ONE

A Technology and an Argument Introduced

PHOTONICS AND ITS INDUSTRIAL REVERBERATIONS

In the general material clutter of our daily lives, photonics has just begun to make an inroad. The compact disk player, in which a laser device replaces a phonographic needle, has become a ubiquitous middle class possession. Fiber-optic lines stretch across the continent and the oceans. Optical computer memories encode small reference libraries on plastic disks weighing an ounce or two. Cash register clerks fumble with bar codes to be read by laser scanners. Hospital patients are subjected to laser surgery and fiber-optic catheterization, among other novelties.

Beyond the horizons of daily life, satellites relay digital images of weather patterns and missile emplacements. Machine-vision systems work in factories as diligent if unversatile product inspectors. Using digital cameras, which record images on a small diskette, journalists can electronically convey a photograph to an editor. Pilots of stealth bombers, flying at night, view distant battlefields and invisible enemies as hologram images projected on the windshield.

Technological prognosticators tell of integrated optoelectronic systems supplying homes and businesses with services that combine communications, computing, entertainment, high-definition images, and information retrieval. Not much further in the future, the most prodigious of computing machines, the optical computer, might also become possible, tying together fiber-optic communications and information processing services at the speed of light.

What these new technical possibilities have in common is that they work through the application of light. The prospect of new industries founded on optics has caused considerable excitement. None the wearier for the space age and atomic age, *The Futurist* and *Time* magazines have already heralded the age of light.[1] But even those who would hesitate at welcoming still another technological age might acknowledge that the new technology, *photonics*, is setting off reverberations throughout the world economy.

Technological change of such magnitude has effects running the breadth of human affairs, effects medical and environmental, military and industrial. The technology yields imaging devices of fine resolution for medical diagnosis and equipment for less invasive surgical procedures. At the same time, in the search for materials that simultaneously carry electricity and light, the manufacture of exotic new optoelectronic materials adds to the world's stock of environmentally hazardous substances. The technology also has momentous military significance. A variety of night-vision, range-finding, guidance, detection, and display devices depends on photonics. Optoelectronic imaging is essential to the satellite reconnaissance systems that make arms control verification possible, and also to the guidance systems of low-flying intermediate range missiles that can destabilize arms control. These very techniques yield enormous quanitites of data, which themselves create demands for the rapidity of optical communications and, if they can be perfected, optical computers.

Most of all, photonics has consequences for numerous industries. They include core industries making specialized optoelectronic components, lasers, image-capture devices, and optical components. They also include industries making final products: computer peripherals, medical equipment, telecommunications equipment, avionic instrumentation, automatic inspection systems, home entertainment appliances, scanning devices, and document imaging systems. And these devices and systems often prove to be critical elements in the productivity of still other industries: retailing, insurance, manufacturing processes, telecommunications, and office work of every description.

The industrial blessings are mixed, as usual. The technology creates new industries making optical cable, optical computer memories, and optoelectronic imaging systems, but it cuts into older industries such as copper cable and satellite communications, magnetic computer memories, and chemical photography.

Since the technology transforms production in almost every branch of the economy, photonics already qualifies to be classified with the select company of technological revolutions that have transformed twentieth-century industrial society. Photonics takes its place alongside internal-combustion technology, pharmaceuticals, electricity, petrochemicals, and microelectronics. It also belongs alongside the more revolutionary of the current generation of destabilizing technologies, such as advanced ceramics, superconductivity, and biotechnology. Photonics is, however, more advanced in its industrial effects than are the other recent technological entrants. It has already attained worldwide commercial significance.

Since 1980, the multifarious technical possibilities along with military, industrial, and consumer uses for the new products have drawn numerous firms to photonic technology. By 1988, a directory listed more than twenty-two hundred domestic companies and divisions, small and large, with an interest in photonics. These American firms, along with foreign ones, represented considerable industrial production. A rough estimate from various sources suggested that by 1989 the worldwide market for products predominantly dependent on photonic technology was in the $15–20 billion range. It was a much larger commercial market than that of another and better known technological development, biotechnology.[2]

According to Japanese figures, that country's production of optoelectronic goods increased from $350 million in 1980 to more than $8 billion in 1987. The increase seems greater in dollars than in yen, since the yen's value in U.S. dollars rose sharply in 1986. Nevertheless, even in terms of yen, production in Japan had an average annual growth rate of 50 percent through 1986. Japan's optoelectronic trade association has asserted that this was a rate of growth greater than that of any other Japanese industry.

