When Does Environmental Regulation Stimulate Technological Innovation?

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Some experts argue there is an inherent tension between environmental regulation and technological innovation. Others argue that they are complementary. Neither of these positions is right all of the time.

Environmental regulation usually requires businesses to take actions they would not take in response to market forces alone.[1] Compliance with regulation should reduce the damage to the air, land, water, and living creatures that would have been caused by market-motivated business activity. Although these benefits are often difficult to measure, they outweigh the costs when regulation is well designed.

Technological innovation allows businesses to sell new products and services and to reduce costs by introducing new production processes. It is a very important cause of improvements in living standards in modern society. A majority of long-term economic growth is attributable to technological innovation.[2]

Some experts argue there is an inherent tension between environmental regulation and technological innovation. Environmental regulation deters risk taking that leads to innovation, according to their view. When complying with regulation, firms use well-established methods to minimize uncertainty, even when doing so is costly. Also, spending on regulatory compliance may crowd out alternative investments that might otherwise have led to valuable innovations.[3]

Other experts argue that environmental regulation and technological innovation are complementary. They hold that the need to comply with regulation stimulates businesses to explore neglected technological pathways—which leads to the development of new and improved products and processes. Environmental regulation, from this perspective, is a win for both the public and the regulated industry, because the resulting innovations reduce or even eliminate the cost of compliance even as they limit pollution.[4]

Neither of these polar positions is right all of the time. The Zero Emission Vehicle regulation California established in 1990 is a good example of the tension between environmental regulation and technological innovation. This regulation had to be scaled

back when automakers were unable to produce cars that could comply with it at a reasonable cost.[5] Regulation implementing the Clean Air Act of 1970, which required electric utilities to install scrubbers to remove pollutants from power plant smokestacks, on the other hand, illustrates the possibility of complementarity. Innovation yielded scrubbers that were relatively inexpensive, confounding industry predictions of imminent regulation-induced bankruptcy.[6]

These two examples demonstrate the importance of identifying the conditions under which environmental regulation stimulates technological innovation.[7] My review of a growing expert literature on the topic yielded 12 such conditions, which are elaborated in this report:

1. Compliance with regulation is expected to be expensive.
2. Higher authorities are unlikely to force regulators to relax.
3. The threat of regulatory enforcement is legitimate and credible.
4. Industry expects regulation to become increasingly stringent over time.
5. The technological landscape for regulatory compliance is target-rich.
6. Regulated firms have slack resources.
7. The regulated industry is competitive.
8. Prospects for shifting production to "pollution havens" are limited.
9. Regulators rely on performance standards.
10. The regulatory process induces an open exchange of information.
11. Regulators have a sophisticated understanding of the regulated industry.
12. Technology policy complements regulation.

The presence of each condition raises the likelihood that firms will respond to environmental regulation by innovating. But the literature does not show any single condition (or even a combination of conditions) to be a magic bullet that will ensure this outcome in any particular case. Nor does it suggest all 12 must be present for innovation to occur.

Even though the literature does not yield simple prescriptions for environmental policymakers, this list of conditions allows them to diagnose complex situations, so that their actions increase the odds of an innovative response to regulation. To do so, they should adopt an open-minded, patient, long-term, and goal-oriented approach.

In the next section, I define the key terms of this long-running argument among experts and explain why it is important enough to occasionally take on a quasi-religious tone. Brief sections follow, covering each of the 12 conditions that influence whether environmental regulation will stimulate technological innovation. The report concludes by spelling out some rules of thumb to guide environmental policymakers.

INNOVATION AND REGULATION: FROM HEAT TO LIGHT

Pollution is the classic negative economic externality. If a company making steel (or computer chips or anything else) can dump its waste into a nearby pond (or landfill or any other place) for free, it keeps its costs down—even if the waste ultimately harms a third

party. The purpose of environmental regulation is to avoid imposing this harm on the third party, who is external to the transaction. Regulation forces the would-be polluter to pay for pollution control, thereby internalizing the cost of avoiding the harm.

