970s (raising the alternative possibility that productivity increases were overstated earlier). Nor is it reasonable to assume that innovations in IT were somehow less potent before 1973, or their effects easier to capture. Businesses purchased unprecedented numbers of IBM's 360 and 370 series machines, the first models of which reached the market in 1964, primarily to automate transactional applications such as financial records. It would be hard to argue that these applications constituted, in some sense, a large-scale failure.[8] If the slowdown cannot be attributed to mismeasurement, at least wholly, then "technology," defined broadly to include the organization of production, remains as the presumptive cause.

5.2. What is changing in technology?

Much has happened in the US national system of innovation since the 1970s. Patent protection has been strengthened, for good or ill. The ratio of industry to government R&D spending has moved from roughly 45:55 in the mid-1970s to something over 70:30. Industry is not only spending more money but spending it differently. While downsizing or closing centralized laboratories, firms have established closer technological linkages with one another and with universities.

One way to view the changes, conjecturally but in the context of the shift to services, is to suggest that private R&D may be being reabsorbed into the larger organization. Formal R&D and the industrial research laboratory date, in the United States, to the first decades of the 20th century in dominant manufacturing firms such as General Electric and DuPont (and AT&T, a service firm that produced its own equipment). Technical activities had earlier been distributed rather than concentrated, just as today they seem to be spread broadly within service firms that do not necessarily think of themselves as engaged in R&D when they develop new products or processes. Reabsorption of R&D would be consistent with broad trends of decentralization, organizational flattening, and reduction in hierarchy. After all, one of the characteristics of high-technology firms is that technical work is more-or-less everywhere rather than the province of research laboratory and engineering department.

[8] Most of the many well-documented failures in business applications of IT have resulted from efforts, not to automate transactions, but to create competitive advantage through new or differentiated product offerings that depend, typically, on proprietary software. See Keystone Research Center (1998), pp. 24–53, and the references cited therein.

Turning to the input side, Fig. 3 showed that R&D in service industries, though poorly measured, has been rising, while Table 1 showed a similar rise in technical employment in services. Engineers make up the majority of the technical workforce, outnumbering scientists in the United States by more than seven to one (including computer professionals with the engineers). Engineering employment rose from under 0.15% of the labor force in 1900 to about 1.5% by 1970, but has changed little since then, even as more engineers took jobs with service firms. Most of those engineers have degrees in one of the traditional fields of civil, mechanical, electrical, chemical, or industrial engineering. Those disciplines evolved alongside major goods-producing sectors: civil engineering with canals and railroads, mechanical and electrical engineering with capital and consumer goods, and so on. Relative latecomers like aeronautical/aerospace and computer science and engineering likewise responded to demand on the goods-producing side of the economy. Although many US engineering schools have introduced non-traditional and interdisciplinary curricula, such as systems or biomedical engineering, most such programs remain modest in size; they account for fewer than one in seven graduates.

Is it possible that the pool of technical personnel from which service firms hire is either inappropriately trained or notably constricted, thereby dampening productivity growth? Although entry-level wages for engineers are high, there is little other evidence to support such conjectures. Recent reports of shortages of IT workers have stressed needs for support staff and programmers trained for routine tasks as much or more than 4-year college graduates. For decades, US employers have asked engineering schools to provide more and better training in communications skills and some grasp of economics, but extensive revisions of accreditation criteria, which go into effect in 2001–2002, show no indication that employers are demanding new skills otherwise. Nor do patterns of continuing education and training, which have expanded primarily along traditional lines (e.g. updates on technical methods). Labor market pressures, in other words, have not been enough to stimulate big changes in either supply or qualifications of engineers. For the US labor force as a whole, average levels of education continue to increase. While the quality of the schools has often been criticized, and education in any case is a poor surrogate for many types of skill, it would seem difficult to link a slowdown in productivity growth or innovation with a shortage of appropriately skilled workers.

It is hard, in sum, to see much on either the input or the output side of the US innovation system to account for the longrunning productivity slowdown. US industrial R&D dipped during the first half of the 1990s, but has risen strongly since. The science community has pressed with considerable success for increases in research support — great success in the case of the National Institutes of Health (NIH). The seeming absence of demand for "new engineers" to work in the new economy suggests that the technical skills associated with practice remain more-or-less adequate. By most indications, the US innovation system seems to be flourishing, more than ever to be vital, flexible, adaptable. That is the essence of the paradox.

