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Understanding Technological Responses of Industrial Firms to Environmental Problems: Implications for Government Policy

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TECHNOLOGICAL CHANGE AND POLLUTION PREVENTION

Technological change is now generally regarded as essential in achieving the next major advances in pollution reduction. The necessary technological changes must include: (1) the substitution of materials used as inputs, (2) process redesign, and (3) final product reformulation. Initiatives for focusing on technological change must address multimedia pollution and reflect fundamental shifts in the design of products and processes. Distinguished from end-of-pipe pollution control, those new initiatives are known as *pollution prevention*, *source reduction*, *toxics use reduction*, or *clean technology* (OECD 1987). The practices of in-process recycling and equipment modification are sometimes also included in the approach. The term *waste reduction* is also used, but it appears to be less precise and may not include air or water emissions. Pollution prevention has also been discussed as a preferred way for achieving sustainable development, giving rise to the term sustainable technology (Heaton et al. 1991).

This chapter argues that the key to success in pollution prevention is to influence managerial knowledge of and managerial attitudes toward both technological change and environmental concerns. Encouraging technological changes for production purposes (i.e., main business innovation) and for environmental compliance purposes must be seen as interrelated, rather than separable, activities that must be fully integrated (Ashford, Heaton, and Priest 1979; Kurz 1987; Rip and van den Belt 1988; Schot 1992). To bring about this integration, management must be committed to expanding the "problem space" of the engineer/scientist/technologist to include environmental and safety concerns so that those concerns are reflected in both design and operational criteria of a firm's technology. This may require a fundamental cultural shift in the firm. A related cultural shift in the regulatory agencies that influence how firms respond to environmental demands is also essential.

The above discussion addresses managerial factors that influence technological change. The technology of the firm, however, also influences managerial style and may limit the kind and extent of technological changes that are likely or possible. Thus, the design of governmental (or corporate) policies for encouraging a fundamental shift in the technologies of production must rest on an appreciation of the different kinds of technological change, as well as the dynamics of achieving those changes under a regulatory stimulus.

Technological Change Defined

Technological change can involve both technological innovation and diffusion. *Technological innovation* is both a significant determinant of economic growth and important for reducing health, safety, and environmental hazards.[1] It may be major, involving radical shifts in technology, or incremental, involving adaptation of prior technologies. Technological innovation is fundamentally different from *diffusion*, which is the widespread adoption of technology already developed. The term *technology transfer* is somewhat imprecise, sometimes referring to the diffusion of technology from government to industry, or from one industry to another. If that transfer involves significant modifications of the originating technology, the transfer can be said to result in incremental or minor innovation. Finally, the term *technology forcing* is used to describe regulation and is similarly imprecise, usually meaning forcing industry to innovate, but sometimes meaning forcing industry to adopt technology already developed and used elsewhere.

The Dynamics of Regulation-Induced Technological Change

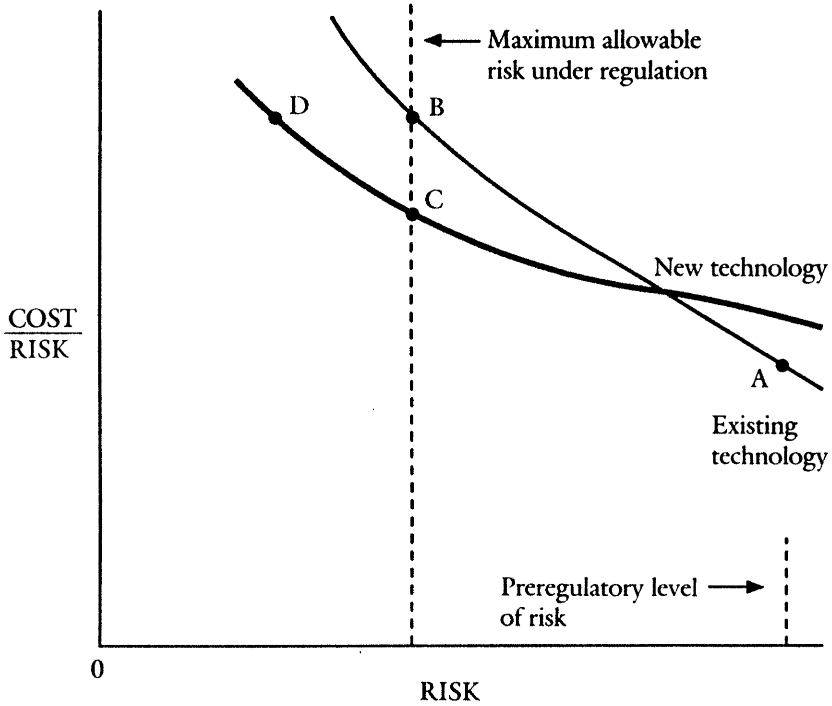
Several commentators and researchers have investigated the effects of regulation on technological change.[2] On the basis of this work and experience gained from the history of industrial responses to regulation during the past twenty years, it will later be argued that it is now possible to fashion regulatory strategies for eliciting the best possible technological response to achieve specific health, safety, or environmental goals. Underlying a regulatory strategy aimed at stimulating technological change and achieving a significant level of pollution prevention is a rejection of the premise that regulation must achieve a *balance* or compromise between environmental integrity and industrial growth, or between job safety and competition in world markets.[3] Rather, such a strategy builds on the thesis that health, safety, and environmental goals can be *co-optimized* with economic growth through technological innovation (Ashford, Ayers, and Stone 1985).[4] Although a new technology may be a more costly method of attaining current environmental standards, it may achieve stricter standards at less cost than adaptation of existing technology. Figure 10.1 illustrates the difference.

Suppose it is determined (by either market demand or regulatory fiat) that a reduction in health risk from point A in Figure 10.1 to the risk represented by the longer dotted line is desirable. Use of the most efficient existing technological capabilities would impose a cost represented by point B.[5] However, if it were possible to stimulate technological innovation, a new technology "supply curve" would arise, allowing the same degree of health risk reduction at a lower cost represented by point C. Alternatively, a greater degree of health protection could be afforded if expenditures equal to costs represented by point B were applied instead to new technological solutions represented by point D. Note that co-optimization resulting in "having your cake and eating it too" can occur because a new *dynamic* efficiency is achieved.[6] Because end-of-pipe approaches have been used for a long time and improvements in pollution control have probably reached a plateau, it is argued that the new technology curve or frontier will be occupied predominantly by pollution prevention technologies—that is, new products, inputs, or production processes. The use of initiatives to bring firms into environmental compliance using new technologies is termed ***innovation-driven pollution prevention***.

