Regulation, Business, and Sustainable Development

The Antecedents of Environmentally Conscious Technological Innovation

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A growing number of firms have begun work toward the development of innovative systems that consume fewer resources, reduce waste, enhance productivity, while creating new market opportunities. However, all of this environmentally friendly innovation occurs under varying types/levels of regulation and the role of such regulation is still debatable. To date, little research exists that investigates the relative importance of market-driven versus regulatory actions in influencing environmental technological innovation. This article presents a model of the antecedents of environmentally conscious technological innovation under high and low amounts of regulation. The authors present four abbreviated case studies undertaken as part of a larger U.S. Environmental Protection Agency (EPA)–funded study that describe environmentally conscious product and process innovations in high and low regulation environments. The authors use the case studies to examine the extent to which the data support our model. The article concludes with a discussion of the implications of our findings.

Increasingly, businesses are adopting strategies that advance the societal goal of sustainable development by reducing the environmental impact of industrial products and manufacturing processes (Hart, 1997). Although still mired in the early stages of the transition toward sustainability, a growing number of firms have begun to actively engage their creative energies toward the development of organizational and technological systems that consume fewer resources, reduce waste, enhance productivity, and create new market opportunities. However, all of this change toward environmentally conscious manufacturing occurs under varying types and levels of regulation and the role of such regulation is still open to debate. To date, little research exists that investigates the relative importance of market-driven and government regulatory actions in influencing technological innovation that surpasses regulatory compliance (Alm, 1992). As such, it is not clear what role governmental regulations have played in stimulating techno-

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logical innovation of environmentally benign products. Furthermore, we have little evidence about the effects that regulated markets have had on the evolution of corporate environmental strategies that seek to meet consumer desires for improved environmental quality (Maxwell, 1996). This article presents a propositional, theoretical model of the antecedents of environmentally conscious technological innovation under high and low amounts of regulation. We then present four case studies that describe environmentally conscious product and process innovations that occurred in high- and low-regulation environments. We use the case studies to see how the data support our a priori model. The article concludes with a discussion of the implications of our findings.

Although a growing body of literature has suggested that environmentally conscious technological innovations can translate into improved corporate performance and reduced environmental impact, much of the evidence that supports this view has been largely anecdotal in character and with little theoretical structure (cf. DeSimone & Popoff, 1997; Gladwin, 1993). Moreover, the role of regulatory regimes in advancing environmentally conscious technology is also unclear because that role seems multifaceted (Ashford, 1993; Porter, 1991; Porter & van der Linde, 1995). To this end, Schot and Fischer (1993) have argued that more in-depth case studies be undertaken that employ theories developed within the framework of strategic management, organizational, and innovation studies.

The case study analyses in this article allow us to examine the research question, What are the forces that lead firms to innovate in green ways? Extensive research has occurred on the internal forces that lead firms to innovate per se (see Tornatzky and Fleischer [1990] for an extensive review of this literature). However, relatively little attention has been paid to forces outside the firm and their effects on innovation in general or green technological innovation in particular. Furthermore, there is a growing body of literature (e.g., Attewell, 1992; Brown, 1981; Eveland & Tornatzky, 1990) that suggests that new, more complex technologies (e.g., green processes) "require new perspectives better suited to understanding the dissemination of these technologies" (Attewell, 1992, p. 1).

We have narrowed the scope of our article to looking at the effects of the degree of regulation present on the adoption of green technological innovation. We have chosen this topic because of the ongoing debate as to the value of government intervention in environmental matters and because the literature that exists on the subject is not conclusive (see Rothwell, 1992). The research on the relationship of environmental regulation and technological innovation (e.g., Ashford & Heaton, 1983; Organization for Economic Cooperation and Development [OECD], 1985) only shows a weak, slightly negative effect (Office of Technology Assessment [OTA], 1994). Rothwell (1992) argues that the results have been equivocal because most of the research looked at the direct effects of regulation and not any indirect effects. In addition, Stewart and Wibberly (1980) argued that another problem with research on the regulation-innovation linkage is that only "highly aggregated measures of innovative output" have been used (p. 120).

In this article, we attempt to address both of the two previously mentioned shortcomings. In terms of an examination of indirect effects, we propose that rather than having a direct effect on innovation, the level of regulation moderates the relationships between three sets of factors and the development/adoption of green technological innovations. Specifically, we examine the moderating effects of regulation on innovation's relationship with the extent to which the firm's costs or profits are affected by the innovation, the level of both internal and external institutional pressure the firm faces, and the type of regulatory relationship that the firm has with its regulators. We also examine the direct effects on a firm of the innovations rather than aggregated reports of innovative output.

THEORETICAL FRAMEWORK

Two theoretically divergent views underscore our examination of the role of regulation in the stimulation of green technology. Transaction cost-economic (TCE) theory (e.g., Williamson, 1975) and institutional isomorphism theory (e.g., Dimaggio & Powell, 1983) act as our underpinning. There were several reasons why we chose these two theoretical perspectives to underscore our project. First, Eveland and Tornatzky (1990) argue that to understand innovation development, one must examine the context within which the developments occur. Our review of the innovation literature suggests that the two most compelling parts of the context are the economic challenges that firms face in developing green technological innovations and the institutional "barriers and facilitators to diffusion" (Attewell, 1992, p. 2).

From the beginnings of the innovation development literature (e.g., Mansfield, 1968), economics has played an important theoretical role. For innovation adoption specifically, we see the Williamson (1975) concept of markets or hierarchies as especially helpful. Whether a technically successful innovation is developed in a large measure depends on whether it is more profitable for a firm to do so. The adoption of the innovation implies that the innovation is more profitable than any other alternative. This decision is often made based on whether the firm's transaction costs are greater when internalizing the process or buying the innovative product or service from the marketplace.

We chose to look at institutional theory because it provides a basis by which we can examine both the external and internal social forces driving and preventing development of green technological innovations. We suggest that these external institutional mechanisms can be explained via Dimaggio and Powell's (1983) arguments about institutional isomorphism. The underpinning of institutional-isomorphism theory is that there are forces in the institutional context that pressure firms to be similar. These forces are classified as coercive (through law or regulation), normative (as a result of a dominant set of professional values), or mimetic (where the firm desires to be similar to a market-leading firm). We also see institutional forces inside the firm that force it to make choices that are consistent with internal institutional structures as opposed to those choices that might be more technically or economically rational (Meyer & Rowan, 1977).

Although TCE and institutional theories are compelling, we introduce a necessary third, theoretical element into our examination from the regulatory relationship literature (the relationship between the regulated and the regulator). For example, Rothwell (1992) suggests that there are several elements of the regulatory relationship that affect levels of innovation, for example, degree or intensity of the regulation, competence of the regulators, degree of cooperation in the establishment of the regulations, and so forth. He also suggests that these issues are growing in importance as successive U.S. administrations strive to make the regulatory process less burdensome, more participative, and more effective.

