Implementing Technology-Forcing Policies: The 1970 Clean Air Act Amendments and the Introduction of Advanced Automotive Emissions Controls

David Gerard and Lester B. Lave

Center for the Study and Improvement of Regulation
Department of Engineering and Public Policy
Carnegie Mellon University

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Abstract: Technology forcing is a strategy where a regulator specifies a standard that cannot be met with existing technology, or at least not at an acceptable cost. Using the 1970 Clean Air Act for mobile source emissions as our baseline example, we argue that the implementation process is an underappreciated factor in the relationship between regulations and technological change. The 1970 legislation required 90 percent reductions in tailpipe emissions for new 1975 and 1976 automobiles, which presented automakers with major technical and economic challenges. Nevertheless, EPA successfully forced the adoption of two marquee control technologies – the catalytic converter in 1975 and the three-way catalyst in 1981. By comparing the implementation process leading to the development and diffusion of these two technologies, we identify the conditions where regulatory pressure is likely to be effective.

Keywords: Technology Forcing, Automobile Regulations, Policy Implementation, Air Pollution

Corresponding Author:

David Gerard
Center for the Study and Improvement of Regulation
Department of Engineering and Public Policy
Carnegie Mellon University
129 Baker Hall
Pittsburgh, PA 15213

(412) 268 1273
dgerard@andrew.cmu.edu

INTRODUCTION

The degree to which regulations can effectively, and perhaps even efficiently, accelerate the development of advanced pollution control technologies is a continuing theme of environmental policy (Jaffe, Newell, and Stavins, 2003; Parry, Pizer, and Fischer, 2002). Economic analyses of these relationships have focused in two areas: the relative effectiveness of alternate policy instruments in providing incentives for firms to innovate (Magat, 1978; Downing and White, 1986; Milliam and Prince, 1989; Jung, Krutilla, and Boyd; 1996; Kemp, 1997), and whether the benefits of induced innovations overwhelm the regulatory compliance costs (Porter and van der Linde, 1995; Palmer, Oates, and Portney, 1995). Most of these models take policy implementation as given, hence overlooking or abstracting from the importance of stakeholder involvement in the regulatory process. Yet, interactions of legislators, firms, regulators, and the courts play a critical role in shaping regulatory policy and firm behavior, which influence both technological and environmental outcomes.

In this paper we examine the role the regulatory implementation process plays in inducing technological change by examining technology-forcing policies in the U.S. auto industry. Technology forcing is a strategy where a regulator sets a standard that is unattainable with existing technology, at least at an acceptable cost. Examining the regulatory process for technology-forcing policies is well suited for a study of implementation for two reasons. First, the express purpose of technology-forcing policies is to elicit advancements in environmental control technologies. Second, in a technology-forcing setting, regulators and firms each attempt to change the actions of the other party. Regulators want to force firms to commit resources to R&D, while firms want regulators to delay, relax, or rescind the standards. Consequently, the outcomes of these conflicts are key determinants in whether and how environmental regulations affect the rate of technological innovation and diffusion.

We focus specifically on how the 1970 Clean Air Act affected the development and diffusion of advanced emission control technologies for new automobiles. The statute mandated 90 percent reductions in tailpipe emissions over a four to five year period, and instructed the nascent Environmental Protection Agency (EPA) to implement these standards (Table 1). Congress intentionally set technology-forcing standards, presenting automakers with major technical and economic challenges. The internal combustion engine was a mature technology that had not seen any substantial improvements in 20 years, and it was not clear that the standards could *ever* be met without replacing it altogether (Austin, 2001). Even if the necessary technologies emerged, the industry faced billions of dollars in R&D, capital and equipment, and installation costs. Congress and the EPA were aware of both the technological challenges and the high costs, and no one was surprised by the contentious, adversarial nature of the implementation phase.

Although car manufacturers did not meet the performance standards by the statutory deadlines, the technology-forcing episode resulted in the development and diffusion of two marquee technologies – the catalytic converter in 1975 and the three-way catalyst in 1981. These control technologies helped reduce aggregate emissions of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NOx) between 1975 and 1985 despite a 34 percent increase in vehicle miles traveled over the same period. At the same time, automakers incurred heavy costs of developing and adopting emissions controls, especially when the two new technologies were introduced in 1975 and 1981 (Figure 1).

We begin by reviewing models of the technology-forcing process that characterize the incentive structure of regulators, firms, and related stakeholders (Puller, 2002; Kemp, 1997; Kleit, 1992; Yao, 1988). We draw on these models to inform our account of the regulatory process that unfolded following the 1970 Clean Air Act. We develop this history using a range of sources, including descriptive accounts of the administrative process (Doyle, 2000; Krier and Ursin, 1977; Stork, 1977, Davies and Davies, 1975) and the development of emissions control technologies (Mondt, 2000), as well as evaluations of various economic impacts (White, 1982; Bresnahan and Yao, 1985; Crandall, Gruenspecht, Keeler, and Lave, 1986). To sharpen the connections between theory and practice, we conducted interviews with individuals from the automakers, the EPA, and the California Air Resources Board (CARB) who were involved in the regulatory process through the 1970s.