A MODEL OF THE EFFECTS OF REGULATION ON TECHNOLOGICAL CHANGE

Prior work has developed models for explaining the effects of regulation on technological change in the chemical, pharmaceutical, and automobile industries.[7] Figure 10.2 presents a modified model, structured to assist in

FIGURE 10.1.
AN INNOVATIVE RESPONSE TO REGULATION

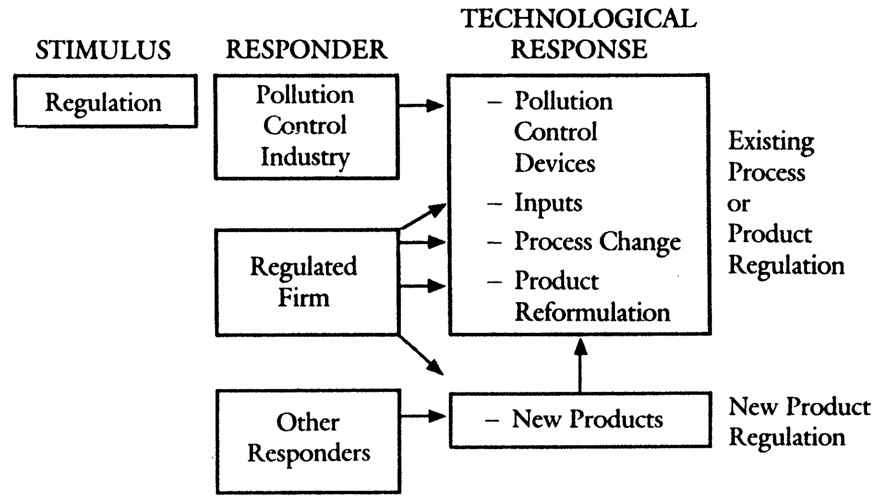


designing regulations and strategies for encouraging pollution prevention, rather than simply to trace the effects of regulation on innovation.

THE REGULATORY STIMULUS

Environmental, health, and safety regulations affecting the chemical-using or chemical-producing industry include controls on air quality, water quality, solid and hazardous waste, pesticides, food additives, pharmaceuticals, toxic substances, workplace health and safety, and consumer product safety.[8] These regulations control different aspects of development or production, change over time, and are "technology forcing" to different degrees.[9] Thus, designers of regulations should consider that the effects on technological innovation will differ among regulations that: (a) require demonstration of product safety prior to marketing (pesticides, food additives, pharmaceuticals, and, in some cases, new chemicals)[10]; (b)

FIGURE 10.2.
A MODEL FOR REGULATION-INDUCED TECHNOLOGICAL CHANGE



require demonstration of the efficacy of products prior to marketing (pharmaceuticals)[11]; (c) require proof of safety or the control of product use after marketing (existing chemicals under the Toxic Substances Control Act, worker protection, and consumer products)[12]; (d) control production technology to reduce risks to workplace health and safety[13]; and (e) control emissions, effluents, or wastes (air, water, and hazardous waste regulation).[14]

Furthermore, the internal structure of regulations may alter the general climate for innovation. Elements of that structure include: (a) the form of the regulation (product versus process regulation); (b) the mode (performance versus specification standards); (c) the time for compliance; (d) the uncertainty; (e) the stringency of the requirements; and (f) the existence of other economic incentives that complement the regulatory signal.

The distinction between regulation of products and regulation of processes suggests yet a further division.[15] New products differ from existing products, and production process components differ from unwanted by-products or pollutants.[16] Regulations relying on detailed specification standards or on "best available technology" may discourage innovation while prompting rapid diffusion of state-of-the-art technology. Similarly, although a phased-in compliance schedule may prompt only incremental improvements in technology, it allows a timely industry response.

An industry's perception of the need to alter its technological course often precedes promulgation of a regulation. Most environmental regulations arise only after extended scrutiny of a potential problem by government, citizens, workers, and industry. Prior scrutiny, according to a study done by the Massachusetts Institute of Technology,[17] often has greater effects on industry than formal rule making, because anticipation of regulation stimulates innovation. For example, formal regulation of polychlorinated biphenyls followed years after the government expressed initial concern. Aware of this concern, the original manufacturer and other chemical companies began to search for substitutes prior to regulation. Similarly, most firms in the asbestos products industry substantially complied with the Occupational Safety and Health Administration (OSHA) asbestos regulation years before it was promulgated. This preregulation period can allow industry time to develop compliance technologies, process changes, or product substitutes while allowing leeway for it to adjust to ensure continued production or future commercial innovation.

The government's initial show of concern is often, however, an unreliable stimulus to technological change. Both technical uncertainties and application of political pressures may cause uncertainty regarding future regulatory requirements. Nevertheless, some regulatory uncertainty is frequently beneficial. Although excessive regulatory uncertainty may cause industry inaction, too much certainty will stimulate only minimum compliance technology. Similarly, too frequent change of regulatory requirements may frustrate technological development.

Regulatory stringency is the most important factor influencing technological innovation. A regulation is stringent either (1) because compliance requires a *significant* reduction in exposure to toxic substances, (2) because compliance using existing technology is *costly*, or (3) because compliance requires a *significant* technological change. Policy considerations dictate different degrees of stringency as well, since some statutes require that standards be based predominantly on environmental, health, and safety concerns, some on existing technological capability, and others on the technology within reach of a vigorous research and development effort. In the early 1970s, most environmental, health, and safety regulations set standards at a level attainable by existing technology.[18] The regulations reflected both a perceived limit to legislative authority and substantial industry influence over the drafting of standards. More recent regulations have tended toward greater stringency but still rely on existing techniques, though in minority/rare use.[19] (Examples are the technology-based standards for hazardous substances under Section 112 of the 1990 Clean Air Act, requiring the use of maximum achievable control technology [MACT] or the lowest achievable emission rate [LAER] under the new source regulations of Section 111.)

The effect of the regulatory agency's strategy on innovation is not confined to standard setting. Innovation waivers,[20] which stimulate innovation by allowing noncompliance with existing regulation while encouraging the development of a new technology, are affected by enforcement strategies as well.[21] The degree to which the requirements of a regulation are strictly enforced may influence the willingness of an industrial sector to attempt to innovate. The implementing agency ultimately may strictly enforce environmental regulations against those firms receiving waivers or, alternatively, it may adopt a "fail-soft" strategy where a firm has made an imperfect effort but a good faith attempt to comply.[22] The latter strategy is an important element of the regulatory stimulus to innovate as it decreases an innovator's risk of incurring severe agency action in the event of failure. (Additional policy instruments to encourage pollution prevention are discussed later in this chapter.)

Characteristics of the Responding Industrial Sector

The industry responding to regulation may be the regulated industry, the pollution control industry, or another industry (see Figure 10.2). Regulation of existing chemical products or processes might elicit (1) a pollution control device, (2) input substitution, (3) a manufacturing process change, or (4) product reformulation. The regulated industry will likely develop new processes and change inputs; the pollution control industry, new devices; and either the regulated industry or new entrants, reformulated or new products. Regulation of new chemicals (i.e., premarket screening), however, will simply affect the development of new products.