ECONOMIC PREDICTORS OF ENVIRONMENTALLY CONSCIOUS TECHNOLOGICAL INNOVATION DEVELOPMENT

The business firm cannot operate in the long term at a price point lower or a cost point higher than the intersection of marginal costs and marginal revenues (P). The only things that can change this point occur when something about the production process changes such that marginal production or transaction costs are lowered or the firm gains the ability to charge prices above "P." Unless green technological innovations allow the firm to lower costs or raise prices, it is unlikely to engage in innovation. When the firm faces little regulation, this argument is most likely to hold. Furthermore, in nonregulated markets, innovations from green technology are only one of many potential sources of innovation or competitive advantage. As such, green innovation ideas should compete with other innovations for managerial attention. As such, the probabilities are lower that any particular green innovation will occur. Thus,

> *Proposition 1:* Under low levels of regulation, the more that the development of any given environmentally friendly technological innovation decreases operating and/or transaction costs or allows the firm to increase prices, the more likely environmentally conscious technological innovation will occur.

Under high levels of regulation, the role that economics plays in the development of innovation is less clear. The OTA (1994) report on *Industry Technology and the Environment* suggests the following:

> Regulations can hinder innovation by diverting funds from capital investment in new plant and equipment and commercially oriented R & D. Because regulatory requirements are often stricter for new facilities . . . than for older plants, new investments may be discouraged. Finally regulation can increase the risk of innovation. If firms feel that regulations are likely to change so as to make pending innovations obsolete or unusable, they may wait until they receive clearer signals. (p. 285)

We adopt the OTA (1994) position as the basis of our next proposition:

Proposition 2a: Under high levels of regulation, firms are less likely to perceive economic incentives for environmentally conscious technological innovation development.

However, there may be situations in which the nature of the regulation is such that there are incentives for green technological innovation. Two approaches to regulation (i.e., pollution prevention and costs of pollution) may provide better incentives for innovation. Pollution prevention activities encourage firms to find ways to stop pollution from occurring rather than having to treat it after it occurs. The pollution prevention approach provides firms with a wide range of alternatives within which to explore. The more flexibility the firm has in meeting its environmental management targets, the more likely the firm is to develop or adopt green technological innovation. If the regulations impose large enough transaction costs on pollution emissions, firms have an incentive to find ways to reduce their pollution. In such markets, all participating firms have a similar marginal cost structure—due to the constraints that the regulations impose. These similar marginal cost structures provide little if any opportunity for competitive advantage. If a firm can find a way to reduce its environmental impact through greener technology, it may also lower its marginal cost structure and create pricing advantages for itself. If the incentive is strong enough, firms are more likely to develop green technological innovations. Each of these arguments leads to a proposition that is a corollary to Proposition 2a.

Proposition 2a.1: Under high levels of regulation, the more flexibility that a firm has to innovate, the more likely it is to perceive economic incentives for environmentally conscious technological innovation development.

Proposition 2a.2: Under high levels of regulation, the higher the costs are of pollution, the more likely the firm is to perceive economic incentives for environmentally conscious technological innovation development.

INSTITUTIONAL PREDICTORS OF ENVIRONMENTALLY CONSCIOUS TECHNOLOGICAL INNOVATION DEVELOPMENT

We have argued elsewhere (Sharfman, Ellington, & Meo, 1997) that much of the impetus on business firms to improve their environmental performance stems from institutional sources. Attewell (1992) argues that institutional theory is a potentially highly useful, albeit underused, theoretical basis for the study of innovation. We suggest that internal (cf. Meyer & Rowan, 1977) and external (cf. Dimaggio & Powell, 1983) institutional forces play a critical role in green technological innovation.

External institutional pressures—Low levels of regulation. We frame our examination of external institutional forces using Dimaggio and Powell's (1983) ideas about institutional isomorphism. In this theory, the authors suggest that there are three sets of forces causing firms to become isomorphic, that is, coercive, mimetic, and normative forces. Under low levels of environmental regulation, the coercive forces for green technological innovation are essentially nonexistent. As for normative isomorphic forces, they occur when some actor can influence the collective values of a focal firm. Often, normative isomorphic pressures occur when professional organizations issue statements or codes of professional conduct. Among the professional business associations concerned with natural environmental issues, one has exerted some normative isomorphic pressure. The International Chamber of Commerce has promulgated their "Business Charter for Sustainable Development." This statement covers a wide variety of environment/economic development issues including the need for green technological innovation.

Society itself plays a role in forming normative isomorphic pressures. Much of the general pressure in society toward increased environmental awareness comes from Reilly's (1990) argument that "once the present seems relatively secure, people can focus on the future" (p. 17). By this statement, Reilly suggests that as societies develop economically beyond subsistence, individuals within those societies shift their focus from immediate to long-term survival issues. The adoption of a long-term survival perspective is often coincident with increased environmental awareness and pressure on firms to be better environmental "citizens."

As for mimetic isomorphic forces pushing for green technological innovation, they are exerted in a variety of ways, including when market-leading firms exhibit behavior that other firms in the industry perceive a need to imitate. The well-known and highly visible members of the Global Environmental Management Initiative (GEMI) (e.g., AT&T, Dow Chemical, Duke Power, Du Pont, etc.) regularly tout their environmental activities as part of advertising programs. By forming GEMI and adopting its slogan ("To foster environmental excellence by business worldwide"), these firms set an example for other organizations to follow.

We suggest that the normative and mimetic isomorphic pressures described above have led to some small increases in green technological innovation. However, in markets with low levels of regulation, we suggest that most of the green technological innovation that has occurred has happened because of market or cost considerations (cf. Walley & Whitehead, 1994). Therefore:

> *Proposition 3:* Under low levels of regulation, the relationship of environmentally conscious technological innovation development to external institutional pressures will be positive.

External institutional pressures—High levels of regulation. When firms operate under high levels of environmental regulation, the third of Dimaggio and Powell's (1983) isomorphic forces (i.e., coercive isomorphism) plays a role. Dimaggio and Powell suggest that isomorphic pressures in general are highest in situations where firms have high levels of government interaction (e.g., highly regulated environments). We suggest that the presence of high levels of environmental regulation augments the pressure on firms from other sources in society to improve company environmental performance. As firms perceive this increased pressure, they are likely to search out new ways to respond to this pressure. As markets around the world get more competitive, firms often are faced with using technology to gain advantage (Porter, 1991). As such, when faced with high levels of isomorphic pressure for improved environmental performance, firms are more likely to turn to green technological innovations. Thus:

Proposition 4: Under high levels of regulation, the more that a firm perceives coercive isomorphic pressures for improved environmental management, the more likely it will be to develop environmentally conscious technological innovations.