It will come as no surprise that America's contemporary economic nemesis forged ahead in photonics. Optoelectronics figured prominently in Japan's industrial growth in the 1980s, and Japan became the primary supplier of the world's optoelectronics. By contrast, the United States showed a middling industrial performance. It did well in some years in the export of optical fiber, but progressively lost its relative share of world sales in other photonic products.

By the late 1980s, several sets of data revealed that photonics had become another of the technological sectors in which the U.S. was showing declining industrial competence. Foreign shares of U.S. patents in light-wave communications technology grew from 21 percent in 1973 to more than 50 percent in 1987. The Japanese increased their production of technical papers in the field much faster than U.S. scientists did. Panels of American experts comparing Japanese and U.S. developments in the field reported Japanese advances that were significantly ahead of those in this country. A National Research Council report on photonics concluded that the United States was "already a follower—or, worse, an observer—in developing many of the commercial products of the field."[3]

Since skills in photonics are essential to the industries taking advantage of the new field, it would seem reasonable to suppose that investment in research and development and a history of technical strength in a field would have much to do with a nation's success in the technology. Yet, though lasers, fiber optics, and optoelectronic imaging had largely domestic origins, U.S. industrial capability in the field was being overtaken by that of Japan and Western Europe. Japan did better with photonics despite a research investment that was, at least initially, smaller than that of the United States.

In the critical early years of the 1980s, when industrial possibilities were still open, Japanese industrial research expenditure on optoelectronics only moderately exceeded that in the U.S. When U.S. industrial, military, and university research expenditure is added together (though with rough estimates from disparate sources), domestic research investment turns out to have been much greater than that in Japan. Faltering U.S. industrial strength in photonics was, then, not primarily attributable to the lack of domestic research investment.

The relative decline of U.S. competence in photonics despite substantial domestic expenditure leads to our central problem: Why does a capitalist nation, presumably dependent to a large extent on the market for technological choices, perform worse than others in gaining industrial advantage from a revolutionary new technology?

THE ARGUMENT, VERY BRIEFLY

The chapters that follow contend that we can answer this question after we come to understand photonics as a technological paradigm. In contrast to the widely held conception of technology as an assemblage of discrete artifacts and inventions, the idea of paradigms has us think of it as having integral properties.

As it came into widespread use in the 1980s, photonics was becoming an integral body of technical skill and knowledge. In optical communications and in imaging applications, it was being implemented as integrated systems of devices and software. And it was bringing about a set of technological relationships among diverse industrial sectors. Photonics came to have integral characteristics in all these respects—as a body of technical knowledge, as technical systems, and as technological interrelationships among industries. Photonics acquired its massive importance in the world economy in the 1980s by dint of its properties as a technological paradigm.

If a technology is seen from the usual perspective, as discrete artifacts and pieces of intellectual property, we can reasonably conceive of these items being efficiently traded on markets. But if industrial change is better seen as the outcome of the emergence of a technological paradigm, then the argument for an unfettered market response becomes problematic. Private firms operating in markets might in themselves respond inefficiently to the technological interdependencies inherent to paradigms. In an internationalized economy, firms would operate more successfully in the presence of industrial policies that recognize the integral properties of technology and plan for massive technological changes in the economy.

The idea of technological paradigms, then, gives us a rudimentary criterion by which to assess public policies toward technological sectors: those policies are good that can recognize integral technological relationships in the economy. If so, we can plausibly explain lagging industrial performance in photonics by investigating the policies through which the U.S. has responded to the technology.