One big debate in environmental policy swirls around this cost. Particularly when the harm is uncertain or far in the future, firms forced to pay a large cost now to avoid this harm will object to being regulated. Take, for example, the wastewater from the steel mill in the previous paragraph. Although it might contain toxins that, in high doses administered in a laboratory, have been shown to kill mice, it could take scientists decades to determine whether real-world concentrations of those same toxins could cause serious harm to people or ecosystems. The cost of avoiding real-world exposure, however, would be borne by the company immediately.

If the levels of such toxins could be reduced at very little cost, the steel mill's objection to being regulated would lose force. Such is the promise of technological innovation. The innovation could be a filter installed at the "end of the pipe" to eliminate the effluent, or a change in the steel-making process that reduces the use of a toxic substance inside the plant. If this kind of technological fix is cheap and easy, the benefits of regulation are more likely to outweigh its costs, because the costs would go down.

Like the harm that might be caused by pollution, technological innovation that reduces the cost of regulatory compliance is usually uncertain. Until firms conduct research and development (R&D) on pollution control, they do not know whether innovation is feasible, and until they implement the results of R&D in practice, they do not know what it would cost.

These twin uncertainties often lead experts who study the relationship between environmental regulation and technological innovation to fall back on preexisting assumptions. If one believes competition is fierce and firms are constantly optimizing their production processes in order to sustain slim profit margins—as many economists do—the notion they are overlooking cheap and easy technological fixes that would reduce pollution seems ludicrous. "There's no such thing as a free lunch," their motto goes, and such innovations look suspiciously like just that.

If one believes, however, that firms are creatures of habit that tend to follow the same standard operating procedures (SOPs) as long as their key stakeholders are happy—as many management scholars do—then shaking up those SOPs might lead to unexpected discoveries, including cheap and easy fixes to pollution. Under these assumptions, regulation can do the shaking up. Indeed, the most famous hypothesis in the literature, named after Michael Porter of Harvard Business School, goes beyond the claim that innovation stimulated by environmental regulation reduces the cost of compliance and states that it can make firms better off. In other words, they become both "green and competitive,"—which also happens to be the title of an article in which Porter advanced his hypothesis.[8]

The Porter hypothesis has stimulated a lot of research over the past 25 years. For better or worse, this research has not yielded a simple right or wrong verdict. One recent, massive review concluded there is "considerable heterogeneity" in the findings of this body of work.[9] Yet, because the Porter hypothesis challenges the fundamental assumptions of economists and has important policy implications, the debate about it has often been heated.

As long as this debate is framed around a simple yes-or-no question, it is bound to generate more heat than light. Environmental regulation and technological innovation are both complex phenomena. There is no good reason to expect the relationship between them should be simple. It makes more sense to expect complexity. The heterogeneous findings in the literature should not be denied, but rather, used. They allow us to unpack the complexity of the relationship and identify conditions that make an innovative outcome more likely in any particular case.

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The fact that the relationship between environmental regulation and technological innovation plays out over time—years or even decades—adds to its complexity. Regulators and regulated firms learn about one another, anticipate one another's moves, and adapt their behavior as they interact. Many of the conditions on which the relationship depends must therefore be understood in terms of the evolving mutual perceptions and expectations among these players. Nicholas Ashford of MIT, who pioneered research on this topic, put it this way in 1979, "Regulation is not a simple, single-point-in-time phenomenon that elicits an industrial response."[10] Or, as Rene Kemp, another leader in the field has stated, "The stimulus-response model is too simple."[11]

The alternatives available to firms faced with environmental regulation also influence their responses to it. Firms may choose to take political or legal action designed to obstruct or alter regulation, rather than simply comply with it. They may be able to shift the location or tempo of their activities in order to limit its impact. They may be able to comply without undertaking innovation. These choices, too, may evolve over time as political and economic conditions change.

Firms will choose to search for innovative ways to reduce their costs of compliance when such a search appears to them to be their best alternative—based on how they expect the regulatory process to unfold in the future. Sometimes, but not always, this search leads them to a free—or at least low-cost—lunch. The literature suggests there are 12 conditions that are most conducive to such an outcome.