There is also an institutional structure created by the presence of regulations. This institutional structure can also affect the degree to which firms are willing to develop environmentally conscious technological innovations. One element of the regulatory institutional structure is called "Technology Lock-In" (Environmental Protection Agency [EPA], 1993, p. 11). When a regulatory standard is based on a particular technology, "the engineering community and regulated parties are reluctant to depart from using the technology on which the standard is based and which EPA describes in the control technology guidance documents accompanying the regulation" (EPA, 1993, p. 11). By promulgating a regulation based on a particular technology, the regulator gives the technology in question the imprimatur of legitimacy. Innovators will face barriers to their innovations because "potential customers and their advisors are typically unwilling to risk non-compliance by using a relatively unknown and unproven technology" (EPA, 1993, p. 11). When technology lock-in occurs in an industry, we are less likely to see further innovation in that industry. Therefore:

Proposition 5: The greater the degree of technology lock-in is, the less likely that firms will be willing to develop environmentally conscious technological innovations.

Internal institutional pressures—Low levels of regulation. Internal to the organization, one is likely to see institutionalized structures that limit the likelihood of green technological innovation. Rigidly defined institutional structures in a firm are likely to impede green technological innovation. Of the elements that make an institutional structure in a firm rigid (cf. Rothwell, 1992), two components are likely to prevent the development of green technological innovation: (a) the presence of a well-developed political structure and (b) rigid organizational decision making as characterized by high corporate "hurdle rates" or inflexible approaches to discounted cash flows.

Although there is a great deal of variation in the extent to which firms exhibit political behavior, nearly all organizations exhibit some political activity in some sort of political structure. Political structures in organizations stem from the resource distribution inherent in them (Pfeffer & Salancik, 1978). The development of any innovation requires resources and, as such, in most organizations will require a resource redistribution. Because political structures in organizations seem resistant to change (Pfeffer, 1981), any attempt to gain resources for green technological innovation would likely face resistance. Thus,

Proposition 6: Under low levels of regulation, the more that political structures reduce the level of available resources to research and development, the less likely that environmentally conscious technological innovations will occur.

Managers often claim that much of their decision making follows what could be called Simon's (1945) "rational model." Inherent in this rational model are several different kinds of analytic tools, including financial analysis. Two of the financial tools that are most salient to innovation decision making are "hurdle rates" and discounted cash flows (OTA, 1994). Hurdle rates are internal return-on-investment targets that capital investments must meet or exceed to gain approval. Discounted cash flows allow firms to assess the future value of present-day investments based on a variety of criteria including costs of capital. Investment decision making often requires that specific future values be indicated in order for the capital investment to be approved. Rarely do hurdle rates or the targets for discounted cash flows stem from formal rules; rather, they develop as managerial preferences evolve and become a rigid, institutionalized part of the operation of the firm (cf. Meyer & Rowan, 1977). The rigid institutionalization of hurdle rates or of discounted cash flows can impede green technological innovation development. Innovations designed to reduce the firm's environmental impact may have few, direct effects on the "bottom line." Rather, these innovations may prevent future costs such as increased insurance rates, penalties, or cleanup costs. Alternatively, the effects on profits or costs from green innovations may occur in a time frame that is longer than the one used in standard discounted cash flows analyses (OTA, 1994). The longer period would cause the analytic tool to estimate lower discounted cash flows and therefore decrease the likelihood that a given capital expenditure would be approved. The use of rigid, institutionalized decision-making tools and rules restricts the level of green innovation. As such, *Proposition 7:* Under low levels of regulation, the more that firms use rigid decision-making rules and tools for evaluating environmentally conscious technological innovations, the less likely these innovations are to occur.

Internal institutional pressures—High levels of regulation. Under high levels of regulation, the increased isomorphic pressures and the presence of external threats may cause the members of the firm to either pull together and forget petty political concerns or try to find innovative ways to respond to the threat (cf. Dean, Sharfman, & Ford, 1991). Conditions of an external threat may cause managers to become more interested in the existence of the "pie" rather than about the size of their particular "piece." Once the external threat allows managers to put away their self-interests, the firm may have the impetus it needs to change internal systems that may no longer be responsive to current circumstances. As the firm searches for new ways to combat the external threat, we should see a concomitant rise in green technological innovation. Furthermore, as use of an innovation increases and it gains legitimacy, institutional pressures for its use may build inside the firm. Thus,

Proposition 8: Under high levels of regulation, the more flexible the internal response to external isomorphic pressures is, the more likely the firm will develop environmentally conscious technological innovations.

REGULATORY RELATIONSHIP PREDICTORS OF ENVIRONMENTALLY CONSCIOUS TECHNOLOGICAL INNOVATION DEVELOPMENT

Under conditions of low regulation, the relationship between the focal firm and its regulators is trivial so we do not offer any predictions about it. This section is concerned only with the relationship under conditions of high regulation. Consistent with Rothwell (1992), our review of this developing literature suggests that a key factor concerning the regulatory relationship affects the level of green technological innovation. This factor is the degree to which the regulatory process is participative. When firms are allowed to participate in the development and maintenance of regulatory standards, innovative solutions to problems are more likely. We have already discussed the role that types of regulation play in giving firms flexibility and the role this flexibility plays in green technological innovation. By allowing firms to participate in the regulatory process, they are more likely to be willing to take the risks to develop or adopt needed innovations. Anything that can be done to reduce the risks involved in green technological innovation will increase the likelihood that the innovation will occur (OTA, 1994). Therefore,

Proposition 9: The more participative a regulatory process, the higher the likelihood of environmentally conscious technological innovation development.

METHOD

CASE SELECTION

We selected the cases for this project to ensure variance across two critical dimensions. First, as innovations are classified as either product or process changes, we worked with the participating companies to ensure that two of our cases would examine process innovations and two would examine product innovations. The second dimension of interest was the degree of regulatory pressure within which the firm worked. Again, we looked at two dimensions. The first is what we called "normal" levels of regulation (i.e., standard Occupational Safety and Health Administration [OSHA], EPA, and Equal Employment Opportunity Commission [EEOC] regulations that all firms face). Our second class we broadly defined as "high" levels of regulation where a firm faced specific higher level scrutiny from regulations such as the Clean Air Act (CAA); Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); or the Resource Conservation and Recovery Act (RCRA). We then selected the cases (based on the criteria we outline below) so that we would have a process and a product innovation case in each of "normal" and "high" regulatory environments.