Direct examination of IT applications yields a more mixed picture. It takes a great deal of time and money to develop proprietary software and learn to use it. Evidently, the majority of such projects fail technically; functionally satisfactory applications often fail to meet strategic business objectives. Productivity in programming has improved slowly compared with hardware performance, so that software generation, maintenance, and support consume ever growing fractions of IT spending. Employees may need months or even years to master specialized skills (2 years for clerical and administrative workers at an insurance company we studied who faced 85 different software applications). Companies rarely succeed in measuring the costs and benefits of IT projects in an accounting sense; many do not even try. Yet firms continue to invest. And of course learning does take place. Successful applications replace those that fail initially. At the business function level, payoffs to IT have presumably been there at least since the 1960s.

The unanswered questions therefore concern, on the one hand, aggregate productivity performance, and on the other, wide and unexplained variations in productivity trends across service industries. That some industries show high rates of measured productivity increase (wholesale trade) while others show decreases (grocery stores) argues against a single, overarching explanation and suggests that policymakers consider measures likely to improve performance regardless of whether the improvements are of a sort likely to show up in industry-level statistics.

5.3. Performance improvement in services

Because the interpretive model characterizes so much of the service economy, workforce capabilities matter more than in manufacturing. Capital equipment, particularly specialized equipment (blast furnaces or stamping presses as opposed to generic IT), is correspondingly less significant. In the interpretive model, it is up to workers, individually and collectively, to produce appropriately configured, high-quality outputs. Service workers at all levels, not just professionals, must "think on their feet."

In the engineering model, conceptualization precedes production. Design, in many respects the heart of technical activity in the "old" economy of mass manufacturing, research laboratories, and large hierarchical firms, proceeds iteratively from preliminary stages of concept generation through definition of details. Experts make technical decisions with the support of extensive analyses based on the mathematical models of engineering science. Calculations, simulations, and testing help predict and verify performance.

In the engineering model, product definition and production are separate, sequential, and subject to managerial control. In the interpretive model, they are integrated and interdependent; only rarely can managers exercise close continuous oversight. In the engineering model, performance improvement comes from improved product designs (car doors with fewer parts) and production processes that, at least cost, minimize deviations between design and delivered product (precision forming of car-door skins). In the interpretive model, performance gains follow from improvements in the ability of workers to elicit, understand, and respond to the "customer" (a third-grader with mild symptoms of attention deficit disorder) or the situation (a medical emergency with comatose patient unable to engage in interpretive dialog), to select and follow work practices from an available repertoire, and to learn or invent new practices as may be appropriate. The sources of performance improvement and productivity increase differ radically between the two models.

Even in science-based sectors like health care, links with formal technical activity are looser than in goods-producing industries. Medicine itself remains an art based on science. Clinical practice is characterized by uncertainty and ambiguity. Each patient and condition is unique. With several thousand recognized diseases, often occurring in combination, and many others yet to be identified, the diagnostic permutations are for practical purposes uncountable. Codification of practice remains a distant goal. Even so, managed care operates reflexively on engineering-model principles, in part because there are no widely accepted measures of health (sickness, wellness, etc.) that might be related to the services delivered by care providers. Lacking such measures, managers and policymakers seek instead to control costs, minimize errors, and provide "appropriate" levels of care, i.e. avoiding "underutilization" or "overutilization" of services.

There is an alternative perspective. That is to take diagnosis and the planning of treatment, or the equivalent in other services (devising an advertising campaign, a television series, an engineered theme park), as the core activity, just as design is the core activity in traditional manufacturing. In the health care case, this should cause both policymakers and the leaders of the profession to pay more attention to the skills and knowledge of working physicians. Policies aimed at reducing downstream errors such as inadvertent drug interactions (in emulation of systems approaches as in aviation safety), while certainly desirable, assume that diagnosis is unproblematic (Institute of Medicine, 2000). In fact, diagnosis is the most difficult task routinely faced by medical practitioners other than specialists such as surgeons whose skills are biased towards the procedural.