Past research on the innovation process (in the absence of regulation) has focused on the innovation "dynamic" in diverse industrial segments throughout the economy.[23] The model there refers to a "productive segment" (a single product line) in industry, defined by the nature of its technology.[24] Over time, the nature and rate of innovation in the segment will change. Initially, the segment creates a market niche by selling a new product, superior in performance to the old technology it replaces. The new technology is typically unrefined, and product change occurs rapidly as technology improves.[25] Because of the rapid product change, the segment neglects process improvements in the early period. Later, however, as the product becomes better defined, more rapid process change occurs. In this middle period, the high rate of process change reflects the segment's need to compete on the basis of price rather than product performance. In the latter stages, both product and process change decline and the segment becomes static or rigid. At this point in its cycle, the segment may be vulnerable to invasion by new ideas or disruption by external forces that could cause a reversion to an earlier stage.

The Design of Strategies

The implications of this model of innovation relate directly to the design of strategies to promote innovation in three ways. First, the model suggests that innovation is predictable in a given industrial context. Second, it asserts that the characteristics of a particular technology determine the probable nature of future innovation within an industrial segment. Third, it describes a general process of industrial maturation that appears relatively uniform across different productive segments. That model does not, however, describe sources of innovation, nor does it elucidate the forces that may transform a mature segment into a more innovative one. (See Rip and van den Belt [1988] and Schot [1992] for insights into these dynamics.)

The value of this theory of innovation is that it provides a rationale upon which (1) the regulatory agency may fashion a regulation aimed at the industry most likely to achieve a regulatory goal and (2) the industry can plan its response to environmental problems. Consistently, the theory relies on the assumption that the regulatory designer may determine the extent of an industry's innovative rigidity (or flexibility) and its likely response to regulatory stimuli with reference to objective determinable criteria.

The regulatory designer must make the following three determinations:

1. What technological response is desirable? (For example, should the regulation force a product or a process change [see Rest and Ashford 1988] and, further, should the regulation promote diffusion of existing technology, simple adaptation, accelerated development of radical innovation already in progress, or radical innovation?)
2. Which industrial sector will most likely innovate?
3. What kind of regulation will most likely elicit the desired response?

The first determination requires a technological (or, more correctly, a technology options) assessment, the second a knowledge of a variety of industrial segments, and the third an application of the model considered in this chapter.[26]

A HISTORY OF REGULATION AND ITS EFFECTS ON INNOVATION

In prior work, a brief review of regulation and its effect on technological change was presented that provides empirical support for the model of

regulation-induced technological change discussed earlier in this chapter.[27] The review confirms that product regulations tend to call forth product innovations, that component or pollutant regulations[28] tend to elicit process innovations, and that the stringency of regulation is an important determinant of the degree of technological innovation.[29] In addition, the respondent's technological rigidity helps explain the particular technological solutions adopted.

The review was restricted to regulation between 1970 and 1985 under the U.S. Clean Air and Water Acts,[30] the Toxic Substances Control Act,[31] the Occupational Safety and Health Act,[32] and the Consumer Product Safety Act.[33]

Table 10.1 summarizes the pertinent characteristics of the ten regulatory cases considered in the review. In no case was the industrial response to regulation uniform. Even when the predominant response was highly innovative, a few firms selected a noninnovative solution and, in some cases, chose to exit from the industry rather than comply with the regulation. Conversely, some regulatory responses characterized as noninnovative included a few innovative solutions as well, but these were the exception in those industries.

The history demonstrates that standard setting can be used to encourage all the varieties of technological innovation as well as diffusion for both product and process change. The period from 1970 to 1985 reveals significant innovation and essential compliance with very stringent regulation.[34] Product-focused regulation primarily elicits a product response (substitution by existing products or a new product). Sometimes the new product (e.g., lead-free gasoline) is accompanied by significant process innovation as well.[35] Process-focused regulation can elicit either a process response or a product change. If a process restriction is stringent enough, product substitution may be the only practical response.

Stringency of regulation can be evaluated in terms of both the extent to which it reduces risks and the extent to which it forces development of new technology. Stringent regulations that do not require new technological solutions may appear sufficient but fall far short of their potential to achieve maximum protection. For example, the failure to adopt a 0.1 fiber/cc standard, the lowest level detectable, for worker asbestos exposure inhibited development of substitute products by the asbestos industry. The industry was able to comply with the 2 fiber/cc standard simply by installing existing pollution control equipment. By failing to adopt the more stringent standard, OSHA effectively inhibited new product development and product substitution. Thus, contrary to the widely held belief that too stringent a regulation inhibits innovation, in some cases a stan-

Table 10.1
A Summary of Recent Regulations and the Industrial Responses

Substance	Application	Regulatory Agency	Type of Regulation	Stringency	Industry Response: Degree	Industry Response: Type
PCBs	All	EPA	Product	Very Stringent*	Radical Incremental	Product Process
CFCs	Aerosol	EPA CPSC	Product	Very Stringent*	Radical Incremental	Process Product
Mercury	Paint	EPA	Product	Very Stringent	Diffusion	Product
Lead	Paint	CPSC	Product	Very Stringent	Diffusion	Product
Lead	Fuel Additive	EPA	Product	Very Stringent	Incremental	Product
Mercury	Chloralkali	EPA	Process	Stringent	Incremental Diffusion	Process Process
Lead	All Manufacture	OSHA	Process	Very Stringent*	Radical Diffusion	Both Process
Vinyl Chloride	All Manufacture	OSHA EPA	Process	Very Stringent*	Incremental Diffusion	Process Process
Cotton Dust	All Manufacture	OSHA	Process	Very Stringent	Diffusion	Process
Asbestos	All Manufacture	OSHA	Process	Mildly Stringent	Diffusion	Process

* Substantial doubt about the standard's technological feasibility at the time the standard was proposed.

dard that is not stringent enough may inhibit innovation. A more recent example, lax regulation of formaldehyde levels for occupationally exposed garment workers, similarly failed to stimulate new product development (Rest and Ashford 1988).

Stringency may be affected, in practice, by legislative directive of the agency issuing the regulation. For example, the EPA, OSHA, and the Consumer Product Safety Commission (CPSC) have different legislative mandates. The Office of Management and Budget (OMB) directed the EPA Office of Toxic Substances to construe the scope of its regulatory authority narrowly and to refer appropriate regulation to other agencies. In particular, the OMB directed the EPA not to ban three uses of asbestos, but to pass on the regulatory responsibility to OSHA. Since it has questionable authority to ban dangerous substances, OSHA could probably only regulate worker exposure in the manufacturing process or user industries.[36] Thus, the directives would provide for regulation of ambient levels, rather than a ban, encouraging the diffusion of ventilation technology rather than the substitution of new industrial products.[37]

Uncertainty in regulatory signals or agency position can also deter innovation. Faced with uncertainties that create risks that the technology developed will not ultimately be needed or will be unnecessarily costly, potentially innovative industries will simply adopt low-risk existing technology. Thus, only diffusion will occur. Both standard setting designed to encourage innovation and innovation waivers have encountered problems with regulatory uncertainty in the past.[38]

The preceding discussion focuses on the regulation of existing chemicals, though some new chemicals are developed as part of the technological response. If the EPA desires to encourage the development of new chemicals to replace toxic chemicals currently in use, it must take more definitive actions. First, it must be clear about its premanufacturing notification process by providing definite guidelines regarding the specific safety evaluations that should be undertaken on different classes of chemicals.[39] Second, it must increase the likelihood of market penetration by appropriate regulation of existing toxic chemicals. This consolidation of new and old chemical regulation is essential to effect the desired product transition.