Condition #1: Compliance with Regulation Is Expected To Be Expensive

The first condition is an obvious one, but still worth stating: Regulated firms must expect that compliance will be expensive if they are to innovate in response to regulation.[12] If compliance is cheap, firms have no incentive to invest in pollution-control R&D. "Grandfathering in," or exempting preexisting activities and emissions from new regulation, can slow down innovation by making compliance cheap. A chemical manufacturer whose current product is grandfathered in to a toxic substances control regime, for instance, has little incentive to develop new, safer products that comply with

this regime.[13] Likewise, small firms that are exempted from regulation with which large firms must comply are unlikely to innovate.[14]

A related situation occurs when all regulated firms in an industry face the same cost of compliance. In such a case, the industry may be able to add the cost of compliance using existing technology to its cost structure, and its customers may have no alternative but to absorb that addition. As long as compliance is not more expensive for one set of firms than another, it provides little incentive to innovate. Regulatory standards that require the "best available" or even the "maximum achievable" control technology, such as those implementing some sections of the Clean Air and Clean Water acts, have sometimes had this stultifying effect. Such standards may diffuse the current state of the art in pollution control, but do not encourage firms to push beyond it.[15] Regulation that sought to reduce water pollution caused by the use of chlorine in paper making in the 1990s, for instance, had this effect.[16]

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The expectation that compliance with regulation will be expensive, either in absolute or relative terms, may be necessary to stimulate innovation, but it is not sufficient. If regulated firms do not perceive a technological pathway that promises to reduce the cost of compliance to a reasonable level, they will do something other than try to innovate. The California Zero Emission Vehicle regulation, when it was initially imposed in 1990, is a good example. It prompted a decade of lobbying and litigation, but not much new vehicle development, largely because the battery technology needed to comply with it was far beyond automakers' capabilities at the time. [17]

Condition #2: Higher Authorities Are Unlikely to Force Regulators to Relax

Firms that are disinclined to comply with regulation may choose to fight it. In the United States, there are many venues in which to pursue such fights. Legislatures may overrule, intimidate, or defund regulatory agencies. Courts may overturn agency decisions. State and local implementation and enforcement partners may deviate from plans made in Washington, D.C. Firms have developed a wide repertoire of "nonmarket" strategies to pursue their objectives in venues other than within the regulatory process itself.[18]

Firms are more likely to respond to regulation by innovating when they expect nonmarket strategies to fail, and therefore have no appeal to a higher authority to avoid compliance. A societal consensus about the goals and legitimacy of regulation reinforces this condition. If firms do not expect a future phase of the electoral cycle to change environmental policy, they are less likely to advocate for the overturning of regulatory decisions, and instead get on with compliance.

The state of California today is a case in point. Environmental regulation, endorsed by many Republicans as well as Democrats, is very popular there. The state also has special standing in federal environmental statutes like the Clean Air Act, blocking off avenues to appeal to the federal level. The consensus on environmental regulation is that it has contributed to California's electric power industry becoming one of the most innovative in the United States.[19]

Condition #3: The Threat of Regulatory Enforcement Is Legitimate and Credible

Firms are more likely to invest in innovation in response to environmental regulation when managers fear noncompliance could have significant negative consequences.[20] For such a belief to arise, regulators must have adequate financial and technical resources to enforce the rules they make. Regulatory enforcement, too, must be perceived to be legitimate; otherwise, it may simply open a new avenue for appeal to a higher authority.

The recent Volkswagen (VW) diesel scandal illustrates the importance of credible enforcement. In Europe, the firm seemed to have been trusted to comply with clean air regulation on its own, while in the United States, compliance testing was not as sophisticated or rigorous as consumers and legislators believed. Volkswagen developed "defeat devices" that detected when tests were being performed and brought diesel-powered vehicles into compliance long enough to fool the authorities.[21]

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The development of defeat devices by VW shows firms may occasionally choose to innovate to circumvent regulation, rather than comply with it.[22] Weak enforcement provides a perverse incentive for this kind of innovation. Firms may decide it is in their best interest to advance technology that exploits holes in a weak regulatory fabric rather than innovate to achieve regulatory objectives more efficiently.