We might first expect that the U.S. responded through market solutions. Indeed, on grounds of the allocative superiority of free markets in responding to technological change, an important domestic debate in the 1980s about declining technological competitiveness led to the rejection of industrial policy. But in actuality the U.S. responded only in part through market solutions to technological change. Recognizing that U.S. retrogression in the technology occurred to mutual detriment, corporate, academic, and military leaders sought a more concerted response. Amid widespread rejection of industrial policy as faulty economics, and in the absence of an intellectual means of understanding the integrality of technological change, their response to photonics occurred not through unfettered markets, nor through explicit public policy, but through a *privatization* of policy-making.

Privatized policy took on three forms. First, government assets were disaggregated unit by unit to interested parties through pork-barrel appropriations, business participation in agency operations, and review committees representing eventual beneficiaries. Second, collaborative committees of university faculty and corporate affiliates used public funds to set the technological research agenda, but without accountability to public concerns about technological change and its industrial implications. And third, sector-specific technological research programs, chosen in part with civilian industrial effects in mind, took place in the political shelter of the military establishment.

Privatized industrial policy did not surrender policy-making in favor of market solutions but rather shifted an interventionist economic policy into the shadowy realms of pork-barrel politics, public-private partnerships, and military bureaucracies. This privatization made for debilitating policy. Operating in the absence of vision or strategy, it failed to respond to the integral characteristics of photonics understood as a technological paradigm.

U.S. industrial retrogression in photonics, therefore, reflects the domestic policy-making inability to respond coherently to technological change. To the extent that the U.S. has responded similarly to other technological paradigms and to other economic resources (such as skill and physical infrastructure) having integral qualities, we can draw from the case of photonics the broader lesson that the decline of American industrial capitalism in the 1980s occurred because of the domestic inability to plan.

SOURCES AND LIMITATIONS

The argument so briefly summarized above rests on a case study of the public response to the rise of photonic technology in the United States, especially in the years 1980–90.

The start of the decade saw the introduction of the word *photonics* in trade publications and research laboratories to express the technological possibilities seen in the convergence of traditional optics, lasers, fiber optics, optoelectronic imaging, and optoelectronic computing. By the end of the decade, the technology was absorbed into the operations and strategies of numerous industries and accounted for a substantial worldwide industrial sector. Though the technology had origins going back to the previous century, its full industrial flowering occurred in the decade of the 1980s. Importantly for the present argument, it was the same decade that saw widespread recognition of the internationalization of the U.S. economy and growing concern over declining U.S. industrial competence in world markets.

In looking at the public response to photonics in this decade, this study by and large restricts itself to research and development policy. This is not a desirable limitation, since the spread of the industrial applications of photonics is shaped by several kinds of policies. These include policies addressing technical training and advanced engineering education, military acquisitions, the deregulation of telecommunications, technological export controls, and technical standardization, as well as R & D. But if the study was to be practicable, its scope had to be narrowed. Hence, the limitation to R & D. Even the discussion of the U.S. agency that deals with standardization will concentrate on the agency's R & D effort, and not on standardization policy, though that in itself is an important component of industrial policy.

Unlike biotechnology and semiconductor technology, photonics (by that name or under other rubrics, such as optics) has remained uninvestigated in social-science literature. The present study therefore had to find its material in original sources. And since the subject is not well recognized and cataloged with regard to questions of public policy, the sources are various and disparate. Prominent among them are interviews with governmental, industrial, and university professionals concerned about photonics. Other sources include congressional hearings, articles in the general press, and back issues of the trade press (*Laser Focus World*, *Lasers and Optronics*, *OE Reports*, *Optics and Photonics News*, and *Photonics Spectra* by these or earlier names). Still other sources included a variety of what librarians call "fugitive materials": U.S. and foreign government documents, consultants' reports, brochures, draft documents, and so forth.

Now and then in the text, references appear to Rochester, New York, and its academic institutions. In part, Rochester's prominence just reflects that the research on this study was conducted there. More importantly, Rochester belongs in the text, since it continues as the traditional home of American optics, especially in its applications to imaging.