It is not our intention to evaluate the efficiency of technology forcing relative to other policy alternatives; rather, we take it as given that regulators are interested in pursing a technology-forcing strategy. It may well be the case that other policy instruments would have met the desired policy goal more efficiently (such as aggressive inspection and maintenance programs or steep gasoline taxes). Indeed, a comprehensive cost-benefit analysis of the 1970 Clean Air Act found that the costs of the mobile source program have been far greater than the benefits (Freeman, 2002). Yet, for all its warts, technology forcing has enjoyed far more political support than gasoline taxes and other instruments that might be more cost-effective at achieving policy goals.

TECHNOLOGY FORCING LITERATURE

The dominant feature of models of technology-forcing regulations is the interaction between regulators and firms, where both firms' R&D decisions and regulator enforcement decisions are treated as endogenous. The challenge for regulators is to prod firms to expend R&D dollars on the development of new technologies, and the objective of firms is to maximize profits.

Assuming that environmental performance conveys no effect on product demand, a profit-maximizing firm minimizes the sum of its discounted R&D and compliance costs. Therefore, the optimal firm strategy depends on the probability that a regulation will be enforced. Firms will have lower costs if regulations are not enforced regardless of whether an adequate control technology becomes available. Therefore, it might be in the interest of the firm – or the industry collectively – to lobby regulators to delay or rescind the standard. Firms often have greater information about their own technological capabilities than regulators, and might be able to exploit this information asymmetry by hiding their true innovative capabilities, under-investing in R&D, and claiming that the standards cannot be met. Where an information asymmetry exists, firms can attempt to force a regulatory delay by deliberately missing the standard (Yao, 1988; Kleit, 1992). Active collusion is not necessary to achieve this result. For example, if a firm believes that no other firm (or potential entrant) can meet the standards, that firm will autonomously reduce its R&D. If each firm adopts these expectations, then the expectations will be self-fulfilling.

If firms argue that meeting a standard is impossible, and regulators have no foundation to contradict them, it is unlikely that regulatory pressure will persuade firms to make R&D outlays. Therefore, regulators must establish some credibility by limiting or erasing any information advantages. As a practical matter, regulators might limit the asymmetry by targeting a specific technology (Lewis, 1996; Marino, 1998), or by setting less ambitious performance targets in the first place. The regulator's ability to make a credible commitment to enforcement depends on a number of other factors, including the costs and benefits of the program and the level of public and political support for the regulatory objective.[1]

Competitive pressures complement regulatory pressure in fostering R&D. Competition can emerge if a firm believes that it can raise its rivals' costs by developing a new technology and convincing a regulator to use that technology as the regulatory standard (Hackett, 1995; Puller, 2002). In a more benign sense, a firm that believes the regulatory standards will be implemented will conduct R&D to reduce its own compliance costs. There are a number of other possible sources of competition. Domestic automakers might feel confident that EPA will not shut them down, but the same might not be true for foreign competitors. Successful innovation by foreign firms undermines the claims of domestic firms that standards are unattainable. By credibly asserting that they will enforce standards against foreign companies, EPA could play off foreign companies against domestic ones. Similarly, components providers have the incentive to demonstrate the effectiveness of new control technologies as a means to expand the market for their products. These competitive pressures could prompt domestic firms to increase their own R&D.

The intuition of these models has to do with expected levels of industry R&D: If regulators can persuade firms that they will not relax standards, we would expect more

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[1] Two more factors dampen incentives to innovate. The first is problems appropriating the full value of an innovation. If competitors are able to duplicate new technologies, then it is less likely that any firm will undertake R&D to develop a new technology. The second is the ratchet effect. Regulators might respond to firms meeting a standard by setting even more stringent standards In fact, if firms innovate and reduce marginal compliance costs, the efficient level of abatement will increase (Puller, 2002).

environmental R&D and a faster rate of technological development. Yet, the models say relatively little about the types of new technologies that are likely to emerge. Kemp (1997) discusses technology choice as a product of the regulatory standards. He argues that in response to a short time horizon firms will favor and subsequently lock-in an inferior, yet more expedient, end-of-pipe fix, rather than possible technologies that will fundamentally alter the current process. Extending the time horizon, however, might facilitate more technological leaps, but such time horizons are also more likely to institutionalize information asymmetries between regulators and firms, extending the time horizon for implementation perhaps indefinitely.

The implementation phase of the technology-forcing process is murkier than the theory suggests. For example, the link between R&D and innovation is not deterministic. Therefore there are questions about the likelihood of technological breakthroughs, even in cases where firms make good faith efforts. There is also uncertainty surrounding the costs of incorporating a new technology, its effectiveness and reliability, unanticipated environmental impacts, and the possible lock-in of inferior technologies. There are opportunity costs associated with forcing firms to target R&D funds to meet technology-forcing standards, and it is not possible to know how technology would have progressed in absence of the regulations.

The pervasive uncertainty puts pressure on all of the stakeholder groups. Regulators must push firms to conduct R&D, evaluate their progress, assess the costs and benefits of compliance, and decide whether to enforce, relax, delay, or rescind the regulations. If firms fail to meet the standards, regulators face unpalatable decisions about levying fines or shutting down an industry. Legislative bodies have to decide whether to accept regulator decisions, or to step in and modify them. Firms have to make capital outlays in an uncertain environment, and must decide whether or not to petition for delay or to sue the regulatory agency. There are questions about the likelihood of technological breakthroughs, the costs of R&D, installation, and maintenance, as well as the reliability and effectiveness of incorporating a new technology. If the standards are enforced, firms could be put in the position of using unproven or unreliable technological fixes. The rapid adoption of new technologies can lead to unintended consequences, as well as the possible lock-in of an inferior short-term fix at the expense of a superior long-term alternative. Moreover, regulations can potentially affect related industries, introducing further complications.