Innovation waivers apply mostly to process change, are expressly innovation forcing, and do not promote diffusion. The regulatory designer seldom uses a waiver mechanism for promoting radical process innovation because of the long time generally necessary to develop the innovation. The waiver mechanism, however, might well encourage both incremental process innovation and acceleration of radical innovation already underway. Success requires the EPA to give early, clear, and certain signals to the

developer of the technology to minimize the risk of that technology being found unacceptable. Furthermore, good faith efforts resulting in significant, though incomplete, achievement of the pollution reduction goal should be rewarded by fail-soft strategies, using appropriate and adjustable economic sanctions.

Thus, the model of the effects of regulation on innovation applied to the history of standard setting and innovation waivers can contribute to more rational and deliberate design of regulation. The design should combine an assessment of the innovative capacity of the possible responding industrial sectors with levels and forms of regulation tailored to that capacity. The entire process should reflect a realistic evaluation of the best possible achievable technological goal. In that way, regulation can be used both to stimulate technological change for health, safety, and environmental purposes and to bring about a desirable restructuring of the industrial process.

POLLUTION PREVENTION: A NEW ETHIC OR NEW RHETORIC?

The current new emphasis on pollution prevention must be understood in a historical context. The regulations discussed in brief in the previous section had their origin in the 1970s, when somewhat aggressive government intervention was in vogue. The environmental progress and technology forcing that did occur resulted from clear and stringent regulatory requirements. Understandably, industry not only did not want to be "forced" to develop new technology, it did not want to be forced to make any technological changes that were costly or that compromised production efficiency. Government regulation was criticized as being too focused on "command and control," but for different reasons. Industry objected originally because regulation was seen to require (i.e., to command) unnecessarily low levels of permissible emissions or effluents—that is, the *stringency* of the regulations was objected to. On the other hand, some economists objected because they believed that economic measures such as pollution taxes that would affect the prices of inputs and final products were superior to mandated pollution levels for achieving environmental improvement—that is, the *method* of achieving compliance was objected to. In addition, industry and the economists argued that specification standards (of which there were precious few) stifled industry's use of more innovative and efficient ways to comply. Industry should be left to choose its method of complying. Industry, in fact, was never in favor of the economists' pollution charges, although pollution credits and trading did appeal to those industries that had pollution reduction capability to spare.

The 1980s ushered in an antiregulatory federal government whose philosophy was couched in rhetoric that rejected command and control regulation in favor of voluntary action. Carrots (economic incentives), rather than sticks, would be the governmental approach. But the term *voluntary* came to mean voluntary as to whether or not a firm would choose to comply. While existing regulations (on emissions and effluents) were not reversed, they were not vigorously enforced. Instead, new government regulations focused on information and reporting requirements (such as the reporting of emissions to air, water, and land in the Toxics Release Inventory [TRI] and the requirement to inform workers of toxic exposures) and on negotiated rather than government-dictated rule making. Given this antiregulatory era, how did it come about that pollution prevention was eventually endorsed by both government and industry? And just what kind of pollution prevention did they have in mind?

Although companies such as 3M had long argued that "pollution prevention pays," that rhetoric became identified with the idea that pollution prevention made good sense because it was grounded in the economic rationality of the industrial firm. It was argued that the firm, faced with its own hidden costs of pollution, and presented with the correct information, would change its operations to reduce environmental pollution. Industry began to embrace pollution prevention (initially without any deep understanding of what it meant), partly because the costs of waste disposal were becoming prohibitive and partly because pollution prevention contributed to a positive corporate image.[40]

Government, faced with renewed citizen demands for reduction of environmental pollution but still ideologically committed to economic instruments, began to realize if economic incentives were to reduce environmental pollution, those incentives had to be fashioned as supplements to, rather than as wholesale replacements for, regulations. Regulations continued to adhere to traditional emission and effluent restrictions and actually went even further in entertaining product phase-outs (e.g., for chlorofluorocarbons) and product bans (e.g., for asbestos). Rhetoric continued against command-and-control regulation, but now the objection that was voiced concerned overspecification of the means of achieving pollution reduction rather than the stringency of levels of pollution control. Government became increasingly committed to stringent (but flexibly implemented) regulation backed up by tough enforcement. How did industry come to accept this return of government to more serious concern with the environment?

The credibility of chemical-using and chemical-producing industries suffered greatly in the 1980s, and the fact that industrial product and emissions information was now accessible to citizens and workers through so-called right-to-know legislation (see Chapter 8) convinced companies that they must do something. The increasing prohibition on landfilling, cleanup costs at contaminated sites, and citizen action ended the do-nothing period for pollution prevention. But what, in fact, did industry do during the 1980s while waving the pollution prevention banner?

Several studies, to be discussed subsequently, throw light on the question. It turns out that, while pollution control technology was in situ, most industrial firms were not using the pollution prevention options open to them. Their first response was to undertake housekeeping changes and equipment modifications that could have been instituted much earlier had they perceived the federal government to be serious about environmental regulation. The firms also discovered that they could save money. Recycling increased and was financially attractive, partly because it was accompanied by material reclamation and partly because off-site waste treatment was becoming expensive. In other words, firms had been so suboptimal in their industrial operations that almost anything they did yielded an improvement in the efficiency of pollution abatement; referring to Figure 10.1 and the earlier discussion, firms were above the efficient frontier in their pollution control efforts (see also notes 5 and 6). What the record shows, however, is that input substitution, process redesign, and product reformulation were rare events. They were rare events because environmental requirements were not stringent enough on their face and/or because there was inadequate enforcement to force technological change.

Although a number of specific self-reports of individual accomplishments of "pollution prevention" in industry are found in the open literature,[41] three comprehensive and critical overviews compiled since 1985 discovered little fundamental technological change (INFORM 1985; OTA 1986; and EPA 1992).

The EPA has initiated several activities or programs that focus on pollution prevention: (1) the creation of the Office for Pollution Prevention, emphasizing source reduction in the manufacturing or use of chemicals and materials; (2) the creation of the Technology Innovation Office in the Office of Solid Waste and Emergency Response, emphasizing remediation technology; and (3) the creation of the National Advisory Council for Environmental Policy and Technology (NACEPT), addressing diffusion and innovation of all environmentally relevant technologies from pollution control to pollution prevention. NACEPT was created by former EPA administrator Lee Thomas to complement the science-oriented EPA Science Advisory Board with a technology-focused advisory committee. The council is working with various offices and divisions in the EPA to effectuate a cultural shift from preoccupation with risk assessment to promoting technological change.