The argument that follows emerges, therefore, from an explicitly restricted scope of investigation. The scope encompasses the responses of one nation, the United States, to the emergence of one resource, photonic technology, in one decade, from the vantage of an author living in one city. The observations to be made all suffer from the limitations of a case study. The limitations being understood, the study builds on this case a broader argument on U.S. public response to technologies (and other resources, such as education and physical infrastructure) that are the common resources of capitalist industrial production.

THE ARGUMENT IN OUTLINE

The book is divided into eight chapters, of which the first is the present introduction. Chapter 2 defines photonics, traces its history, shows its commercial importance, and gives evidence of lagging U.S. performance in the technology relative to other nations, particularly Japan.

Chapter 3 argues that photonics should be considered a technological paradigm, because it exhibits integral properties of three kinds. First, photonics is (or is becoming) an integral body of knowledge, technical skill, and engineering practice. Second, photonics exhibits the properties of a system, because it comes into practical use through networks of interrelated devices and software. And third, the technology interweaves numerous industries that have become dependent on it or vulnerable to it. The photonics paradigm, therefore, cannot be properly understood as an assemblage of individual innovations.

Technological paradigms are not unique in having such properties. Paradigms fall under a broader class of common resources that includes physical infrastructure and educational and training resources. In these other collective resources, as in technological paradigms, the development of the resource becomes knowable. Nations (and regions) can use such knowledge to formulate public policy that responds to the development of the resource—to technological development in our case—and its industrial implications.

In a capitalist state equipped with institutions that can use such planning knowledge for coherent allocation of technological resources, private firms are better prepared than are firms in other states to take industrial advantage of a new technology. The concept of common resources then provides us with the principle by which we can assess policy responses to photonic technology.

As chapter 4 relates, photonics achieved its industrial importance in the 1980s, a decade of U.S. industrial retrogression relative to other capitalist nations. Since a nation accustomed to high standards of living would especially need to maintain its strength in technology-intensive production, the decade's declines in technologically advanced industries have been seen as the most disturbing. American industrial resurgence might then hinge on technology. What role, if any, should public policy have in reinvigorating technology?

The question occasioned a short-lived debate about industrial policy as a potential response to the decline. It was the outcome of the debate that while industrial policy was rejected by federal policymakers and mainstream intellectuals, it was widely implemented, but in sublimated, privatized form. It came to be known as "industry-university cooperation," "industry-led policy," "competitiveness policy," "defense industrial base policy," and "defense technology policy"—the euphemisms of privatization.

This was surely a curious result. By cherished belief, the U.S. would be expected to take the path mandated by tradition and by widespread depictions of its political economy. The U.S. would, in this view, act consistently with liberal economic principles and seek market solutions to technological change. If there were also to be ad hoc subsidies or protectionist measures, these were more or less frequent, more or less harmful exceptions. The political triumph of the opponents of industrial policy would be expected. It fit a capitalist state known for its market ideology.

To the contrary, however, the privatized response to photonics did not mean a return of technological decisions to the market. It meant, instead, that an interventionist economic policy came to be pursued under public-private, private, and military auspices.

To critics of industrial policy, such an outcome is distressing mainly because such policy is, from the start, misconceived economics. The privatization of policy-making then represents a species of bungling, just the sort of effect to be expected when government is given industrial responsibilities. Such policy is misguided less by dint of privatization than by the wrong-headedness of the policy itself.

If our assessment is to be any different from that of the opponents of industrial policy, then we must confront and find a flaw in their resolution of the industrial policy debate. Such an encounter should start with a definition. Industrial policy may be best defined as policy toward specific industrial sectors that operates through knowledge of, and judgment about, those sectors. The definition highlights the very issue on which the debate turned: the ability of government to make decisions that are better than those of the committed entrepreneur, technical researcher, and investor.

Advocates of industrial policy contended that certain sectors, especially certain critical technologies, were strategic to the broader performance of the economy, so they required special attention in policy-making. The opponents of industrial policy retorted that government policy might then have to target some technologies or industries, a process that would require detailed knowledge of economic sectors. Government bureaucrats, as their counter-argument went, would be put in a position of having to intelligently choose among sectors or even engage in planning, though such intelligence had frequently escaped them on previous occasions.