Condition #4: Industry Expects Regulation To Become Increasingly Stringent Over Time

The fourth condition that encourages firms to respond to environmental regulation by pursuing technological innovation is a shared expectation of increasing stringency over time. Innovation can be a slow process, particularly when the preexisting knowledge base to support it is weak. A phase-in period allows adequate time for new technologies to be tested in realistic conditions before they are put fully into practice.[23] It also permits adjustments to be made should the innovation process not yield the results the parties anticipated when the standards were set.[24]

This condition is particularly important in capital-intensive industries, which have long planning cycles. Innovation in such industries tends to be very costly. When managers perceive that the timetable for implementing regulation is so aggressive that it will put their current investments at risk, they are likely to resist. On the other hand, once expectations of increasing stringency have been set and investments in innovation have been made, managers are likely to want to see these expectations realized.[25]

Air conditioning and refrigeration-equipment manufacturers, for instance, operate on a design cycle of five or more years. Anticipating the imposition of tighter restrictions on hydrofluorocarbon greenhouse gases (HFCs) in the near future, U.S. manufacturers have budgeted $5 billion over the next decade to commercialize the next generation of HFC-free refrigeration technology. A 2018 report by an industry association called for "regulatory certainty" and a "firm timetable" to ensure this investment would not be jeopardized.[26]

Condition #5: The Technological Landscape for Regulatory Compliance Is Target-Rich

The threat of credible enforcement of stringent environmental regulation must be matched by opportunity if firms are to respond to it by innovating. The more "target rich" firms perceive the technological landscape to be, the greater the likelihood of such a response. In the case of regulation to reduce ozone depletion caused by chemical compounds such as chlorofluorocarbons (CFCs) used in air conditioners in the 1980s, chemical manufacturers opted to attempt innovation in part because they believed they could develop new compounds (HFCs and hydrochlorofluorocarbons (HCFCs)) that could be "dropped in" to existing air conditioners replace the old ones.[27]

Some industries are more accustomed than others to innovating and therefore may be more inclined to respond to regulation by doing so. The chemical industry, for example, spends 6.7 percent of its revenue on R&D, while the average manufacturing industry spends less than 4 percent.[28] Other things being equal, experts who study regulation expect the chemical industry to be more likely than the average industry to innovate in response to environmental regulation, as it did in the case of ozone depletion.

Varied perceptions of the landscape of technological opportunity among firms *within* an industry are less widely recognized than variations *across* industries, but may also have important implications to the relationship between environmental regulation and technological innovation. If some firms within an industry perceive technological targets of opportunity that others do not, regulation may create an opportunity for an innovative firm to differentiate itself from its competitors. Toyota's invention of the hybrid-electric drive, which led to the introduction of the Prius in 1997—years ahead of other carmakers—is a case in point.[29]

Condition #6: Regulated Firms Have Slack Resources

In order for a firm like Toyota to make an invention as radical as the hybrid automobile powertrain in response to a regulatory stimulus, it must also have slack. Managers must have permission, implicit or explicit, from shareholders to take the risks involved in searching for innovative solutions to pollution-reduction challenges. When risk-averse shareholders hold a tight rein over R&D spending, or there is too little cash available to place bets on game-changing new technologies, environmental regulation is unlikely to stimulate innovation.

Slack is central to the Porter hypothesis. In Porter's view, most firms have the autonomy and resources to adopt a pollution-reducing technology strategy, but managers rarely think to do so. Their attention, which is focused on executing current SOPs as effectively as possible, is the factor that limits innovation. Regulation can cause managers to step back from the day-to-day press of business and see opportunities they had previously ignored. They can then target slack resources to realize these opportunities.[30]

Porter and his colleagues uncovered many cases in which firms jolted by a regulatory stimulus quickly found "innovation offsets" that more than covered their immediate costs. For instance, 3M was "forced to comply with new regulations to reduce solvent emissions

by 90 percent," so it "found a way to avoid the use of solvents altogether by coating products with safer water-based solutions." "Innovation offsets" in the 29 chemical plants they studied, "were achieved with surprisingly low investments and very short payback times."[31]

As noted above, economists who have assessed the Porter hypothesis—that innovation offsets to environmental regulation make firms better off—have not generally found support for it.[32] Most such studies, however, take a relatively static approach that does not explore how managerial choices play out over a period of years. Researchers who take a more dynamic perspective discover that managers often find some innovation offsets, particularly through process innovation, even though they may not entirely eliminate the costs regulation imposes.[33]

Other things being equal, a reasonable but not excessive level of competition within a regulated industry raises the odds managers will respond to regulation by innovating.