The effects of all the above pollution prevention activities on the regulatory signals given to industry by the EPA are yet to be realized. Specific projects include: (1) negotiating pollution prevention responses into enforcement agreements with polluters, (2) revising water effluent standards to encourage pollution prevention, and (3) a "voluntary" program with industry to reduce emissions to air, water, and land of seventeen solvents and heavy metals by 33 percent and 50 percent by the end of 1992 and 1995, respectively, using source reduction and in-process recycling. (The seventeen solvents are among 189 hazardous substances whose emissions to air are to be regulated under the 1990 Clean Air Act. Thus, there may be regulation spurring the voluntary effort.)

BARRIERS TO POLLUTION PREVENTION

Even if strong signals are sent to a company to undertake pollution prevention, there may be both regulatory and industry barriers to a desired response. An appreciation of these barriers is important if successful pollution prevention policies are to be designed and implemented. The regulatory barriers for environmental technology innovation were recently addressed in a report by NACEPT focusing on permitting and compliance policy (EPA 1991a). Since the emphasis of this chapter is on the response of the firm, regulatory barriers are not discussed in detail here. The NACEPT report emphasizes a need for technological considerations in regulatory permitting and enforcement, to remove disincentives to innovate. A second NACEPT report (EPA 1991b) addresses regulatory barriers for the diffusion of technology and information relevant to pollution prevention and policies for overcoming them. (However, neither report addresses incorporating technological considerations in the design of regulation to stimulate innovation. Future work of NACEPT is expected to address that issue.)

In a report addressing problems with achieving waste reduction in the electroplating industry and in degreasing processes (New Jersey Report 1988), the authors identified a long list of mostly nonregulatory barriers to technological change and categorized them as follows:

1. *Technological:*

- Availability of technology for specific applications.
- Performance capability of technology under certain economic requirements and process design standards.
- Lack of (some) alternative substances to substitute for the hazardous components.
- Higher degree of sophistication with operation of some waste reduction technologies.
- Skepticism in performance of certain technologies and therefore a reluctance to invest.
- Process inflexibilities.

2. *Financial:*

- Research and development costs of technology.
- Costs related to risk of process changes with regard to consumer acceptance and product quality.
- Noncomprehensive cost evaluations and cost-benefit analysis as well as cost calculation method.
- Lack of understanding and difficulty in predicting future liability costs (e.g., of waste disposal).
- Short-term profitability calculations resulting in low tolerance for longer payback periods of equipment investment.
- Alleged drawback in competitiveness as other companies are not investing in waste reduction technologies.
- Lack of capital investment flexibility due to low profit margin.
- Economies of scale preventing smaller companies from investing in waste reduction options (e.g., in-plant recovery technologies).
- Possibilities that investment in process modification can be inefficient for old companies.
- Company financially (and even technically) tied up due to recent investment in wastewater treatment plant.
- Actual cost of current technologies masked in operating costs.

3. *Labor force–related:*

- Lack of person(s) in charge of management, control, and implementation of waste reduction technology.
- Reluctance to employ trained engineers for the alleged time-consuming design of waste reduction technologies.

- Inability to manage an additional program within the company and, therefore, reluctance to deal with a waste reduction program.
- Increased management requirements with implementation of waste reduction technologies.

4. *Regulatory:*

- Disincentives to invest in reuse and recovery technologies due to RCRA permit application requirements for recycling facilities in addition to compliance requirements, application costs, and so forth (work-intensive).
- Depreciation tax laws.
- RCRA waivers available only for hazardous waste treatment technology or process.
- Uncertainty about future environmental regulation.
- Regulatory focus on compliance by use of conventional end-of-pipe treatment technology (may result in investment in those treatment technologies rather than waste reduction technologies).
- Compliance with discharge standards, thus having "EPA off your back" provides no incentive to invest in waste reduction.

5. *Consumer-related:*

- Tight product specifications (e.g., military purposes).
- Risk of customer loss if output properties change slightly or if product cannot be delivered for a certain period.

6. *Supplier-related:*

- Lack of supplier support in terms of product advertising, good maintenance service, expertise of process adjustments, and so forth.

7. *Managerial:*

- Lack of top management commitment.
- Lack of engineering cooperation to break hierarchical separation of areas of responsibility (e.g., production engineers do not cooperate with environmental engineers in charge of the treatment and disposal of hazardous substances).
- Reluctance on principle to initiate change in the company ("Uncle John did it this way; therefore we are doing it the same way!").

- Lack of education, training, and motivation of employees (e.g., in good housekeeping methods or operation and maintenance of recovery technologies).
- Lack of expertise of supervisors.

Most of the barriers listed above can be disaggregated to a more detailed level. One could ask, for example, why there is a lack of top management commitment. This might be caused by various factors: (1) lack of information from the financial department to top management concerning the profitability of waste reduction technologies in general; (2) lack of confidence in performance of new technologies; (3) lack of managerial capacity and capital to deal with the transition costs of reorganizing the production process, educational programs, consumer demands, or discharge waivers; (4) lack of awareness of long-term benefits of waste reduction approach, resulting in waste reduction being a low-priority issue.

In discussing barriers and incentives for "waste reduction," the Office of Technology Assessment (OTA) concluded that:

> Proven technologies and the opportunities industries have for waste reduction do not themselves guarantee these technologies will be used. Factors that affect the ability and willingness of companies to implement waste reduction measures include:
>
> (1) the nature of the company's industrial processes,
> (2) the size and structure of the company,
> (3) technology and information available to the company,
> (4) attitudes and opinions that affect company operations,
> (5) the economics of waste reduction, and
> (6) government regulations.
>
> Whether these factors serve as constraints or incentives for waste reduction will vary even among different plants within the same company.
>
> Because the Federal Government's current waste minimization program is *voluntary* . . . , the degree to which these factors motivate or deter industry from waste reduction has determined the amount of waste reduction accomplished to date. Understanding these constraints and incentives is therefore essential for formulating Federal policy. They will affect regulatory options, for example, because the economics of waste reduction in different industries may influence the decisions government makes about mandating levels of waste reduction. However, these elements of industrial decisionmaking are particularly important in assessing nonregulatory Federal policy options. Nonregulatory programs rely on persuasion rather than on coercion to influence decisions. (OTA 1986, 94)

The reason for articulating the earlier long list of mostly nonregulatory barriers is to emphasize that significant government intervention, including carrots and sticks, may be necessary to stimulate change in industrial sectors bogged down with inertia and attitudinal problems. In the next section are addressed those policy mechanisms most likely to (1) give a clear, unambiguous regulatory signal, so that what is expected of a firm in terms of environmental performance becomes a definable goal for the firm, and (2) effect changes in managerial knowledge and attitudes toward undertaking technological changes both to improve productivity and to reduce environmental pollution. It should be emphasized that these policy mechanisms will not reduce all barriers. However, they will change the total environment in which the firm makes decisions and thus promote pollution prevention over end-of-pipe approaches to pollution reduction.