To summarize, the basic structure of the technology-forcing models involves the interplay between regulators and the industry, specifically how regulatory pressure influences industry R&D. These models suggest that firms are more likely to invest in R&D when (1) regulators can credibly commit to enforcing a standard; and (2) when there is competitive pressure to develop new technologies from within the industry, from foreign competitors, or from components providers. Although we expect a positive correlation between R&D expenditures and technological advance, there is a high degree of uncertainty about forcing invention or innovation on schedule.

A Brief History of Automobile Emissions Legislation and Regulations

Urban air quality across the U.S., especially in California, steadily deteriorated through the 1950s. Research established that HC and NOx were precursors to urban smog, and many cities had elevated concentrations of CO, a debate began as to the appropriate governmental course of action, if any. Congress balked at making air pollution a federal issue, and instead California enacted the first major legislation for automobile emissions in 1960.[2] The California regulations mandated the installation of positive crankcase ventilation (PCV) valves for 1963

[2] The initial legislation set up the Motor Vehicle Pollution Control Board. In 1967 the MVPCB was replaced with the California Air Resources Board (CARB), which remains in place today.

vehicles[3] and set performance standards for 1966 vehicles (Krier and Ursin, 1977).[4] As states other than California moved to regulate vehicle emissions, automakers began to support the federalization of emissions regulations (Elliott, Ackerman, and Millian, 1985; Krier and Ursin, 1977). In 1965 Congress directed the Secretary of Health, Education, and Welfare (HEW) to set the first national standards, limiting emissions of HC and CO. Two years later in 1967 the Air Quality Act preempted states other than California from regulating vehicle emissions.

The initial legislation was not particularly ambitious, but it gave federal legislators a foothold in the regulation of the automobile, and a series of public relations setbacks set the stage for more aggressive emissions limits. In 1965 Ralph Nader published *Unsafe at Any Speed*, criticizing the safety record of U.S. automobiles. In the wake of the report, General Motors (GM) hired private investigators to look into Nader's affair. When Nader learned of the investigation, GM executives were soon publicly apologizing for their actions. These incidents lionized Nader, fostered distrust of the industry, and paved the way for watershed auto safety legislation in 1966. The incidents cast doubt on whether automobile manufacturers were concerned with safety of their customers, and the industry suffered a further setback in 1969 when the Department of Justice filed an antitrust suit. The suit accused automakers of using the cover of a joint research venture to suppress the development and diffusion of pollution control technologies. The parties settled the case through a controversial, sealed consent decree that dissolved the national partnership (Hackett, 1995; Doyle, 2000).

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[3] Automakers voluntarily put PCV valves on California cars in 1961, and on all U.S. cars in 1963 (Mondt, 2000).

[4] California also dabbled with requiring cars already on the road to be retrofitted. The retrofitting was so spectacularly unpopular that the idea of regulating existing sources has been largely scrapped (Krier and Ursin, 1977). Many states have since implemented inspection and maintenance programs to monitor in-use emissions. The goal of these programs is to keep emissions of in-use vehicles from rising above some threshold level, not to reduce emissions below where the car was certified.

It was against this backdrop that Senator Muskie introduced a bill to set new emissions standards in 1969. In addition to being one of the principal proponents of environmental issues, Muskie was a potential presidential candidate in 1972. Muskie's proposed amendments set more stringent standards, but were consistent with current technology and economic feasibility. President Nixon countered with a proposal to set national air quality standards, automobile emissions regulations for 1975 vehicles, and vehicle emissions research targets for 1980 vehicles. (Elliott, Ackerman, and Millian, 1985). The research targets were based on estimates that HC, CO, and NOx would all have to be reduced to 10 percent of current standards in order to meet ambient targets. Accordingly, these estimates had no connection with the technological feasibility or costs of making such reductions (Stork, 1977).

Senator Muskie moved to outflank Nixon by pushing through a more aggressive version of the Nixon Administration proposals (Elliott, Ackerman, and Milliam, 1985). The boldest element was establishing the 1980 research targets as the actual standards for 1975 and 1976 vehicles. Specifically, the legislation required 90 percent reductions from 1970 standards in HC and CO for 1975, and the same level of NOx reductions for 1976. Despite industry protests, the technology-forcing emission standards of the Muskie bill made their way into law with overwhelming congressional support. Although President Nixon opposed the bill, he recognized that a veto would be overridden with relative ease, so he signed the Clean Air Act Amendments into law on December 31, 1970 (Davies and Davies, 1975). Automakers would begin turning out 1975 model year vehicles in mid-1974, and therefore the mandate provided roughly a three and a half year time horizon for automakers to develop a way to reduce emissions by 90 percent.

Administrative Procedures and Congressional Delegation

Congress often sacrifices some control of the regulatory process by delegating authority to a regulatory agency, which is better able to make technically informed decisions. Congress can maintain control by establishing procedures that make it more likely that the outcome of the regulatory process will be consistent with the preferences of the coalition responsible for enacting the enabling legislation (McCubbins, Noll, and Weingast, 1987). Yet, despite the extensive information demands, Congress took the unusual step of delegating little discretion to EPA. Instead, the statute explicitly specified the performance standards, the deadline for compliance, criteria for delaying enforcement, and the fines for non-compliance.