Condition #7: The Regulated Industry Is Competitive

Porter also argues that managers are more likely to search for innovation offsets in response to environmental regulation when they face competition. A very large body of research has shown that competition has a two-sided relationship with innovation.[34] Industries that are hypercompetitive, like farming and furniture-making, have low levels of innovation because firms in such industries have little slack. In addition, even if these firms were able to invest in innovation, they would get little benefit in return because their competitors would rapidly imitate them.

Monopolistic industries, like certain segments of finance and retailing, also tend to have low levels of innovation. While firms in such industries have plenty of slack and no fear of imitation, they also have little incentive to add the cost of R&D to their balance sheets. The optimal level of competition for spurring innovation lies between these two extremes, although scholars continue to debate just what that level is.

Other things being equal, then, a reasonable but not excessive level of competition within a regulated industry raises the odds managers will respond to regulation by innovating. However, regulation can also change the level of competition, thereby complicating the analysis. For instance, many studies have found regulation favors larger over smaller companies within an industry because of the specialized skills required for compliance.[35] But regulation can also induce firms to enter the regulated industry in order to offer new products or services, like pollution-control equipment, that are made profitable by the demand for compliance.[36]

The response of the auto industry to federal regulation of tailpipe emissions provides an excellent example of these dynamics. When such regulation was first considered in the 1960s, the response from the "Big 3" Detroit automakers was so sluggish the U.S. government sued them for acting like monopolists and colluding to suppress emissions-control technology.[37] The catalytic converter, an innovation that gave automakers a way to comply with regulation at much lower costs than they had anticipated, was introduced a few years later by a new entrant to the automotive supply industry, Johnson-Mathey.[38]

Condition #8: Prospects for Shifting Production to "Pollution Havens" Are Limited

The notion that the Big 3 Detroit automakers could act like monopolists is antiquated. International trade and investment have heightened competition in the auto industry since the 1970s. They have also complicated the relationship between environmental regulation and technological innovation. If a viable production base can be established in another jurisdiction that is less stringently regulated, producers who must pay the cost of compliance in the home market may be squeezed to the point they lack the resources to innovate. These producers' choices seem stark: either offshore their own production or lose market share.

Multinational firms often prefer to invest in innovation that allows them to comply with the most stringent regulation, rather than try to avoid this cost by seeking out jurisdictions with looser regulation.

This "pollution haven" hypothesis involving a "race to the bottom" has prompted a large literature. Its logic seems indisputable, paralleling that of firms seeking to reduce their labor costs by offshoring production to low-wage countries. Yet, an accumulating body of evidence points in the opposite direction, documenting more races to the top than to the bottom.[39] Multinational firms often prefer to invest in innovation that allows them to comply with the most stringent regulation, rather than try to avoid this cost by seeking out jurisdictions with looser regulation. These firms assume the looser jurisdictions will eventually catch up that with the global frontier and become more stringent over time. If their products and processes can meet the highest standards now, even though their costs may be higher, such firms will be well positioned as more countries race to the top in the future.

These dynamics can be seen at work in the global auto industry in recent years. Tough emissions standards have induced compliance through innovation in leading auto-producing countries, and as developing countries expand their auto production, they import these innovations from the more advanced nations.[40] This race to the top has very recently prompted a growing number of countries to announce plans to phase out internal combustion engines altogether. These plans have two objectives: reduce pollution and seize competitive advantage in auto production.[41]

Condition #9: Regulators Rely on Performance Standards

Experts exploring the relationship between environmental regulation and technological innovation have focused more intently on the design of regulation and the regulatory process than on the technological, industrial, and political conditions I have reviewed to this point. In particular, they have debated the relative efficacy of performance standards and technology mandates. The former specify the outputs of the regulated industry, such as the level of acceptable pollution, without prescribing what firms must do to achieve it, while the latter dictate which equipment and processes they must install.