POLICY IMPLICATIONS

In twelve interviews conducted for this chapter with state and federal personnel administering pollution prevention initiatives, the overwhelming opinion was expressed that *stringent and certain* regulatory demands (such as emission, effluent, or exposure standards, or product bans and phase-outs) were necessary to effectuate pollution prevention. Economic instruments were seen as complements to, not substitutes for, regulatory requirements. The proper combination of stringent requirements with flexible means must then be designed with something specific in mind.

It was argued earlier in this chapter that regulations must be explicitly designed with technological considerations in mind—that is, they should be fashioned to elicit the type of technological response desired (see, for example, Rest and Ashford [1988]). Again, both stringency and flexibility (through innovation waivers or enforcement practices) are important. Enforcement and permitting procedures must augment, not frustrate, the regulatory signals. Regulatory design and implementation are largely in the hands of government, the exception being negotiated rule making or voluntary compliance efforts involving an industry-government effort.

Once the regulatory signals are crafted, a firm must be receptive to those signals that require change. It was argued earlier that a key to success in changing a firm is to influence both managerial knowledge and managerial attitudes affecting decision making involving both technological change and environmental concerns. Managerial knowledge, managerial attitudes,

and the technological character of the firm are not actually independent factors, although policies can be devised to affect each directly.

Relevant to managerial attitudes and decision processes, Karmali recently reviewed three different theoretical approaches that are useful in understanding what influences managerial attitudes that affect the willingness (or even the ability) of the technology-based firm to undergo change:

> *Technological determinism* is based on the principle that technological developments have their own dynamics and constraints that determine the direction of change even when stimulated by external forces.[42] *Economic determinism* considers the market and economic competition to be the main driving forces behind technological innovation. Essentially, this approach treats technology as a black box. Unlike the first two approaches, *social constructivism* attempts to move away from such unidirectional models and suggests that different social groups, such as the users of the technology and those potentially affected by it or its impacts, are able to exert influence on those who develop the technology. Any technological change is thus seen as the product of a dynamic interaction, rather than one driving force from inside or outside the firm. Social constructivism can thus be viewed as a means of bridging the gap between the organizational internalists and externalists discussed above. (Karmali 1990, 71)[43]

All these factors may well influence managerial attitudes and, hence, decision making toward environmental demands, but further, policy instruments that *per se* affect technology, as well as economic incentives and social relationships, can be used to influence the firm toward a more socially optimal technological response to environmental problems.

Decisions, of course, are also affected by the knowledge base of the firm. This can be improved by requiring the firm to identify technological options for source reduction and conduct throughput analysis (i.e., a materials accounting survey) (Hearne and Aucott 1991; National Academy of Sciences 1990) and by providing for technical assistance to firms, demonstration projects, continuing education of engineers and materials scientists, and the use of appropriate engineering consulting services (New Jersey Report 1988).

Table 10.2 lists the elements of solutions, both micro- and macropolicies, for employing a technology-focused risk management approach, coupled with policies that align important forces. (See also Chapter 9 for a discussion of similar policy initiatives utilizing government agencies and firm-focused prevention teams.) The policies fall into five groups: regulatory initiatives, technical assistance, economic instruments, stakeholder participation, and international policies.

TABLE 10.2
POLICIES TO PROMOTE CLEAN TECHNOLOGY

Regulatory Initiatives

- Shift attention from risk to risk reduction
- Focus on the appropriate target
  - —Individual hazards
  - —Industry sector
  - —Industrial processes
- Source reduction
  - —Input substitution
  - —Product reformulation
  - —Process redesign
- Multimedia focus, including worker health
- Coordination of environmental, energy, and industrial policies
- Design regulation to get the technology wanted
- Strict standards with flexible provisions

Technical Assistance

- Technical assistance to firms

Economic Instruments

- Tax policy
- Taxes on inputs and production
- Liability and financial responsibility

Stakeholder Participation

- Involve citizens and workers

International Policies

- Devise international policies

REGULATORY INITIATIVES

First, it is necessary to shift attention from assessing risk to identifying technologies for risk reduction. Second, the focus must be on appropriate targets. Risk assessment and federal regulations have focused historically on individual hazards. It is essential to think about whether regulating a whole industry would not be preferable, whether substituting one industry for another would not be preferable, or whether focusing on industrial processes, such as degreasing, that are common to many industries would not be preferable. Third, source reduction must be an integral part of a successful strategy—that is, changing the inputs, changing what industry

makes, and changing how industry makes it. Fourth, a multimedia focus is needed—not just on air, water, and waste, but taking the opportunity when redesigning technology to include concerns for worker health and consumer product safety, because worker exposure and indoor air pollution are generally the two greatest sources of human exposure. It would be a mistake to design technology optimally for reducing external pollution without optimizing the reduction of worker and consumer exposure. Environmental, consumer, and worker interests should be aligned with those of the firm. Fifth, coordination (i.e., co-optimization) of environmental, energy, and industrial policies is needed. In this case, interests that have gone about their goals independently in the past would be aligned. The common theme is the design of technology, not the control of hazards. The challenge is to meet energy needs, industrial growth needs, and environmental needs by means of new technology, a new deployment of resources, and the use of process engineers, chemists, and materials scientists to design safety into technology. Sixth, as already discussed at length, it is necessary to design regulation to get the technology desired, not simply to encourage adoption of the technology that exists. Strict standards are needed, but with flexible provisions to allow and encourage innovative responses by industry.

TECHNICAL ASSISTANCE

It is essential to provide technical assistance to the firms that are not in a position to innovate. This includes information transfer, demonstration projects, the education of consultants, and joint ventures.

ECONOMIC INSTRUMENTS

Although instruments might be described as economic incentives, they must have the force of law behind them in order to work. Tax policy for investment must be seriously reconsidered. In the United States extra tax incentives are given, in the form of accelerated depreciation, for pollution control equipment. Investments in new production technology are not similarly treated, so firms that have a choice whether to adopt a pollution control device or to change their technology are better off, dollar for dollar, buying from an environmental technology vendor at present. It is necessary to consider taxes on inputs and production to provide incentives to shift away from harmful materials. It is essential to emphasize liability and financial responsibility for both property/environmental and public health damage (Ashford, Moran, and Stone 1989; Ashford and Stone 1991). Nowhere have the effects of economic and financial incentives been seen as powerfully as in the liability area. The hazardous waste industry in the United States has been dramatically restructured as a result of forcing companies to come up with insurance policies or adequate collateral to pay for cleanup, and that has caused a dramatic shift in who stays in the business (Ashford, Moran, and Stone 1987). The same must be done for industries that produce and/or use chemicals.

Stakeholder Participation

Citizens and workers need to become involved. Especially where workplace hazards are concerned, "technology bargaining" must be encouraged between management and labor (Ashford and Ayers 1987). Whatever dramatic successes have been seen in the United States are in no small part due to the fact that the nation has an active consumer and labor movement and an informed citizenry through freedom of information. Even in other countries with Anglo-Saxon legal systems, such as Canada, England, and Australia, the same success has not been seen.

International Policies

Finally, international policies must be devised that focus on encouraging technology innovation and not on the transfer of inappropriate or environmentally outdated technology. Here interests are aligned on a global basis.