We chose cases to meet the following criteria:

1. The case had to have begun within the previous 2 years so that the participants would still be available and would have a reasonably clear memory of the events.
2. The cases had to involve an important change in the product or process that was motivated at least in part by environmental concerns.
3. The innovation had to be complete, that is, the product was on the market or the process change had been integrated into the ongoing efforts of the firm.
4. The innovation had to have been at least partially successful, that is, had accomplished at least some objectives the firm had for it.

DATA COLLECTION

We used a combination of interviews and reviews of archival materials to prepare the case studies. In consultation with our contact at each firm, we explained the criteria we describe above. With those contact people, we identified a set of candidate innovations. By examining each innovation in detail, we could winnow the cases down to the ones we describe below. Once we selected the final candidates, again in contact with the contact people, we identified those individuals who were most knowledgeable about the candidate innovations. Appointments were made to visit with the identified individuals. These people were either seen in a series of interviews during the same visit as in the Consumer Plastics Division and GreenKill cases or, because they were located at geographically disparate facilities, were seen individually as was the case with the Conoco and Verdigrease cases. For each interview, we used a standard interview protocol. We tape-recorded each interview and then reviewed these transcripts to identify trends, themes, and concepts related to our theoretical model. In most cases, two researchers attended each interview to allow for a comparison across perspectives. Once the interviews were completed, we approached the contact person in each firm to request any background documents that were available and relevant to the innovation under study. We examined these documents using the same style of informal content analysis that we used to review the transcripts of the interviews.

THE CASE STUDIES AND THEIR FINDINGS

We present the following case studies with the discussion oriented toward product and process innovations under high and low levels of regulations. Except for the Conoco case, the names of the firms and the individuals identified with them are completely fictitious pending approval by the participating corporations for public release of the completed case studies.

CASE STUDIES

Pestil, Inc.: A Case of High Regulation—Product Innovation

Pestil, Inc., an agricultural products manufacturer, was familiar with the many hurdles that had to be overcome to get a new insecticide registered for commercial use. EPA closely regulates agricultural chemicals, especially organophosphate insecticides, which are especially toxic compounds. Nevertheless, several scientists in Pestil's labs had become convinced that an organophosphate formula the firm had obtained through an earlier acquisition properly applied would be a significant improvement in controlling insects. The enthusiasm for the chemical was due to the fact that target agricultural pests could be killed in such a way that only a small amount of the active ingredient needed to be put at the critical location where it would remain active for a very long time without dissolving and washing away. It is well-known that farmers are exposed to toxic risks whenever they apply conventional insecticides. The scientists became convinced that their new product should be approved by the EPA because it could be applied in a way that greatly reduced these risks. Before that could happen, however, years of additional research, technology development, and field trials would be required to demonstrate the product's effectiveness and safety.

When Pestil Inc. bought the rights to "GreenKill," it had not planned to give much effort to the development and marketing of another insecticide. It appeared that the overall market was too small for a new product entry. Also, the company held the rights to the compound for the U.S. market only, the time required for meeting EPA standards was too long and costly, and there did not appear to be the potential for adequate profit because GreenKill's application was limited to only a few crops. Despite these setbacks, Pestil Inc.'s research staff argued that GreenKill had some extremely appealing properties that made it far safer for farmers to handle, that it could be applied in very small doses compared with existing insecticides, and that it held significant potential for revolutionizing the way farmers applied insecticides to their fields. The research staff argued that although the EPA had approved other organophosphate insecticides in the past, their environmental impact was still serious, and unless improvements were forthcoming, many existing products were not likely to receive reregistration under stringent regulations. As an alternative to the current product mix, it appeared to make sense for Pestil Inc. to develop the product along with a safe handling and delivery system to show the EPA how a truly effective and safe insecticide system could be developed.

The research team realized that it faced several challenges. First, farmers had been applying insecticides the same way for the past 35 years. They would empty bags of insecticide into a hopper attached to their tractor and apply into their fields. This was a very inefficient and often messy way to handle toxic compounds. On windy days, farmers could easily end up covered in insecticide far away from a shower or hose to rinse it off. The EPA recognized that repeated use of insecticides this way was an acknowledged risk to farmers, but there was scant incentive for product innovation to occur under the grandfathering scheme that permit approval granted. Second, the team realized that even if they could develop a delivery mechanism for GreenKill in the lab, Pestil Inc. lacked the technological expertise to develop and test a field delivery system that farmers would accept. For GreenKill to reach the marketing stage, Pestil Inc. would have to find a suitable partner who could design and develop the proper insecticide delivery system. Finally, the team realized that the new product would have to pass very tough regulatory standards that were far more stringent than what existing insecticides had to pass. They realized that the company would have to carry out several years of costly laboratory and field trials to show GreenKill's inherent toxicological advantages, and that Pestil Inc.'s management might lose its interest in the promising product. Someone had to "champion" the product.

By 1988, the research staff had figured out how to get GreenKill's active ingredient onto a delivery system that would enable it to protect crops from attack. The scientists used a dilute solution of GreenKill's active ingredient with a common material as a carrier. Once placed in the ground, the product would be less susceptible to runoff and dissolution. That same year, the company submitted its first request for registration by the EPA, which turned down the request 2 years later because the agency believed that the risk to nontarget species was too great. Then, the company resubmitted its request only to have the EPA request that the company conduct an additional set of toxicological studies on aquatic species. After the firm dug a set of test ponds at a cost of more than $1 million, the EPA stated that it would not review the terrestrial species data without the aquatic species data. These additional tests delayed the company an additional 2½ years. Although the EPA subsequently relaxed its requirements for test data, opting to review smaller, but more targeted studies, the agency later awarded the company a conditional registration that required a particular aquatic species study plus a worker exposure study. While the company engaged in the lengthy and costly process leading to registration, it also had to find a cost-effective way to get the chemical-laced particles to the critical area without exposing the farmer to toxic risks.

Through market research and a series of events, Pestil Inc. discovered that a farmer in the Midwest had developed a prototype for a very safe system for applying insecticides from his tractor. Using this prototype, Pestil Inc. formed a working partnership with farm equipment companies to refine the system further so that it could pass EPA's rigorous review and get to the market. After several years of technology development and field trials, Pestil Inc.'s research staff had seen their dream realized. Through very close collaboration with the partner companies' engineering and technical staffs, a system was developed that was fully functional from the tractor cab and that posed no risk of human contact with GreenKill. A preliminary version of the system was demonstrated to the EPA, which reacted positively to the technology. The regulators were extremely impressed and indicated to Pestil Inc. that they would try to move approval forward quickly and a final version of the delivery system was approved. The company had only a few more years of toxicological tests and human-risk field trials ahead of it. By the mid-1990s, field-testing of GreenKill to determine its toxic risk potential to birds, fish, and humans had cost the company more than $100 million. The company had conducted several field trials in different regions to compare GreenKill's performance with its seven competitor products.