Two factors might have influenced the congressional decision to limit agency discretion. First, Congress instructed the National Academy of Sciences (NAS) to examine the feasibility and compliance costs. The NAS involvement would mitigate information problems, and therefore delegation was not necessary. A second possibility is that the legislative standards were used as a signaling mechanism to the industry that the administrative agency could not rubberstamp a delay. According to Senator Muskie's aide, Leon Billings, for example, Congress wanted to tie the hands of EPA administrators: "Everyone understood that the goal could not be reached with state-of-the-art technology, but the debate was not over the 90 percent cut. It was over what could be done if the automobile industry could not meet the standard. Muskie's theory was that a bureaucrat would always extend the deadline, so he wanted Congress to make the decision" (Doyle 2000).

The first order of business was for the EPA to establish a new Federal Test Procedure (FTP) to estimate emissions and certify vehicles, and the 90 percent reductions were to be based on this new FTP. In addition, the FTP effectively set new HC and CO standards for 1973 vehicles, and new NOx standards were also set to go into effect in 1973. The deadline for meeting the 90 percent HC and CO reductions was 1975, and the deadline for the NOx standards was 1976. Automakers faced a $10,000 fine for each car it sold of a model line that had not passed the EPA certification test.[5] This was an extraordinarily stiff penalty, given the average price of a new vehicle in 1975 was approximately $5,000 (Wards, 2002). EPA had the option to delay implementation of the standards for one year if the necessary technology and hardware did not become available.

The legislation gave EPA broad discretion to regulate fuel content. These stipulations were clearly designed with the catalytic converter in mind. Lead plugged up the catalytic converters, rendering them useless as a pollution control device. The removal of lead from gasoline set off a parallel regulatory process (Stikkers, 2002).

THE INITIAL IMPLEMENTATION STAGE

After EPA established the new FTP, automakers had to determine how to make initial reductions to meet 1973 and 1974 standards, and then make the more drastic cuts for 1975 and 1976 vehicles. Even the modest reductions for 1973 and 1974 vehicles were creating problems for U.S. producers. Compliance strategies included retarded spark timing and air injection systems for HC and CO emissions, and exhaust gas recirculation (EGR) for NOx emissions. Cars with retarded spark timing got poor fuel economy, and the lean burn from air injection systems resulted in cars that were underpowered and that could stall out even at cruising speeds (Colucci, 2001; Mondt, 2000; Starkman and Bowditch, 1977). An examination of the resale market reveal that the performance penalties for the average 1973 vehicle were roughly six times higher than the compliance costs (capital costs, costs of the devices, fuel penalties), and the overall costs of

[5] Unless otherwise indicated, reported figures are in current dollars.

emissions were more than 20 percent of the price of an average vehicle (Bresnahan and Yao, 1985). Coupled with the jump in fuel prices, these poor-performance vehicles, made imports more attractive, and compromised continued public support of the emissions programs.

The extent of the problems with the 1973 and 1974 vehicles was not yet evident when regulators and industry engineers began to evaluate strategies for the 90 percent cuts in HC and CO for 1975. EPA examined a wide range of technologies, including thermal reactors and stratified charge engines, and identified catalytic converters as the best alternative. EPA was confident that modest improvements in available technology would be enough to meet the HC and CO targets (Austin, 2001; Stork 2001). In fact, the staff found that catalytic converters had such enormous benefits at such modest costs that it was not going to be practical to reduce emissions by 90 percent and beyond without catalysts (Austin, 2001).

The catalytic converter was not a new technology; the devices had been used in factories since the early part of the century. The major problem facing catalyst adaptation to the automobile was that, unlike industrial machines, cars are constantly adjusting operating power. Automakers had been experimenting with prototypes since 1959. EPA had also been experimenting with the devices, and the technical staff was able to equip its own vehicles built with carburetors and no on-board electronics that met the standards for 50,000 miles (Austin, 2001). In effect, the EPA technical staff had erased the industry's information advantage, and consequently put itself in a favorable position to force the installation of catalytic converters. Although Congress set performance standard, EPA was pushing a *de facto* technology standard, at least for domestic producers.

GM and Ford were also convinced that the catalytic converter could provide major emissions reductions. In 1970 GM president Ed Cole promised to put catalytic converters on all

GM vehicles if EPA took steps to make unleaded gasoline available. However, making the catalytic converter operational would require significant fixed costs (R&D), and yearly variable manufacturing and installation costs. The initial estimates for meeting the 90 percent reductions were $860 per vehicle (Mondt, 2000). Thus, each year the standards were pushed back the industry stood to save more than $5 billion per year in equipment costs alone. Without obvious performance benefits, companies were reluctant to equip the entire fleet with the devices.[6] Not surprisingly, by 1973 GM was expressing public opposition to implementation of the 1975 standards.

In response to regulatory pressure, GM and Ford continued R&D on catalyst technologies and continued to set up production facilities to manufacture the equipment. It did not appear, however, that the two companies were competing to meet the standards as a means to raise their rivals' costs. As a result the competitive pressures driving the development and diffusion of catalytic converters was not particularly robust. In absence of competition, EPA would have to make a credible threat to enforce the HC and CO standards by the 1975 deadline.

The implementation phase played out in a manner that Congress had circumscribed by the 1970 legislation (Table 2). The NAS report of January 1972 was the first step of the implementation phase. NAS cited a number of potential problems with technology and expressed doubts about catalyst availability by 1975. On the other hand, it cited expected compliance costs of $288, which were considerably lower than the initial industry estimates. Even these lower costs, however, would translate into heavy expenditures for the industry.