All these policies together—regulatory initiatives, technical assistance, economic instruments, stakeholder participation, and international policies—are the key to effecting technological and human behavioral changes through information transfer, regulation, and economic incentives. All are necessary elements, but in the last analysis it will take an artistic rather than a technocratic effort to bring about success.

NOTES

1. Technological innovation is the first commercially successful application of a new technical idea. By definition, it occurs in those institutions, primarily private profit-seeking firms, that compete in the marketplace. Innovation should be distinguished from invention, which is the development of a new technical idea, and from diffusion, which is the subsequent widespread adoption of an innovation by those who did not develop it. The distinction between innovation and diffusion is complicated by the fact that innovations can rarely be adopted by new users

without modification. When modifications are extensive, the result may be a new innovation. Definitions used in this chapter draw on a history of several years' work at the Center for Policy Alternatives at the Massachusetts Institute of Technology (MIT), beginning with a five-country study, *National Support for Science & Technology: An Explanation of the Foreign Experience*, CPA No. 75-121 (Cambridge, Mass.: MIT Center for Policy Alternatives, August 18, 1975). Some definitions appear in that study at pages 1–12.

2. R. Stewart, "Regulation, Innovation, and Administrative Law: A Conceptual Framework," *California Law Review* 69 (1981): 1256–1377; W. Magat, "The Effects of Environmental Regulation on Innovation," *Law & Contemporary Problems* 43 (Winter-Spring 1979): 4–25. For a review of earlier research at the MIT Center for Policy Alternatives and elsewhere, see N. Ashford and G. Heaton, "Regulation and Technological Innovation in the Chemical Industry," *Law & Contemporary Problems* 46(3) (Summer 1983): 109–57; and Ashford, Ayers, and Stone (1985). See also Irwin and Vergragt (1989); Kurz (1987); OECD (1985); and Rothwell and Walsh (1979).

3. Environmental, health, and safety regulation, as seen by economists, should correct market imperfections by internalizing the social costs of industrial production. Regulation results in a redistribution of the costs and benefits of industrial activity among manufacturers, employers, workers, consumers, and other citizens. Within the traditional economic paradigm, economically efficient solutions reflecting the proper *balance* between costs and benefits of given activities are the major concern.

4. The work of Burton Klein best describes the kind of industry and economic environment in which innovation flourishes (B. Klein, *Dynamic Economics* [Cambridge, Mass.: Harvard University Press, 1977]). Klein's work concerns the concept of dynamic efficiency, as opposed to the static economic efficiency of the traditional economic theorists. In a state of static efficiency, resources are used most effectively within a fixed set of alternatives. In contrast, dynamic efficiency takes into account a constantly shifting set of alternatives, particularly in the technological realm. Thus, a dynamic economy, industry, or firm is flexible and can respond effectively to a constantly changing external environment. Several conditions are critical to the achievement of dynamic efficiency. A dynamically efficient firm is open to technological development, has a relatively nonhierarchical structure, possesses a high level of internal and external communication, and shows a willingness to redefine organizational priorities as new opportunities emerge. Dynamically efficient industry groups are open to new entrants with superior technologies and encourage "rivalrous" behavior among industries already in the sector. In particular, dynamic efficiency flourishes in an environment that is conducive to entrepreneurial risk taking and does not reward those who adhere to the technological status quo. Thus, Klein emphasizes structuring a macroeconomy containing strong incentives for firms to change, adapt, and redefine the alternatives facing them. Regulation is one of several stimuli that can promote such a restructuring of a firm's market strategy.

5. The "existing technology" curve represents (the supply of) lowest-cost technologies from among less efficient existing technological options for achieving various levels of environmental risk. This curve is thus the present efficient frontier of existing pollution control and production technologies having different degrees of environmental risk.

6. If a particular firm was not using the most efficient existing technological option to achieve a certain level of risk, it would lie above the existing technology curve. The firm could improve its efficiency in risk management by either using better end-of-pipe control technology or engaging in pollution prevention, which could be accomplished if the firm changed its inputs, reformulated its final products, or altered its process technology by adopting technology *new to the firm*. This would be characterized as *diffusion*-driven pollution prevention, and the changes, while beneficial, would probably be suboptimal because the firm would achieve static, but not dynamic, efficiency.

7. See Ashford and Heaton, note 2. See also Ashford, Heaton, and Priest (1979, 161) and N. Ashford and G. Heaton, "The Effects of Health and Environmental Regulation on Technological Change in the Chemical Industry: Theory and Evidence," in *Federal Regulation and Chemical Innovation*, edited by C. Hill (Washington, D.C.: American Chemical Society, 1979), 45–66; Kurz (1987); and Rip and van den Belt (1988).

8. The statutes from which these regulatory systems derive their authority are as follows (in the order described in the text): Clean Air Act (CAA), 42 U.S.C. Sec. 7401–7642 (1990); Clean Water Act (CWA), 33 U.S.C. Sec. 1251–1376 (1982); Resource Conservation and Recovery Act (RCRA), 42 U.S.C. Sec. 6901–6987 (1982); Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), 7 U.S.C. 136–136y (1982); Federal Food, Drug, and Cosmetic Act (FDCA), 21 U.S.C. Sec. 301–392 (1982); Toxic Substances Control Act (TSCA), 15 U.S.C. Sec. 2601–2629 (1982); Occupational Safety and Health Act (OSHA), 29 U.S.C. Sec. 651–678 (1982); and Consumer Product Safety Act (CPSA), 15 U.S.C. Sec. 2051–2083 (1982).

9. Technology forcing here refers to the tendency of a regulation to force industry to develop new technology. Regulations may force development of new technology by different types of restrictions. For example, air and water pollution regulation focuses on end-of-pipe effluents. See, for example, CAA, Sec. 111, 112, 202, 42 U.S.C. Sec. 7411, 7412, 7521; CWA, Sec. 301, 33 U.S.C. Sec. 1311. OSHA, in contrast, regulates chemical exposures incident to the production process. See OSHA, Sec. 6, 29 U.S.C. Sec. 655. The FDCA, FIFRA, and TSCA impose a premarket approval process on new chemicals. See FDCA, Sec. 409, 505, 21 U.S.C. Sec. 348, 355; FIFRA, Sec. 3, 7 U.S.C. Sec. 136a; and TSCA, Sec. 5, 15 U.S.C. Sec. 2604. The degree of technology forcing ranges from pure "health-based" mandates, such as those in the ambient air quality standards of the CAA, to a technology diffusion standard, such as "best available technology" under the CWA. See CAA, Sec. 109(b)(1), 42 U.S.C. Sec. 7409(b)(1); CWA, 301(b), 33 U.S.C. Sec. 1311(b). For a discussion of this issue and a comparison of statutes, see B. LaPierre, "Technology-forcing and Federal Environmental Protection Statutes," *Iowa Law Review* 62 (1977): 771.