For GreenKill to gain farmer acceptance, however, customers had to see for themselves what the advantages of the new product were. This would require the farmers to believe that the product was safer and more effective than other available products. The company moved aggressively toward its market launch date, but it also had to get passing grades on a final EPA test. Until the EPA was satisfied that humans were not at risk from use of the insecticide, the agency had required the company to carry a warning label on all packages that required operators to wear respirators when handling GreenKill. On the basis of its human exposure study, however, the company finally received EPA's permission to remove the warning label in 1996. In addition, Pestil Inc. initiated a bonus program in 1995 for farmers to try the new product on their crops. If farmers purchased the necessary equipment and used GreenKill, they could receive a rebate from the company for the cost of the product. In the last several years, the results have been positive. Pestil Inc. believes it has passed all the hurdles that EPA registration placed before it, farmers are beginning to adopt the product for its demonstrated qualities, and the risks to both humans and the environment have been reduced. While it has been training its field sales agents about the product, the company believes that they have helped to usher in the next generation technology for farm chemical applications and is optimistic about the future.

Conoco: A Case of High Regulation—Process Innovation

On November 15, 1990, CAA amendments were signed into law. This historic legislation established an aggressive program of newly mandated control requirements to address the crucially important air pollution problems of this nation. Although implementation of this massive legislation will carry through the year 2010, a sweeping new permit program would be in place by November 15, 1994 (Title V of the CAA). Recognizing the importance of continuous environmental improvement reflected in Conoco's voluntary environmental initiatives and the potential cost implications of the CAA, an interdisciplinary team of Conoco engineering, operations, and environmental personnel was formed to evaluate the impact of the new CAA on Corpus Christi Division operations. The team was also asked to look for cost-effective opportunities to decrease emissions and minimize environmental impact.

The first task at hand was to complete a computerized air emission inventory (called the Conoco Air Emissions System) for all division facilities and determine how many sites exceeded the air emission thresholds of Title V of the CAA. Division operations and environmental staff completed this task in the fall of 1993. Sixteen facilities were found to exceed CAA Title V and III emission thresholds.

The next step was to define the cost and workforce implications of the CAA on these 16 facilities. The high cost of obtaining and maintaining Title V permits and the limited workers available to comply with the stipulations of each permit focused the team on decreasing facility emissions below CAA Title V permit limits before the legislation became effective. A detailed analysis of each facility's major emission sources revealed significant potential for recovery of hydrocarbons normally vented to the atmosphere. Capture and reuse of these hydrocarbons would dramatically decrease division-wide emissions of volatile organic compounds (VOCs) and five separate hazardous air pollutants. This would also result in the recovery of significant amounts of lost revenue. It was critical that the team find good solutions to these emissions problems. Without timely internal solutions, the firm might be subject the CAA's maximum achievable control technology—something the firm wanted to avoid.

The team faced many important challenges in addressing the CAA. First and foremost, air emission controls used to reduce emissions must be protected under a "federally enforceable" document (such as a state permit) to claim or retain the emission reduction efficiency for that control and thus avoid CAA Title V permits. Monitoring was also required to ensure that the efficiency for the control device is achieved. State air permits, as with Title V permits, are costly and time-consuming; the challenge for the team was to find an alternative means of establishing enforceable emission limits with the state. A strategy of registration under standard exemption for production facilities, which included acceptable monitoring for each control device, was used.

The next key challenge was that all emission reduction modifications and formal standard exemption registrations had to be completed before EPA's approval of the State Title V permit program—November 15, 1994. Division personnel had 9 months to complete modifications at 16 facilities and prepare and submit lengthy registration applications for 15 facilities.

Finally, the team had to achieve a reduction of 2,196 tons per year of VOC emissions and 463 tons per year of hazardous air pollutants at 11 facilities without increasing the electrical load at each facility (the local electric company could not supply additional power over the existing distribution system). Primary sources of these emissions were separator flash gas, generated as the liquid hydrocarbons drop in pressure through each successive stage of separation, and VOCs liberated from glycol dehydration systems (flash tanks and reboiler still columns). In addition, the hazardous air pollutants consisted of compounds such as benzene, toluene, and xylene from storage tanks with no controls and from compressors emitting NO_x.

The previous process had worked as follows: Gas, oil, and water were reduced simultaneously by pressure and gravity separation from a high pressure well. There were several stages needed to get the liquids out of those separators and into storage tanks. Once the product was separated, it was sold either by truck or by pipeline. Water was disposed of by means of injection wells. Gas was taken off directly from the separator. The pressure was reduced using a high-pressure separator and the material was put into the pipeline directly. Then, the condensate in the low-pressure gas wells would come into an intermediate or low-pressure tank. The gas or water, "water three phase" (three-phase separated gas/oil/water), each went into its respective tank. The gas went to a compressor where it was compressed to pipeline pressure and then sold. Before Conoco sold natural gas, they ran it through a tower-based, glycol dehydration system. In this type of system, glycol drips down through several trays in this tower, and gas is funneled up through the tower to absorb any remaining moisture. The glycol was pumped back to what is called a regenerator. The regenerator reheated the condensate, which flashed the water out of the glycol and then sent it back through the same process.

Although the systems worked reasonably well, problems were discovered. Some of the sources of emissions were "fugitive" leaks in the valves and connections where the gas was being transferred, which meant that the company was losing a valuable product. In addition, the components of natural gas themselves are greenhouse gases (GHGs) and hence under increased scrutiny. While the company was investigating the implications of Title V and Title III, it was discovered (by the industry) that these regenerators emit many hazardous air pollutants. The glycol had an affinity for the heavier, hazardous air pollutants, such as benzenes, ethylbenzene, xylene, toluene, and so forth. When the condensate was recycled in the regeneration process, the hazardous air pollutants would be discharged into the air with the water.

Once this discovery was made, it was relatively easy to convince upper-level management of the need to do something. A consensus formed rather quickly that an engineering solution was necessary to recover the hydrocarbons. Management became convinced easily because the team could pinpoint clearly the projected benefits; specifically, the firm would avoid any future regulations, no matter how stringent, and at the same time would have a rapid payback on the investment. The consensus among the Conoco personnel members who were interviewed was that the threat of future CAA regulatory obligations was the principal incentive to begin this initiative.