[6] Ironically, the catalytic converter provided enormous performance benefits relative to the detuned 1973 and 1974 vehicles. Bresnahan and Yao (1985) estimate that these benefits exceeded the costs of putting the equipment on the cars. However, the catalytic converter itself did not improve performance; relative to the 1973 and 1974 vehicles that met standards with engine modifications, the catalytic converter, on average, was worth the installation costs.

Following the NAS report, automakers began to request the one-year delay in March and April of 1972. EPA rejected these petitions in May, prompting the automakers sued EPA in federal court. On December 19 the District of Columbia court of appeals remanded the decision, and instructed EPA to reconcile the NAS findings with its conclusions about technological availability. EPA was convinced that the technology was available, and it affirmed its original decision by providing a technical supplement less than two weeks later. The firms sued EPA again, and the appellate court remanded the decision back to EPA for a second time. The court favored a delay of the 1975 standards, but it also strongly suggested that EPA adopt interim standards (*International Harvester v. Ruckelshaus*, (D.C. Cir. 1973) 478 F. 2d 615).

After the second remand, EPA had 60 days to hold additional hearings, review the evidence, and make a decision. The subsequent hearings revealed that Ford and GM had made significant strides toward meeting the 1975 targets for CO and HC (Stork, 2001). Neither firm was eager to proceed, arguing that the installation of catalytic converters across the entire U.S. fleet would create substantial economic risks. Instead, the companies argued that EPA should allow for a phase-in of the technology – first in California, and then nationally. A two-tiered standard would provide experience with installing the devices and evidence on their effectiveness and maintenance, and would limit any widespread problems, such as those that existed in meeting the 1973 and 1974 standards.

In April of 1973, EPA granted a one-year delay of the 1975 HC and CO standards, but still set interim standards that required roughly 50 percent reductions (1.5 for HC and 15 for CO). The interim standards for California set even lower interim standards (0.9 for HC and 9 for CO). GM and Ford could only meet these standards with catalyst technologies, and both companies equipped their vehicles with the devices. EPA did not induce the emissions performance that Congress had mandated, but it did essentially force the installation of pollution control devices over the protests of Ford and GM.

The widespread diffusion of catalytic converters across the U.S. fleet and the partial removal of lead from gasoline signified impressive achievements for the EPA. Nonetheless, firms had made little progress on reducing NOx emissions. In July of 1973 EPA granted a delay of the NOx standards. Unlike the decision earlier in the year for HC and CO, this decision was not particularly controversial. Neither automobile manufacturers nor the EPA believed that the NOx standards could be met by 1976 (Stork, 1977). In 1975 the NOx standard stood at 3.1, compared with the legislative standard of 0.4.

Company Behavior

The theoretical technology-forcing models suggest that the competitive dynamics of the industry and regulator credibility are two important factors affecting firms' R&D decisions. For U.S. producers, GM and Ford actively pursued catalyst technologies, for perhaps very different reasons, while Chrysler essentially devoted little R&D to emissions control.

GM's Ed Cole pushed development of the converter as a means to improve his company's image in the wake of the bad publicity of the 1960s; whereas Ford's program was more likely a means to avoid falling behind GM's R&D program. Each company knew the catalytic converter would improve performance of the detuned 1973 and 1974 vehicles, and therefore meeting the deadline might convey double benefits – improved performance plus a cost advantage. In the end, however, the economics of the catalytic converter defied competitive pressures because it was unlikely that either Ford or GM could institutionalize a significant cost advantage against one another, and neither Japanese producers nor Chrysler was planning to install the devices. In the end, it was constant, credible regulatory pressure that forced the installation of catalytic converters by Ford and GM in 1975.

In contrast, Chrysler did very little internal R&D and failed to secure external commitments from suppliers, and its failure to come near compliance with the standards was the primary reason for the delay. Whether Chrysler's recalcitrance stemmed from financial distress or from a belief that EPA would not shut the company down remains an open question. There is no doubt that the company was performing very poorly, losing unprecedented sums of money, and hurtling toward a massive government bailout by the end of the decade. As a result, there was little capital to allocate toward the emissions control technologies, regardless of the competitive environment. At the same time, the company was aware that Congress had severely constrained EPA's administrative options: EPA could not to apply the standards to some firms and not to others, and it was not politically feasible to assess the $10,000 per car penalty for non-compliance. Chrysler did not install catalytic converters, and its 1975 vehicles had 38 percent higher HC emissions and 60 percent higher CO emissions than Ford and GM cars (White, 1982).[7]

As Japanese producers expanded their U.S. market share, they became more vulnerable if their producers failed to meet U.S. regulations. Recognizing the possibility that their producers could be shut out of the U.S. market, the Japanese government set standards identical to those of the U.S. (Shibata, 1989). Japanese producers successfully met the HC and the CO targets by the 1975 deadline with the development of the stratified-charge engine. The introduction of this technology did not provide a very robust competitive dimension to meet the standards, however. Ford was familiar with the technology, but reluctant to adopt it for a variety of reasons, notably because it increased NOx emissions (Petrauskas, 2003). Indeed, like their U.S. counterparts, Japanese companies were unable to meet the 1976 NOx standards, and the Japanese government delayed the standards (Shibata, 1989). Moreover, given the economic climate of the 1970s, it is unfathomable for EPA to shut down U.S. producers at the expense of foreign competitors.