In his agenda-setting work, Porter argued that performance standards would stimulate innovative responses to environmental regulation, especially when combined with industrial competition. Under these conditions, he anticipated that regulated firms would pursue diverse approaches to meet their performance goals. Such experimentation would in turn yield unexpectedly inexpensive ways to meet those goals.

Tradable permits for the right to pollute offer further scope for firms to exercise creativity to comply with environmental regulation in this view. The total allocation of all permits under such a system functions as a performance standard for the entire regulated industry. Trades among permit holders may allow innovators to benefit more from innovation than they otherwise would without this option.

A growing body of research supports this argument, including a series of papers by experts at the Organization for Economic Cooperation and Development (OECD), which compared regulatory designs across countries and found performance standards more likely than other designs to induce regulated firms to both innovate themselves and adopt innovations developed elsewhere.[42]

Environmental policymakers can, at best, shape the conditions under which regulation is implemented, so as to make an innovative response by the regulated industry more likely.

However, performance standards and tradable permits will not stimulate innovation if they are not stringent. Performance standards for corporate average fuel economy (CAFÉ) regulation for automobiles in the 1990s and 2000s, for instance, were so loose automakers optimized engine power and sold heavier vehicles rather than take advantage of innovations that improved engine efficiency to reduce fuel consumption.[43] Another exception is the use of tradable permits for sulfur dioxide emissions from power plants under the 1990 Clean Air Act amendments. Fuel-switching from high-sulfur eastern coal to lower-sulfur western coal by many plants allowed the industry as a whole to comply with the regulation even though the fuel switchers did not innovate or adopt new technology.[44]

Condition #10: The Regulatory Process Induces an Open Exchange of Information

Such exceptions have led experts to go beyond the dichotomy between performance standards and technology mandates as they seek to determine which regulatory conditions are most conducive to technological innovation.[45] One finding is that the process by which performance standards are set can shape their impact. An open exchange of information with industry helps regulators establish a level of stringency that stretches the industry's technological capabilities without posing a challenge so daunting firms would rather fight the regulation or leave the jurisdiction than try to comply with it.

An open exchange during the regulatory process cannot be taken for granted, because the parties involved have incentives to distort or conceal vital pieces of information. The regulatory process is much like a negotiation. Control over information during a negotiation shapes perceptions about what would be considered an appropriate and fair outcome, among not only the negotiating parties, but also third parties such as the public and legislators—who might be drawn into the process later. Industry gains leverage when the cost of regulation is perceived to be high, while regulators gain leverage when the benefits are perceived to be large. The information the two sides disclose may be tailored to embed such perceptions.[46]

In addition, the procedural requirements of the federal regulatory process can impede information exchange. Trust built up over time, combined with procedural flexibility, may help to overcome these barriers. When the CAFÉ standards were renegotiated under the Obama administration, the parties agreed to "a detailed step-by-step process of

implementation, which requires reciprocal demonstrations of good faith by regulators and industry…"[47]

Competition among regulated firms may also lead to the revelation of valuable new information to regulators. Over the last 10 years, Tesla, a relatively new entrant into the auto industry, has shown an electric vehicle that appeals to consumers on grounds other than environmental values, such as style and performance, can be built. Tesla's achievements have given regulators insights into the level of stringency with which the auto industry can reasonably be expected to comply.[48]

Condition #11: Regulators Have a Sophisticated Understanding of the Regulated Industry

Trust may be a temporary condition, however, and competition is not always vigorous. Regulators must have a sophisticated understanding of the industry they are regulating in order to verify or challenge information they receive from that industry. Only with a high level of sophistication are they able to calibrate performance standards so as to evoke an innovative response, rather than fight, flight, or complacency.