THE SOLUTION

The solution, although not brand-new technology, did meet the challenges identified by the team. Jeff Mitchell, process engineer for the team, described it as follows:

> We put together different technologies . . . we basically just took a finned-tube heat exchanger, put it on an elevation, built a base for it, put that on an elevation, and fabricated a chimney for it, to draw a natural draft up through it, so that we could take the still column vapors off through this finned-tube heat exchanger and condense them to a liquid. (This would then) go into a vessel from which we could then pump back to our storage tanks to sell. We capture water and a little bit of condensate off that. So, it can actually make us some money. The vapors that will not condense are rerouted back to the fire-tube heater where we rigged up a mixing valve and a burner assembly to combust them. I broke up our dehydration units into three classes: up to 10 million a day cubic feet of gas, up to 20 million, and up to 35 million, and I sat down with a simulation program and calculated what kind of heat exchange tube area I needed to condense this 220-degree vapor, . . . just did the modeling to see what kind of volume we had, and said, all right, I need "x" number of tubes, and so forth. Then I sketched it up and when we went out to bid. We said, these are three types of (we call them condenser packages) that we want somebody to build for us. Here's what we want, here's how we want the stand, and we need 40-1/2 inch or 40-1 inch tubes with 1/2-inch bands on them and then this chimney thing on top.

The beauty of this approach was that it was a closed system with no electric power involved. Besides capturing what had previously been emitted, the technology recaptured the flash gas off the separators and then routed it to compressors for fuel for the on-site equipment. All of this occurred in the presence of high-temperature gas coming off this generator and hot ambient site temperatures.

THE BUSINESS CASE

While DuPont (Conoco's parent company at the time) has a corporate commitment to zero emissions, environmental investments still have to make business sense. In this particular case, the results from the investment were striking. For a total equipment investment of $560,000, the team was able to reduce emissions below CAA permit levels at the 16 facilities within the division that had exceeded CAA Title V limits plus:

- Recovery of $210,000 per year worth of vent gas for use as fuel and the elimination of two gas recovery compressors, saving $35,000 per year in operation costs.
- Aromatic Recovery Unit (ARU) condensation of hydrocarbon liquids from glycol reboiler still columns; 3,633 barrels per year valued at $58,128 per year (based on $16.00 per barrel).
- Average cost savings per facility of $34,000 in CAA Title V permit preparation costs. A total onetime cost savings of $510,000 (initial permit costs). This does not include similar costs for permit amendments, which would be required for future facility modifications.
- Elimination of enhanced monitoring (continuous electronic stack monitoring of air pollutant concentration) on 17 specific sources at an average cost of $105,000 per monitor (onetime cost—purchase and installation). A total onetime cost savings of $1,785,000.
- Average annual cost savings of $66,000 per facility in monitoring equipment operation and maintenance costs, compliance certification, quarterly data-reporting requirements, and record keeping. A total annual cost savings of $990,000.
- Elimination of annual air emission fees of $94,801 (under rule 101.27).
- Cost savings achieved through reduction of emissions below CAA Title III thresholds, thereby eliminating the need for maximum achievable control technology on dehydration systems, storage tanks, and fugitive emission sources at 11 facilities. For these 11 facilities, this equates to savings of $240,000 in capital costs; $158,000 per year in operating costs; and $116,000 per year in monitoring, inspection, record-keeping, and reporting costs.

THE ENVIRONMENTAL CASE

The environmental achievements from this innovation are also striking. The firm reduced its overall emissions by 884 tons per year of NO_x, 2,365 tons per year of VOCs, 76.1 tons per year of benzene, 14.6 tons per year of ethylbenzene, 180.1 tons per year of toluene, 204.1 tons per year of xylene, and 20.1 tons per year of n-hexane. For the division, these emission reductions vastly exceed the internal goal of a one-third reduction of toxic air emissions.

Verdigrease Co.: A Case of Low Regulation—Product Innovation

Verdigrease Co. manufactures lubricants and oils from petroleum products and markets them to a variety of businesses involved in mining, recreation, construction, and related industries. In the wake of the 1990 CAA, Verdigrease Co. had become concerned that its customers were obligated to discontinue their reliance of lubricants that contained chlorinated solvents. In addition, the company had realized that numerous state and local environmental quality standards were becoming more strict with respect to the environmental pathways and fate of open-gear lubricants when they dripped onto the ground. If the company did not begin to investigate alternative product development soon, there was a growing chance that it might risk losing its market share to other products that were more environmentally conscious. This was a risk that Verdigrease Co. did not wish to take, and so it began to develop a biodegradable lubricant that would meet with customer approval. It also found a feedstock that was treated as a waste product in another part of the company and thus turned two problems into a green solution.

In 1992, engineers at Verdigrease Co. began to think through the implications of tightening environmental regulations for their customers. Although its products were well received in the market, the company did not have as much visibility as it would have liked. If the company could develop a new product that could help its customers avoid potential penalties and fines, the company's engineers thought that the company could attain recognition as an industry leader and secure its market. Recent conversations company representatives had with customers indicated that few if any of them had the necessary resources to develop a lubricant that would be able to meet more strict environmental standards, and a few large customers, notably copper- and gold-mining companies, were concerned about the future. In response to this challenge, Verdigrease Co. convened a team to plan a new product development strategy and see it through to success.

The team was composed of almost a dozen individuals, several of whom had spent time in the field and the laboratory. Because of the complementary mix of technical skills that the team had and the novel nature of the challenge, the team thought of itself as a "skunk works" kind of operation in which ideas could be actively pursued. The team consisted of individuals from synthetics, mining, and distribution to ensure that all views could be worked together. Upper management gave its approval for the team to meet regularly and carry out its agreed-upon tasks. Although the team members were spread out over a wide geographic region, they were able to schedule regular meetings every 5 or 6 months at an airport hub city. The team was absolved of the routine responsibility to get written permission or approvals for trials and encouraged to "just do it" by management. This attitude sat well with the team members because every one of them was, in fact, a volunteer and was excited by the intellectual challenge of the task.

Early on someone suggested that one of the waste streams at Verdigrease Co. might be transformed into a kind of lubricant. The argument was made that by heating certain esters in a chemical waste, a biodegradable lubricant might be developed. If the resultant product had the attributes that its customers favored plus the ability to biodegrade, Verdigrease Co.'s customers could avoid a growing number of regulatory compliance headaches. With this in mind, the team began to carry out several experiments and the results looked very promising.

Not only was a large portion of the waste stream able to be used; the resultant compound was able to pass biological tests for degradability. The next step was to find out whether the customers would approve of the use of the experimental lubricant in their expensive equipment.

When the novel lubricant was applied in the field, several problems became quickly evident. First, the experimental lubricant was too "drippy" and failed to stick to moving surfaces for as long as conventional lubricants. The novel mixture also was almost clear. Although this is not necessarily bad in itself, it was a drawback for the equipment operators because they could not tell at a glance whether additional lubricant needed to be put on the gears. Both issues were easily solved back at the plant. With some additional tinkering with the chemical process, the viscosity of the lubricant was altered to make it thicker. By adding a powdered material to the liquid, it was given color. With additional tests, the team was able to document equipment energy savings from decreased operating temperatures and extended gear life in the mining equipment. Due to the familiarity and confidence that equipment operators placed in their conventional lubricants, these benefits were not an immediate sell. The new lubricant had to perform as well as, if not better than, the lubricant it was to replace. After 4 years of continuous improvement, the team accomplished this goal.