Such a perspective might lead policymakers to rethink some of the activities of NIH and other heath-care agencies, in particular, the balance between knowledge creation and knowledge utilization. No matter their diligence, physicians cannot keep up with advances in clinical knowledge; new results accumulate too rapidly, in areas ranging from biomedical science to clinical meta-analysis. The less diligent in this large and relatively diverse community, in the United States numbering more than 700,000, lose touch with too much of what they learned in medical school. Even for the most diligent, continuing medical education is widely acknowledged to be ineffective. For these and other reasons, average standards of practice lag far behind consensus best practices, when the latter can even be said to exist.[9] Part of the problem is a weak set of institutions for diffusion of knowledge to and among practicing physicians.

Efforts to control costs, finally, have been almost entirely uncoupled, not only from efforts to improve standards of practice (no one has yet demonstrated any correlation, positive or negative, between managed care and quality), but from research. NIH, which has recently controlled more than 40% of all federal funds for basic and applied research, spends some US$ 18 billion each year on R&D. Efforts to improve the quality of health care services, e.g. by the Agency for Healthcare Research and Quality, are minuscule by comparison and have had little perceptible effect. It is not that policymakers lack leverage or incentives: federal, state, and local governments pay about 45% of the US health care bill, 60% if tax expenditures are included. Yet the United States continues to support the biomedical sciences as if improvements in service delivery will follow automatically: pipeline models of innovation long since discarded elsewhere remain alive and well in health care.

6. Implications for policy

Since World War II, knowledge creation has been the great strength of the US national system of innovation, knowledge diffusion the great weakness. The reasons lie mostly in the worldwide dominance of US technology and science and US industries in the early postwar decades, circumstances that made diffusion seem unimportant. Even when competitive pressures grew intense, as occurred beginning in the 1970s in a number of US manufacturing industries, the spread of well-proven methods to solve obvious problems such as poor quality took place slowly and sporadically over many years. S&T policies, furthermore, evolved in settings dominated by engineering-model thinking. Knowledge creation was the centerpiece, feeding design and development. Diffusion and learning, mediated by institutions ranging from patents and scientific publications to technical standards and continuing education, harder to comprehend and translate into policy initiatives, were addressed indirectly or left largely alone. Until recently, the U.S. Department of Agriculture (USDA) was singular in its emphasis on diffusion: only at the end of the 1980s did Congress instruct the Commerce Department to put in place technology extension programs (for manufacturing firms). Although robust informal networks enhance communication and learning within communities of active research scientists and in regions such as Silicon Valley, diffusion to and within many professional and semi-professional occupations, including medicine and engineering, remains haphazard. Training has often been poor for non-elite occupations such as construction, where apprenticeships have atrophied and productivity suffered as a result.

In ways other than low priorities for diffusion, the US system of innovation remains a creation of the old industrial era and the Cold War. As noted earlier, most of the institutional foundations were put in place during the 1950s, the decade of the Korean conflict and Soviet Sputnik launches and peak period for manufacturing as a share of GDP. Structurally, the system has changed relatively little since that time. This does not necessarily mean the innovation system is in some sense obsolescent, any more than the rise of the service sector means that manufacturing is becoming irrelevant. But it does suggest a deliberate look at the alignment or articulation between the innovation system and the new economy of services.

Such an assessment should proceed on three main tracks: (1) industry sector studies, including major portions of the economy such as education and health care that have not always been considered “industries” and in which service delivery has rarely been linked with S&T policy; (2) detailed exploration of inputs and outputs associated with innovation in services, comparable to work that has been ongoing for decades in major manufacturing industries; (3) careful analysis of the impacts of government policies on productivity and economic performance more generally, including wage levels, wage dispersion, and career mobility paths.

Sources of productivity performance are best understood at the level of individual industries, subindustries, and firms, of technologies and organizational practices. Sectoral studies of service industries are

[9] Because the large-scale statistical studies that had been expected to support “evidence-based medicine” have yielded few useful findings, best practices have proven hard to define (Schuster et al., 1998). Low average standards of practice have been inferred largely from data showing wide variations in treatment for patients with similarly diagnosed conditions, variations for which no explanation other than differing levels of competence seems plausible.

becoming more common (e.g. Mowery, 1999). But very little is known, for example, about the ways in which the day-by-day work of engineers in service organizations differs from that in manufacturing. How do banks and insurance companies manage "R&D"? What sorts of heuristics do physicians call on? The management literature covers some of these questions, but typically at high levels of generality and with too little quantitative detail to offer much insight into performance, particularly performance measures likely to be of more interest to policymakers than business executives and market analysts.