The opponents of industrial policy, therefore, posed as their paramount objection an argument about knowledge. They held that government would have less knowledge than private actors have in responding to technological opportunities. Government policymakers would then surely provide an inferior substitute for the technological decisions of self-motivated researchers, research managers, and venture capitalists.

But if superior private knowledge was the grain of the argument, an ideological presupposition was its kernel. The idea that private actors have better knowledge than public ones in technological choices makes the unexamined presumption that technology consists of a set of discrete inventions. When technical progress is conceived of as discrete inventions, private firms and inventors are no doubt the ones best suited to deciding which research projects and incipient inventions deserve further effort and have commercial potential. The argument about knowledge, as used by the opponents of industrial policy, rises or falls on the truth of this assumption.

The assumption is breached, however, if technological transformations like photonics have integral properties that exceed the intentions of individual decision-makers. In its integrality, technological change gains a measure of predictability. Individual decision-makers may become better at making technical decisions when they operate in a nation where technology is recognized as having such integral properties and where public policies anticipate and respond to technological change. If so, then we could assess privatized industrial policy by its ability to learn about, respond to, and plan for the structured relationships between technologies and industry.

Hence, chapter 4 provides us with a principle by which we can assess privatized industrial policy. By this principle, we should first ask whether an economic policy is indeed industrial policy (whether it operates through sector-specific knowledge). Then we should ask how privatization worked—how this unexpected kind of policy-making was actually carried out. Finally, we should ask whether such privatized sectoral policy had the ability to undertake the very kind of task that would give it an economic justification within capitalism, the task of responding with planning knowledge to the emergence of a technological paradigm as a common resource.

These questions pose a challenge to the rest of the study. The next three chapters, chapters 5 through 7, set out to assess privatized policy-making. At the risk of excessive schematization, such policy-making is divided into three forms: disaggregation, collaboration, and sheltering.

In *disaggregation*, public funds for technological research in photonics are distributed among beneficiaries, such as university researchers or research-performing businesses, that hold the most direct interests in research. In *collaboration*, a newer class of policies emerging largely since the late 1970s, centers of technical strength are established for the allocation of research resources. In these centers, the research agenda is set by industry-university or all-industry groupings that operate without formal governmental accountability for their technology policy decisions. Recognizing that there are overlaps in the technological needs of industry and the military agencies and that the military agencies afford some protection from factious politics, policy-makers and military bureaucrats also practice *sheltering*. In this form of industrial policy, research endeavors, meant to a significant extent for industrial purposes, are carried out under military agencies.

Disaggregation, collaboration, and sheltering, then, represent the three forms of privatization. But they do not constitute hard and fast distinctions. Every intermediate gradation and every combination of these forms has also been tried.

Discussion of the three forms of privatization is arranged roughly in ascending order, from a lesser to somewhat greater level of organizational capability to respond coherently to the rise of photonics. In disaggregation, examined in chapter 5, government's assets are distributed in cash or kind to universities, firms, and academic researchers through disparate decisions that bear no relationships to each other or to any articulated conception of what is to be accomplished with photonics. Three kinds of disaggregation are discussed: pork-barrel appropriations, business participation in government labs, and review panels that examine funding proposals according to criteria that assess technical merit.

In each kind of disaggregative policy-making examined, someone, somewhere made decisions about the dispersal of public funds specifically for photonics. Means included the strategic lobbying decisions of universities and their consultants, the log-rolling of the budgetary process, mutual consultations between agency employees and business participants, and the research funding decisions of "merit review" panels composed of industrial and academic participants.

Each form of decision-making had international competitiveness in photonics as an expressed purpose. But research policy decisions toward this end were made in large part by the potential beneficiaries of the policy, each beneficiary operating more or less in isolation from the others. None of the decision-makers sought or were given access to a broad conception of the industrial directions that photonic technology would take, except for such ideas that the participants may have collected through serendipitous experience. Disaggregative policy-making was indeed a form of privatized industrial policy directed at photonics, but it operated without any general knowledge of purposes or directions.