Happily, the team has been able to address all of its technical concerns and make a profitable product as well. Initial product placement has occurred and sales are growing slowly. The lubricant innovation helped build Verdigrease Co.'s image as a preferred lubricant supplier and has opened up new markets for the company.

CONSUMER PLASTICS DIVISION (CPD) and the Introduction of Postconsumer Recycle: A Case of Low Regulation—Process Innovation

CPD manufactures plastic that is used by a variety of manufacturers to produce several different types of consumer products. At the beginning of the 1990s, CPD was starting to get questions from its major customers with regard to the environmental characteristics of the material it produced. These questions ranged from "Is it biodegradable?" to "Is it recyclable?" In reality, these were not questions the company had asked. However, the questions were easy to answer once the firm started looking into it. Their material was a high-grade, processed polyethylene, so although it was not biodegradable, it was recyclable. However, just knowing that the product was recyclable was not sufficient. Many of CPD's customers were government contractors and were thus under the strictures of federal purchasing guidelines. The Clinton administration issued several executive orders concerning the recycled content of various products the government purchased. As such, being recyclable was not sufficient; the product had to have recycled content. What made matters even worse was the underlying idea in these purchasing standards that the recycled content be postconsumer as well. It was not sufficient just to reuse factory scrap. Rather, the federal guidelines strongly intimated the need to pull recyclable material out of the general waste stream. The pressure from customers was clear—change the product or we will take our business elsewhere. This threat was made more salient because it was the unit's two largest customers that were the strongest proponents of adding postconsumer recycle (PCR). Given that CPD's product was simply processed polyethylene, one might think that accommodating these customers would be easy. Unfortunately that was not so. The first major problem was a conflict between marketing and production. CPD prided itself on the purity of its product. Its manufacturing unit had spent more than two decades perfecting the production process and reaching the industry's highest level of average outgoing quality. Our interview data suggest that when the marketing staff (where the idea originated) brought the idea to the production staff, the factory folks's first reaction was laughter. "You want to push trash in our product???—You've got to be kidding!!!" was how the reaction was reported to us. The second reaction was much simpler—"*No*." The toughest marketing task was winning over the production personnel.

Once the production staff had been induced to cooperate (thanks to some corporate-level intervention), the problems had just begun. Although there are literally thousands of tons of low-cost, high-density polyethylene (HDPE) in the recycle stream, there is a problem with nearly all of it—it is dirty. By far the largest component of the HDPE comes from milk jugs. There is a wide range of contaminants present ranging from the label, to the label's glue, to dried milk, to dust and dirt from the recycling bins, to who knows what else. Given the production process that CPD used, even very small amounts of contaminants could ruin an entire batch. The task was daunting. Much of the recycled HDPE at the time was going into applications (e.g., plastic lumber, detergent bottles, etc.) where high purity levels were not as much of an issue. As such, no supplier of high-purity PCR HDPE existed. CPD attempted to work with both suppliers and the plastics trade associations to develop a supplier who could deliver the quality level they needed. Finally, after a few unsuccessful alliances, CPD was finally able to find a cooperative supplier.

Then the technological problems surfaced. The desire for quality had to be matched with the technical ability to clean the HDPE stream. With the amount and variety of contaminants in the recycle stream, the firm faced a variety of technical filter and filter-cleaning problems. A series of cooperative efforts with the supplier finally managed to overcome these obstacles.

DISCUSSION

In this section we examine the propositions in light of the cases. For each proposition, we show which of the cases applies and whether the case supported the proposition or not. Proposition 1 examines the extent to which *the develop-*

ment of any given environmentally friendly technological innovation decreases costs or allows the firm to increases prices leads to innovation. Each case had a strong business case inherent in it. However, the Conoco case most clearly shows the power of economics in green technological innovation. In this case, the team was able to develop a technological solution that removed the firm from the strictures (i.e., the transaction costs) of the CAA. The team's charge had been to find the least costly way to survive the new regulations. With some creativity, the team developed a solution that not only saved an enormous amount of money but also generated positive cash flow.

In the CPD case, the economic issue was the protection of business. CPD was told to change the product or its major customers would take their business elsewhere. As such, the firm was working to maintain revenues, not save money or increase prices.

In the GreenKill case, the innovation was done to take advantage of an opportunity. The company had a potentially lucrative new product *if* it could get it through the regulatory process. By innovating both the product itself as well as the delivery system, the firm was able to bring out a product with very good profit potential.

As for Verdigrease Co, the issue was again an opportunity. The team of scientists had determined that the waste stream had some very interesting properties and potentials. By identifying a market niche, the team was able to pursue a specialist strategy into a new market.

Proposition 2 argued that *under high levels of regulation, firms are less likely to perceive economic incentives for environmentally conscious technological innovation development.* The data from the Conoco case seem to contradict this argument. The strictures of the CAA were so tight and the costs of compliance so high that the firm perceived a very large economic incentive to innovate. Perhaps there is a threshold effect operating here. Firms may not see much economic incentive to innovate until the strictures from the regulation increase beyond a certain level—probably where the marginal costs of regulation are high enough to be painful.

The other "high-regulation" case was the GreenKill case. In this circumstance, the project team argued that the potential returns from the pesticide were high enough to overcome the costs of regulation, thereby making it through the firm's project approval process.

Proposition 2a.1 argued that *under high levels of regulation, the more flexibility that a firm has to innovate, the more likely they are to perceive economic incentives for environmentally conscious technological innovation.* The GreenKill case supports this argument. The project team in this case was given wide latitude to pursue the product; however, this was only after the business case had been made. The organizational flexibility in this case was present only because the business argument had been made. It would not have been present without such stellar predictions from the project team.

In the Conoco case, organizational flexibility was not an issue. The firm had a large economic problem in the form of the CAA. The team was charged with fixing that problem in an economically reasonable way. Once they developed the technology, the rest was easy.

Proposition 2a.2 argued that *under high levels of regulation, the higher the costs of pollution are, the more likely the firm is to perceive economic incentives for environmentally conscious technological innovation.* Again, the Conoco case strongly supports this proposition. Permitting alone under the CAA would have cost the firm millions—not to mention the potential fines if permitted levels were exceeded. As such, the firm had a huge incentive to pursue this innovation based on the costs of pollution.

In the other regulated case (GreenKill), the costs of pollution were not an issue. In this case, the firm had to pass the regulatory hoops to be able to market the product so there were no costs of pollution unless the firm got a product to market.