This condition is challenging to achieve not only because of the incentives to distort or conceal information, but because firms inevitably know more than regulators about the processes and technologies they use, the costs they bear, and the customers they serve. This asymmetry gives industry a strategic advantage in the regulatory process.[49] In order to counter it, regulatory agencies must typically hire staff with industry experience and encourage them to spend time with their industrial counterparts. Such familiarity, in turn, runs the risk of regulators losing their independent perspective and falling victim to "capture" by the regulated industry.[50]

Harvard political scientist Daniel Carpenter's detailed study of the Food and Drug Administration (FDA), although it lies in the domain of health and safety rather than environmental protection, demonstrates how a regulatory agency can, over a period of decades, build a sophisticated understanding of the industry it regulates. Aided by scientific advisory committees, FDA has defined the core standards used to evaluate new drugs, such as safety and efficacy, while at the same time maintaining its reputation as an independent adjudicator of these standards —despite facing recurrent challenges over the years.[51] Contributing to FDA's success has been its ability to obtain adequate funding, including through the Prescription Drug User Fee Act.[52]

Condition #12: Technology Policy Complements Regulation

Finally, environmental regulators can encourage more constructive innovative responses by packaging regulation with technology policy. Such packages solve two market failures (which also happens to be the title of a famous paper in this field): the externality that leads to pollution, and the threat of "free riding," which can deter investment in innovation in competitive markets.[53] Free riding arises when innovation is more expensive than imitation, and innovators are unable to prevent it. Although the rational choice in such a situation is imitation, if every firm were to arrive at this same conclusion—such as in the

hypercompetitive industries described in the section on competition (condition #7)—there would be no innovators.

Technology policy can overcome free riding in a variety of ways. Strong intellectual property rights deter imitation and increase the reward for innovation. Tax incentives for private R&D spending reduce the cost of innovation; government R&D grants and contracts can do so, too. Government R&D programs that have specific objectives (as opposed to those that support the pursuit of knowledge for its own sake) are more likely to influence private-sector behavior when they require cost-sharing, which gives the recipient of R&D funding a larger stake in the outcome.

The U.S. Environmental Protection Agency's (EPA) approach to flue gas desulfurization (FGD) illustrates the benefits of packaging technology policy with regulation. In parallel with the implementation of regulation to reduce sulfur dioxide emissions from power plants under the 1970 Clean Air Act, EPA co-funded with industry an R&D program that deployed three pilot plants to test competing scrubbers being developed by power plant equipment vendors. This R&D program played a vital role in reducing the cost of this regulation far more than initial industry projections.[54]

Environmental regulators can encourage more constructive innovative responses by packaging regulation with technology policy.

CONCLUSION: RULES OF THUMB FOR ENVIRONMENTAL POLICY-MAKING

The promise of environmentally friendly technologies that allow businesses to comply with regulation at an unexpectedly low cost is tantalizing. When the promise is realized, the ratio between the benefits and costs of regulation grows larger. But there are no sure things in innovation; it is intrinsically uncertain. Environmental policymakers can, at best, shape the conditions under which regulation is implemented, so as to make an innovative response by the regulated industry more likely.

A review of the expert literature on this topic has led me to list 12 such conditions. Some of these conditions, such as the use of performance standards, fall directly under the control of environmental policymakers. Other conditions—such as anticipated increases in stringency over time—may be brought about indirectly by policymakers. Still others—such as the availability of slack resources to regulated firms—are largely beyond policymakers' reach.

Although our limited understanding of this complex problem prevents us from making definitive statements about what environmental policymakers should do in any particular case, these differences in the degree of control over the 12 conditions do point toward five rules of thumb they can employ. Policymakers should:

1. Study whether the conditions they cannot control in a given case are likely to favor an innovative response from regulated firms.
2. When those conditions are favorable, set regulatory goals over the long term that assume the costs of compliance will decline due to innovation.
3. Be patient but vigilant in the intermediate term as regulated firms explore promising pathways that appear to have the potential to meet long-term goals.

4. Encourage competition among regulated firms to devise specific products and processes that would aid regulatory compliance, while also driving technology policy to create general knowledge they can all draw upon.
5. Develop a sophisticated understanding of the technical and economic challenges facing the regulated industry, in order to credibly and independently assess its progress, and to make adjustments, including loosening standards and schedules, when appropriate.

ENDNOTES

1. Government and non-profit organizations are also subject to regulation. For example, Federal agencies must comply with the National Environmental Policy Act. To simplify the presentation in this proposal, I will focus on businesses as the regulated entities. The impacts on business dominate the literature and the public debate. However, many of the same argument made about business may also apply to government and non-profit organizations.
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