In the collaborative form of privatization, discussed in chapter 6, industrial consortia and industry-university committees made R & D decisions. Industrial research consortia came to have such authority in the 1980s when new federal legislation freed them to pursue joint research. Industry-university research centers were a more important kind of U.S. response to photonics. In the 1980s, federal and state governments established numerous university research centers specifically for photonics (or optics, optoelectronics, or fiber optics) research for the sake of industrial competitiveness.

Inevitably, committees composed of industrial affiliates and academic researchers served on boards of directors and as policymakers for the centers. These committees allocated research funds in the absence of a public role in the allocation decision.

The industry-university joint research centers differed from industrial participation in government labs and from anonymous peer review in that the centers potentially created productive interrelationships among researchers and could allocate funds according to some vision of industrial purposes. The knowledge by which the research centers were to accomplish such allocation was to be acquired through collaborative relationships between academic and industrial participants. But collaboration made the centers vulnerable, on the one hand, to the pressures of some business affiliates who wanted to use the center for cut-rate contract research and, on the other hand, to the contrary pressure of other corporate affiliates and faculty members who wanted to maintain professorial control over the research agenda. The research agenda in each center emerged from a resolution of this tension. The centers never formulated a means by which they could allocate research projects according to a more coherent notion of the effects of photonics.

Finally, in the form of privatization called "sheltering," examined in chapter 7, R & D programs directed at photonics and intended for industrial effect took place under the auspices of the military establishment. With well-developed technological forecasting abilities in the armed services, the military agencies could have been the ones to respond most coherently to initiatives intended to have them take a role in rescuing the civilian economy. Indeed, such a role had merit in military terms, since photonics had extensive military applications, probably more so than any other contemporary technology aside from electronic computing. Domestic suppliers for such a strategic technology were seen as essential to military preparedness.

Various military agencies pursued policies directed at specific industrial sectors to increase productivity, strengthen the ability to mobilize for war, or maintain viability in the face of foreign competition. Such programs could gain strong political support. Sheltered in obscure military bureaus, the programs managed both to serve the constituencies that support military appropriations and to mollify those opposed to explicit forms of economic intervention.

But military agencies responded with ambivalence to calls for their involvement in industrial policy. Programs oriented toward the civilian industrial technology base conflicted with cherished military priorities. In response to military worries and external political pressure, the agencies did set up disconnected research programs meant partly to strengthen civilian industy, but they never integrated them with the services' own technological priorities. And the agencies always had the incentive to simply make claims on industrial spinoffs and economic effects, without investing serious institutional effort toward such ends, since they would in any case not be formally taken to task for results. In military industrial policy, as in other forms of U.S. response to the rise of photonics, technological research programs emerged as a clutter of discrete choices made in the absence of broader vision and planning.

IN ANTICIPATION OF CONCLUSIONS

In the three forms of privatization, therefore, public decisions on technological priorities were driven to the nether worlds of budgetary negotiations, to public-private collaboration, and to the shadow of the military agencies. Each form of privatization failed by the very criterion that necessitates industrial policy: each failed to respond to photonics as a common resource in industrial production. The sum total of policy responses to the rise of photonics represented, in effect, an industrial policy targeted at photonics. But it turned out to be a debilitating industrial policy in which decisions on public ends were made without strategy, vision, planning, or public debate.

Chapter 8 concludes that photonics does not appear to be unique in the response it has elicited. The U.S. response to biotechnology and semiconductor technology also seems to have taken privatized forms. More generally, other collective resources, such as physical infrastructure and skilled knowledge in the labor force, seem to have integral characteristics, as technologies do. And urban land-use and job-training policy are similarly carried out through privatized policy-making bodies. Privatization, then, may well represent the characteristic means through which the United States allocates common industrial resources. Such a debilitating inability to plan bodes poorly in an era when U.S. industry must adjust to a world economy. Yet these privatized structures (and collaborative groups in particular) might themselves provide the institutional foundations for a more coherent and accountable U.S. industrial policy.