In Proposition 3, we argued that *under low levels of regulation, the relationship of environmentally conscious technological innovation development to external institutional pressures will be positive.* Neither of the two low-regulation cases show much direct evidence of institutional forces at work. In the CPD case, the main impetus for the innovation was market pressure. However, institutional pressure in terms of federal purchases guidelines did play an indirect role in helping develop the market for the PCR product.

In the Verdigrease Co. case, the threat of potential groundwater regulation also served as an impetus for the development of the market for the product. In this case, the potential of institutional coercive pressure on customers (cf. Dimaggio & Powell, 1983) from future regulation was sufficient to provide customers with the incentive to try the new product.

Proposition 4 argued that *under high levels of regulation, the more that a firm perceives coercive isomorphic pressures for improved environmental management, the more likely it will be to develop environmentally conscious technological innovations.* We see the effects of coercive institutional pressures in both the Conoco and GreenKill cases where the relevant regulations were much stricter and required major increases in environmental performance. In both these cases, the regulations as coercive institutional forces directed the activities of the innovations in question.

In Proposition 5, we argued that *the greater the degree of technology lock-in is, the less likely that firms will be willing to develop environmentally conscious technological innovations.* In neither of the high-regulation cases we studied was technology lock-in a direct factor. In the GreenKill case, there was no prescribed technology as the EPA did not want to approve additional organophosphate insecticides. In the Conoco case, the fear of technology lock-in served as a motivator to the company that pushed it toward the technical solution it developed. So in one way, the proposition was disconfirmed as the threat of technology lock-in through the CAA's maximum available control technology stimulated rather than restrained the innovation.

Proposition 6 suggests that *under low levels of regulation, the more that political structures reduce the level of available resources to research and development, the less likely that environmentally conscious technological innovations will occur.* In neither the CPD or the Verdigrease Co. case do we see much in the way of political influences. In the CPD case, the only political action of note was when the production personnel originally resisted the introduction of PCR. Although that was a "power play" of sorts, that group was eventually won over by the other members of the team. And even though their resistance did slow things down somewhat, it really did not throw the innovation off its trajectory.

In Proposition 7, we asserted that *under low levels of regulation, the more that firms use rigid decision-making rules and tools for evaluating environmentally conscious technological innovations, the less likely these innovations are to occur.* In all four of the cases (not just the low-regulation ones), the innovations in question were required to pass each respective firm's internal budget allocation processes. One of the key difficulties that potential environmental innovations face is that quantifying their economic benefits is sometimes difficult when using traditional tools such as return on investment. In the high-regulation situations, the presence or threat of new, strict regulation often adds sufficient justification for investments that might not make it through the normal review process. The Verdigrease Co. case supports this proposition because the team had some difficulty passing the internal decision-making hurdles. To do so, they had to spend valuable time developing justifications that could have been spent working on the innovation itself or its marketing. In the CPD case, the firm was in danger of losing major portions of its business so the normal decision-making criteria were not as important. The issue in that case was saving the business with as little damage to margins as was possible.

In Proposition 8, we argued that *under high levels of regulation, the more flexible the internal response is to external isomorphic pressures, the more likely the firm will develop environmentally conscious technological innovations.* We see some support for this proposition in the GreenKill case. The EPA changed the rules as the firm worked its way through the certification process. Without the internal flexibility to respond to these changes, the innovation would have never happened. In the Conoco case, flexibility was not an issue as the threat of the CAA loomed so large. Although the firm had to have some flexibility to even be willing to pursue alternatives, the technical solution dominated any organizational drivers or impediments.

In Proposition 9, we argued that *the more participative a regulatory process, the higher the likelihood of environmentally conscious technological innovation development.* Although there was almost no interaction between the regulators and Conoco, in the GreenKill case, the relationship that developed with the regulators seems to have been crucial. As the GreenKill chemistry and technology were novel, it was incumbent on the firm to iterate back and forth with the regulators even as they were changing the rules. The participants were quite clear that without a good working relationship with the EPA, GreenKill would have never been approved.

CONCLUSION

We see from the above discussion that most elements of our model received some level of support. Those propositions that addressed the economics of innovation under high regulation seem to have been the most strongly supported—particularly Propositions 1 and 2a.2. These results were as expected. Economic incentives have always been motivators for innovation—we predicted that the same would hold true for environmental innovation.

One novel contribution from the cases is that regulations provide not only economic incentives but also institutional pressure, so their stimulating effects on innovation occur in a variety of ways. We see that the federal purchasing guidelines directly helped create the market for CPD's introduction of the PCR product. Potential groundwater regulations helped build the market for Verdigrease Co., and the institutionalized negative perceptions of organophosphates forced Pestil Inc. to develop both a better formulation and a novel delivery system for GreenKill.

We also saw modest support for the technology lock-in proposition. It was not the lock-in per se that motivated the innovation but simply the fear of being subjected to it that stimulated Conoco to develop a technology on its own that would get it out from under the CAA.

Our predictions about restrictive decision rules and political behavior were not strongly supported. Although each decision had to pass hurdles, the fact that the innovations occurred showed that they did. To get a clearer sense of the effects of decision rules, we would need to study a population of proposals that included ones that did not make it past decision rules. As for political issues, again given that these innovations occurred means that they survived the political battles. To see the effects of politics, we would also need to see proposals that were killed via politics.

We also see that participative regulatory relationships are helpful. In the GreenKill case, the firm would have never been able to develop the new product without the help of the EPA regulators.

Finally, there are two new constructs to be added to the model. The preservation of autonomy and/or flexibility of operations was a major motivating factor in the Conoco and GreenKill cases. In each case, the firm used innovation to be able to pursue its business operations the way it so chose. With the Conoco case, the firm maintained autonomy by not having to permit under the CAA. In the GreenKill case, the firm was able to market a product that it believed in despite initial heavy opposition. By innovating in environmentally conscious ways, the firm improved the product, lessened its environmental impact, and increased its market share.

Second, we see the market beginning to view environmental factors as increasingly important business factors. In the CPD case, the market demanded the firm change its product. In the Verdigrease Co. case, the market saw the product as an answer to potential future problems. In the GreenKill case, the market perceived the product as having competitive advantages over competing products. Companies are now more able to innovate in ways that markets will richly reward.

In this article, we presented a theoretical model of the process of environmentally conscious technological innovation. We then presented four case studies of firms that had innovated in such ways. We showed how each element of the model received greater or less support and how some new elements emerged to be added to the model. Finally, we discussed how our model adds to the literature on innovation. We have shown that environmentally conscious technological innovation emerges in theoretically predictable ways. As we develop a richer understanding of how this emergence occurs, we will be in a better position to help firms as they wish to engage in such innovative efforts.

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