The need for better statistics on technical activity in services should be obvious. Questions such as the accuracy of consumer price indices have stimulated a good deal of work aimed at more accurate quality-adjusted output series for service-producing industries. To uncover the reasons for changes in measured output and productivity, it would be desirable to link these more closely with field research on production processes at firm and sectoral levels.

Policy development sometimes reflects analytical understanding, but to considerable extent government agencies do what they have always done. NIH funds research because that has been its mission since the 1930s. DoD prepares for simultaneous major conflicts on opposite sides of the world because DoD knows that will protect its budget. Since the early part of the 20th century, USDA has spent substantial sums on agricultural extension. The policy had its genesis as part of the larger effort to improve rural living conditions at a time of widespread poverty among farm families. An entrenched lobby and nostalgia for a vanishing way of life keep the programs in place.

Seventeen agencies of the US government fund significant amounts of R&D and thereby have some sort of role in implementing technology policy. Commanding the agencies to alter their behavior, e.g. to raise priorities for diffusion, would have little effect, especially in the absence of new funding. Change comes gradually, especially at working levels, absent some sense of crisis such as existed in the early years of the Cold War. The productivity slowdown in services is not likely to generate policy innovations at a faster rate than the competitive difficulties of US manufacturers in the 1970s and 1980s, which were reasonably well understood and easier for policymakers to grasp. At the same time, the decentralization that is such a prominent feature, and such a strength, of the US S&T system provides many opportunities for experimentation.

How might those experiments begin, given that so much of the service sector is uncharted territory? After productivity growth declined in the 1970s, President Jimmy Carter's administration undertook an ambitious Domestic Policy Review (DPR) of Industrial Innovation (U.S. Department of Commerce, 1979). The Carter DPR set the stage for most of the subsequent shifts in US technology policy. Among its recommendations were

- easier licensing of federally-owned patents,
- closer ties between universities and industry,
- help for entrepreneurial firms through small business innovation research funds,
- selective economic deregulation, including signals to industry that antitrust policy did not bar cooperative R&D, and
- tax incentives for R&D.

By the end of the 1980s, all these steps, and others, had been taken. Although the Carter DPR had little to say about the R&D budget, it helped pave the way for the turn toward government-industry collaboration that began a decade or so later (e.g. Sematech, the Partnership for a New Generation of Vehicles), as well as initiatives such as the Advanced Technology Program.

Subsequent administrations showed less capacity for self-examination, President Ronald Reagan's Commission on Industrial Competitiveness notwithstanding. Perhaps, it is time for the United States to conduct another comprehensive policy review. Like the Carter DPR, this might take productivity as its "problem statement," notably productivity performance in services. Such a review should address, not so much the productivity paradox, as the causes and implications of stagnation and inequality in wages. These problems will not be solved by more or better education. Schooling is good for individuals, but there will continue to be many tens of millions of jobs in the US economy, and other postindustrial economies, requiring little more than basic literacy, if that.

7. Conclusion

Productivity growth matters because it provides the foundation for broadly-shared prosperity, among people with less education as well as those with more, and among those outside the labor force, whether still in school or dependent on Social Security. Because everyone lives, in some sense, off the output of those who work, the United States and other postindustrial societies need to devise and put in place technology policies that will foster continuous improvement in the performance of service-dominated economies, replicating the steady increases in manufacturing productivity that, decade after decade, contributed so greatly to rising wages and living standards in the past. This can only be accomplished if the unique aspects of service production, fundamentally different from the design, development, and production of manufactured goods, are recognized and taken into account.

The interpretive model of service production, illustrated in its full complexity by medical diagnosis and treatment and in stripped-down form in many sales transactions, has implications for innovation and technology policy that range from the design of IT systems — e.g. to facilitate diffusion of medical knowledge — to policies for training and workforce development. These have great importance for productivity and economic performance, although terms like "training" are too narrow. Learning is better, though it is often experiential learning, rather than schoolbook learning, that makes the greatest contributions to innovation and performance improvement. Because people learn from one another, through information exchange, mentoring, story-telling, and so on, new institutions to facilitate interpersonal learning, face-to-face and electronically, should span multiple employers (Herzenberg et al., 1998, pp. 123–148). Firms may not have an interest in fostering work-related communication across organizational boundaries, but societies do. Such institutions would enhance both overall economic performance and advancement opportunities for individuals. This is part of technology policy too.

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