10. See FIFRA, Sec. 3, 7 U.S.C. Sec. 136a; FDCA, Sec. 409, 505, 21 U.S.C. Sec. 348, 355; TSCA, Sec. 5, 15 U.S.C. Sec. 2604.

11. See FDCA, Sec. 505, 21 U.S.C. Sec. 355.

12. See TSCA, Sec. 6, 15 U.S.C. Sec. 2605; OSHA, Sec. 6, 29 U.S.C. Sec. 655; and CPSA, Sec. 7, 15 U.S.C. Sec. 2056.

13. See OSHA, Sec. 3(8), 6, 29 U.S.C. Sec. 652(8), 655.

14. See generally CAA, 42 U.S.C. Sec. 7401–7642; CWA, 33 U.S.C. Sec. 1251–1376; and RCRA, 42 U.S.C. Sec. 6901–6987.

15. In practice, product and process regulations may be difficult to distinguish. If a process regulation is stringent enough, it effectively becomes a product ban. Product regulation generally gives rise to product substitution, and process regulation generally gives rise to process change. See *Federal Regulation and Chemical Innovation*, 58. See also, generally, Ashford and Heaton, note 2.

16. Note, however, that component regulations normally specify elements of the production process designed to prevent undesirable by-products. See note 29.

17. N. Ashford, D. Hattis, G. Heaton, et al., *Environmental/Safety Regulation and Technological Change in the U.S. Chemical Industry* (March 1979), Report to the National Science Foundation (CPA No. 79-6) (hereinafter cited as *CPA Chemical Industry Study*). Results of this study were published in *Federal Regulation and Chemical Innovation*.

18. See LaPierre, 837.

19. This historical review concentrates on regulations under the CAA, CWA, OSHA, CPSA, RCRA, and TSCA promulgated in the period 1970 to 1985.

20. See Ashford, Ayers, and Stone (1985).

21. The EPA has also recently initiated a pollution prevention element in enforcement negotiations for firms in violation of standards.

22. See Ashford, Ayers, and Stone (1985).

23. In particular, the work of Abernathy and Utterback offers an important model of the differences in the nature of innovation across industries and over time. See W. Abernathy and J. Utterback, "Patterns of Industrial Innovation," *Technology Review*, June-July 1978, 41. For a fuller discussion of the model in the context of regulation, see generally Ashford and Heaton, note 2.

24. Automobile engine manufacture would be a productive segment, as would vinyl chloride monomer production, but neither the automobile industry nor the vinyl chloride industry would be a productive segment since they both encompass too many diverse technologies.

25. It is typical for the old technology to improve as well, although incrementally, when a new approach challenges its dominance.

26. A research report by the MIT Center for Policy Alternatives may be useful to provide a further conceptual basis for designing regulation. See N. Ashford and R. Stone, *Evaluating the Economic Impact of Chemical Regulation: Methodological Issues* (February 1985) (CPA No. 85-01) (hereinafter cited as *CPA Economic*

Methodology Report). This research reviews and develops methodologies for assessing past and future dynamic regulatory impacts involving technological change.

27. See Ashford, Ayers, and Stone, note 2.

28. Component regulations specify undesirable elements of the production process, and pollutant regulations specify unwanted by-products of the production process. See *CPA Economic Methodology Report*, 26.

29. More precisely, a relatively high degree of stringency appears to be a necessary condition for inducing more innovative compliance responses. When stringency arises from technology-forcing characteristics of the regulation, the response tends to be more innovative.

30. See CAA, 42 U.S.C. Sec. 7401–7642 (1982); and CWA, 33 U.S.C. Sec. 1251–1376 (1982).

31. See 15 U.S.C. Sec. 2601–2629 (1982).

32. See 29 U.S.C. Sec. 651–678 (1982).

33. See 15 U.S.C. Sec. 2051–2083 (1982).

34. Compliance was achieved even though, in many cases, industry argued that compliance with the regulation was doubtful or impossible.

35. In the case of lead-free gasoline, the process innovation was a new cracking process.

36. Whether banning a substance for which a suitable substitute exists is a "feasible" regulatory action under OSHA is an untested subject. See OSHA, Sec. 6(b)(5) .29 U.S.C. Sec. 655(b)(5) (1982). Unlike OSHA, the CPSC has clear authority to ban dangerous products. Its authority, however, extends only to consumer products and not to the largely industrial products that were the subject of the proposed EPA referral. See CPSA, Sec. 2.8.15 U.S.C. Sec. 2051, 2057 (1982).

37. In Sweden, where asbestos has been banned in many applications, several substitutes have been introduced, many of which (particularly gaskets and friction products) have been developed by U.S. firms. See, for example, *Wisconsin Business Journal*, September 1972, 47.

38. See, for example, *International Harvester Co. v. Ruckelshaus,* 478 F.2d 615 (D.C. Cir. 1973), where the court remanded the EPA's decision to deny a one-year suspension of the deadline for strict auto emissions standards. The court observed that if the deadline were strictly enforced, and if any one of the major automobile manufacturers were unable to meet the deadline, "it is a likelihood that standards [would] be set to permit the high level of emission control achievable by the laggard" (638). In that event, the technological leader (Ford Motor Co.) would suffer detriment, having "tooled up to meet a higher standard than [would] ultimately be required" (638). The court was "haunted by the irony" of this situation (637). This kind of uncertainty over whether deadlines will be strictly enforced creates a disincentive to innovate.

39. See TSCA, Sec. 5, 15 U.S.C. Sec. 2604 (1982).

40. Increasing interest in pollution prevention is evident in the spawning of three new journals: *Pollution Prevention Review* (New York: Executive Enterprises Inc.); the *Journal of Clean Technology and Environmental Sciences* (Princeton, N.J.: Princeton Scientific Publishing Co.); and the *Journal of Cleaner Production* (Oxford: Butterworth Heinemann).

41. For a critique of efforts at 3M and DuPont, see Donahue (1991) and Doyle (1991), respectively.

42. Managerial attitudes and responses obviously are influenced by incentives and by the knowledge base, general practices, and procedures (i.e., culture) of the firm. Management's attitudes and responses to environmental problems may also be determined or constrained by the particular technology of the firm itself. There is a kind of "technological determinism" that influences not only what can be done, but also what *will* be done. For example, firms that have rigid production technologies (i.e., processes that are infrequently changed) are unlikely to have managers confident enough to embark on process changes. Certain technologies beget specific management styles—if not particular managers per se. There is probably also a managerial selection in and out of the technology-based firm. For example, if changing or reformulating the final product requires a process utilizing a different scale of production, the firm may not have managers experienced at operating at smaller (or larger) scales. Although much has been written on the influence of the organization of the firm (Karmali 1990; Kurz 1987; OTA 1986, 97–98 and 100; Schot 1992), it is the author's contention that the technology of the firm can determine corporate structure and attitudes as much as the other way around.

43. The reader is referred to research relied upon by Karmali in constructing his views. See Cramer et al. (1989); Cramer et al. (1990); OECD (1989); Rip and van den Belt (1988); and Schot (1992).

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