Assessing the Winners and Losers

The suspension proceedings are often viewed as a showdown between EPA and U.S. producers, and the delay is often interpreted as an industry victory. Indeed, EPA had backed off its goal of meeting the 90 percent reduction targets. Yet, EPA set rigid interim standards that succeeded in getting catalytic converters installed on more than 80 percent of new 1975 U.S. cars (Bresnahan and Yao, 1985). Moreover, there were few recalls stemming from failure of catalyst systems, suggesting that the devices were reliable (Doyle, 2000, Appendix A). The limited number of recalls might be seen as a lax enforcement environment. According to EPA officials, however, failure to meet in-use HC and CO standards generally stemmed from miscalculation of catalyst material, not from the devices malfunctioning (Stork, 2001).

The changes in emissions levels and compliance costs from 1974 to 1975 were staggering. The average in-use emissions of HC dropped from 3.08 grams per mile in 1974 to 1.32 in 1975, and CO emissions fell from 35.9 to 22.9 (White, 1982). The improved emissions performance from new vehicles more than offset the 21 percent increase in vehicle miles traveled between 1970 and 1980. CO and HC emissions 11 and 31 percent, respectively, over that period (Figure 2). In contrast, following the introduction of EGR in 1973 there were no major innovations in NOx controls and consequently NOx emissions increased 17 percent between

[7] White (1982) uses GM as the baseline and uses dummy variables to measure Ford and Chrysler. He finds no difference between Ford and GM for HC in 1975, and Ford has 20 percent

1970 and 1980 – just under the rate of vehicle miles traveled for the period. With the introduction of the catalytic converter, industry capital expenditures jumped from $242 million in 1974 to $1.57 billion in 1975 (U.S. EPA, 1997). These costs were extensive relative to the assessed benefits. As of 1978, Freeman (2002) estimates that the annual costs of the mobile source program exceeded the benefits by a ratio of more than 20:1.[8]

THE IMPLEMENTATION STAGE, CONTINUED

The first administrative delays in 1973 were largely products of an administrative process that Congress had circumscribed when it crafted the 1970 legislation. A series of subsequent delays stemmed from exogenous changes in the economic environment, uncertainty about the environmental friendliness of targeted technologies, and inherent problems associated with forcing the development of new technologies.

The 1973 oil embargo created a major macroeconomic shock, and was an unexpected source of pressure on EPA's emissions program. The policy issue of immediate concern was whether emissions control regulations were having adverse impacts on fuel economy, and that compliance with tighter standards would exacerbate the situation. Taking no chances, in June of 1974 Congress extended the 1975 interim HC and CO standards through 1977 and NOx standards until 1978. EPA anticipated that fuel economy would become an issue, and drew on its database of emissions tests to explore the relationship (Stork, 1977), putting itself in a position

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lower CO emissions.

[8] Freeman (2002) breaks down the EPA assessment of benefits: Reductions in premature mortality and chronic bronchitis associated with lower particulate emissions account for more than 80 percent of the total benefits associated with the Clean Air Act, and these reductions are almost exclusively associated with stationary sources. The primary benefit stream from the mobile source program comes from the elimination of leaded gasoline, not from reductions in ozone levels, though targeting HC and NOx emissions was certainly motivated by improving

where the industry would be unlikely to exploit any information asymmetry to elicit further delays.[9]

The 1974 legislation authorized EPA authority to delay the standards for another year if necessary, and, in fact, there was already a cause on the horizon. In early 1973, Ford found that one of its cars equipped with a catalytic converter was emitting unusually high sulfate levels. EPA had not anticipated the sulfate problem, and consequently did not have enough technical information to reach a definitive conclusion. EPA did not back off the use of the catalytic converter for 1975, but it did extend the full phase-in of the 90 percent reductions until 1978.

EPA's technology-forcing efforts specifically targeted the catalytic converter, which limited the scope of emissions research. This is a potential problem for technology forcing, as there is the possibility that the regulator will target the wrong technology and lock in a bad result, at least in the short run. There was no obvious alternative developed to meet HC and CO standards. If the catalytic converter had been found to be the source of significant health hazards and could not be used, the emissions of 1975 vehicles would have been two to three time higher than for the 1972 to 1974 model years (Stork, 1977).

Second Round of Technology Forcing

Although the oxidizing catalyst brought about major HC and CO reductions, automakers were a long way from the 90 percent reductions required by the 1970 statute. Moreover, there

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local air quality. Freeman concludes that the costs of the mobile source program continue to exceed the benefits.

[9] Compliance with emissions regulations affected fuel economy when automakers retarded spark timing in order to meet the standards. More generally, however, the technology to improve fuel economy has a heavy, complementary overlap with technology to improve emissions. In principle, there is no relationship between emissions and fuel economy because all cars are required to meet the same emission standard. In practice, Harrington (1997) shows that in-use

had been no headway on NOx emissions. In effect, the technology-forcing implementation process was on going, and the technology targeted for the simultaneous reductions of HC, CO, and NOx was the three-way catalyst.

The operation of a three-way catalyst is considerably more complicated than the simple oxidizing catalytic converter. Unlike the catalytic converter, the three-way catalyst required significant engine improvements and computer technology to function properly. Most importantly, the device requires a stable air-fuel ratio in the combustion chamber. The normalized air-fuel ratio of GM cars in the 1960s using carbureted technologies ranged between 12 and 18. In order for the three-way catalyst to be effective, the ratio had to stay between 14.5 and 14.7 (Colucci 2001; Leonard, 2001). To maintain this ratio, an oxygen sensor feeds information about the engine exhaust to an electronic control module that adjusts the fuel input to maintain the required air-fuel ratio (Mondt, 2000). These new control technologies would be both complex to develop and costly to implement. Computers were expensive, delicate, and none had ever operated in the hot, dirty environment of an automobile engine. As a result of these technological challenges, EPA had a much higher hurdle to erase information asymmetry between itself and the automakers.

Once firms had developed the catalytic converter and committed to installing it, there was an industry-wide lull in R&D intensity. As early as February of 1975, EPA suspected that the industry was not committing sufficient resources to R&D, and an NAS committee drew a similar conclusion (White, 1982). Patenting activity increased every year between 1968 and 1974, but dropped sharply in 1975 (Lee, 2003). It is not possible to tell whether this was because the industry faced severe economic pressure or because firms sensed that further emissions

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vehicle emissions tend to increase as cars age, and a relationship between the amount of fuel consumed and emissions emerges.

reductions were not politically viable. Whatever the cause, no new technology emerged to meet the impending 1978 standards.

In August of 1977 U.S. producers began manufacturing 1978 model cars that did not meet the new standards. Because the law prohibited introducing cars into commerce without certification, the manufacturers could not ship them to the dealers. GM filled every parking lot within about a three-mile radius of their plants with cars that could not meet the standards (Leonard, 2001). EPA had exhausted its allotted delays, and Congress was forced either to push the standards back further, or prohibit U.S. producers from selling automobiles. Faced with the prospect of an industry shutdown, Congress passed the 1977 amendments to the Clean Air Act. The legislation pushed the original HC and CO standards back to 1980 and 1981, respectively, and allowed for the possibility of CO waivers to 7.0 for 1981 and 1982 cars. The NOx standard was set at 1.0 g/mi for 1981 cars, with a waiver possible to 1.5 g/mi.

From 1978 to 1981 there was little debate about the timely implementation of the 1977 legislation. A number of factors precluded the reemergence of the type of contentious adversarial process that characterized the first delay. The car companies were given several more years to develop the new technologies, and the NOx standard was more than double what the 1970 legislation called for. Moreover, on-board electronics would provide a platform for vehicle functions that went far beyond emissions control. Having been plagued by years of criticisms of poor quality vehicles and the resultant import penetration, improving quality and reliability became a top priority. Therefore firms were developing these systems as a competitive measure. The regulatory implementation date provided firms with a target date for the initial installment.

By 1981 U.S. producers began to integrate three-way catalysts into many of their vehicles. The regulatory pressure certainly accelerated the installation of the advanced control technologies, as virtually 70 percent of the new U.S. vehicles were equipped with the devices in 1981 (Bresnahan and Yao, 1985). The introduction of the technology was premature nonetheless, and GM recalled every single vehicle that it produced in 1981 and 1982 (Leonard, 2001). A phase-in of the technology would likely have saved the company considerable expense.

ACCOUNTING FOR DIFFERENCES IN THE TECHNOLOGY-FORCING EPISODES

There are a number of possible explanations to account for why EPA was succesful at forcing GM and Ford to develop and install catalytic converters by 1975, but it took ten years to make a dent in the NOx standards. One possibility is that firms spent considerable resources on R&D, but simply failed to make the necessary breakthroughs. This is compatible with the basic idea that it is not possible to force invention. Tom Austin, who was on the EPA technical staff and is now in private consulting, summarizes this sentiment: “You can’t force invention. What you can do is force further R&D on technologies that have essentially already been proven” (Austin, 2001). Japanese producers also were unable to meet the NOx standards also suggests that the technologies simply did not become available.

The evidence of a pronounced R&D lull beginning in 1975 suggests that the difference in the two periods is more than a matter of forcing complex invention versus more straightforward innovation. A number of factors could have played a role in the R&D lull. First, firms did not have funds available to allocate to environmental R&D. The R&D lull coincided with an industry facing substantial import penetration and losses. Second, firms had R&D funds, but did not spend them because there was no credible threat that the standards would be enforced. Equipping vehicles with three-way catalysts was going to be far more expensive than even the catalytic converter had been. It was not clear that EPA enjoyed public or political support to force installation of an unproven technology at upwards of $1000 per vehicle as a means to reduce emissions. The oxidizing catalyst removed a large chunk of the CO and HC emissions, and therefore there were fewer benefits associated with additional reductions (assuming the marginal benefits of emissions reductions are declining). At the time, questions remained about the importance of controlling NOx to reduce urban smog (Starkman and Bowditch, 1977). In addition, it was going to be much more difficult for EPA to erase any information advantage. EPA did not successfully equip test vehicles with three-way catalysts, and had not perfected the oxygen sensors and onboard electronics that were necessary to monitor and adjust the devices. Furthermore, macroeconomic conditions in the 1970s were often dismal, Japanese producers had dramatically penetrated the U.S. market, and U.S. firms were suffering financially. Given these conditions, firms may have shirked on R&D because neither Congress nor the EPA could credibly threaten further restrictions.

Lessons

Our comparison of the regulatory processes that led to the development and diffusion of the catalytic converter and the three-way catalyst provides a point of departure for thinking about the technology-forcing regulatory process more generally. The first factors concern the extent to which the technology must improve to meet the standards and the time horizon for meeting these standards. Stakeholder responses to the regulatory process are likely to play out differently in cases where regulators attempt to force invention of an entirely new process and cases where the target is incremental improvements in an existing but unproven technology. This is the most straightforward explanation for why the EPA was more successful at pushing the development and adoption of catalytic converters as compared to the more complicated electronic control systems necessary for the three-way catalysts.

The case study also illustrates that congressional and agency credibility is needed to force industry to do environmental R&D in a technology-forcing setting. Regulators can establish credibility by limiting information asymmetries, as EPA's technical staff effectively did, and by fostering competition to get firms to reveal information voluntarily. Competition can take a number of forms: Firms attempting to raise rivals' costs, components providers looking to establish a market for their wares, and foreign competitors wary of being shut out of the market are each potentially viable sources of competitive pressure. Each of these factors played a role in catalyst development, but none was decisive.

Even with credible regulators and robust competition, technology forcing is an uncertain strategy with no guarantees of technological breakthroughs. Moreover, the implementation process for technology-regulations is tense, with extensive pressure on regulators, firms, legislators, the courts, and the process is particularly vulnerable to unforeseen consequences. Firms have many outlets to disrupt a technology-forcing timetable, including colluding to suppress technological development and adoption, or litigation and lobbying legislators. Moreover, external factors such as unintended consequences, changes in macroeconomic conditions, or even questions about the economic viability of regulated firms can disrupt the regulatory process.

Further Considerations

There are a number of additional considerations when thinking about the implementation phase of technology-forcing regulations. First is the relationship between Congress and the EPA.

Congress did not delegate authority to EPA and instead wrote very explicit regulatory standards and circumscribed the regulatory process. These congressional mandates were unusual, as in many cases regulators are given discretion to set standards. Here, standards appeared to have some punitive element, with Congress more likely to enforce that penalty. The regulatory process could play out much differently if Congress had less of a stake politically in the outcome, and it provided the regulatory agency with greater discretion (Gerard and Lave, 2003).

A second set of issues concerns instrument choice. Most economists believe that performance standards offer more flexibility and superior incentives to innovate than technology standards. There is an emerging theoretical literature that suggests that in the presence of asymmetric information, it might be more efficient to target a specific technology rather than setting a performance standard (Lewis, 1996; Marino, 1998). Instrument choice did not appear to be a driver in our case study. We observe that EPA targeted catalytic converters, even though the regulatory standard was performance based – i.e., 90 percent reductions. However, if the regulatory standard had been to put catalytic converters on cars, it is not clear how EPA would have addressed the Chrysler situation.

Third, regulatory objectives can complement or contradict each other. Regulations may have unknown impact on some other performance attribute of the product, which puts pressure on automakers, who are required to meet standards simultaneously. There is, however, a piecemeal regulatory approach, where different agencies regulate different product attributes, making it difficult for any individual agency to set optimal standards (Lave, 1984).

Fourth, the state of California has maintained an interest in cleaning up urban air quality. The regulatory programs can influence what the carmakers have to do to meet California standards, and might also influence standard setting at the federal level as federal auto emissions regulations have often followed California's lead. To complicate matters further, the 1977 Clean Air Act Amendments allowed states to choose either California or federal standards. A number of northeastern states have opted in to the more ambitious California program, including the controversial zero-emissions vehicle mandate. In the current study, however, the influence of California on the development and diffusion of the catalytic converter and the three-way catalyst appears to be an indirect role.

Finally, related industries might be integral to the introduction of new technologies. Economists are fond of incentive-based instruments to reduce pollution, such as emissions taxes or marketable permits. Yet, the effectiveness of the catalytic converter relies on the availability of unleaded gasoline, and as such an emissions tax by itself would not have facilitated the diffusion of the catalytic converter.

CONCLUSIONS

A number of agencies have employed technology-forcing strategies when regulating U.S. automakers. In addition to the 1970 Clean Air Act, there have been several other technology-forcing attempts directed at U.S. automakers. In 1969, for example, the Secretary of Transportation required automakers to develop and install airbags on their vehicles to protect unbelted passengers. In 1975 Congress directed companies to double their average fuel economy within a decade. (This was not a direct technology-forcing effort, however, as these standards could be met by altering the mix of vehicle sales.) More recently, the California Air Resources Board required automakers to produce and sell zero emissions vehicles as three percent of their 1998 new car sales, and this percentage eventually was to increase to 10 percent. In each of these cases, the institutional setting played a critical role in shaping both technological developments and regulatory outcomes. An area of future research is to integrate elements of the implementation process with considerations such as standard setting, the use of market instruments, industry competition, the role of foreign producers and components providers.

In the case of the 1970 Clean Air Act, there is no question that EPA pressure led to significant technological advances and environmental improvements. EPA was able to apply pressure because of the extant economic and political conditions, and its ability to limit information asymmetries. Whether regulatory gusto was efficient is a separate matter, and ultimately not central to our analysis. Regulators have repeatedly targeted the auto industry with ambitious regulations, and are likely to offer technology-forcing options in the future. However, if regulators decide to pursue a technology forcing strategy to further improve air quality or to reduce emissions of carbon dioxide, the lessons from this case study should help to develop such a regulatory program. Moreover, the effectiveness and efficiency of technology forcing are important public policy questions in their own right. Evaluating the costs and benefits of technology-forcing strategies against politically viable alternatives is an area that could greatly impact future public policies.

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Figure 1: Annual Per-Vehicle Increases in Emssions Control Costs, 1968-1985 (2000$)

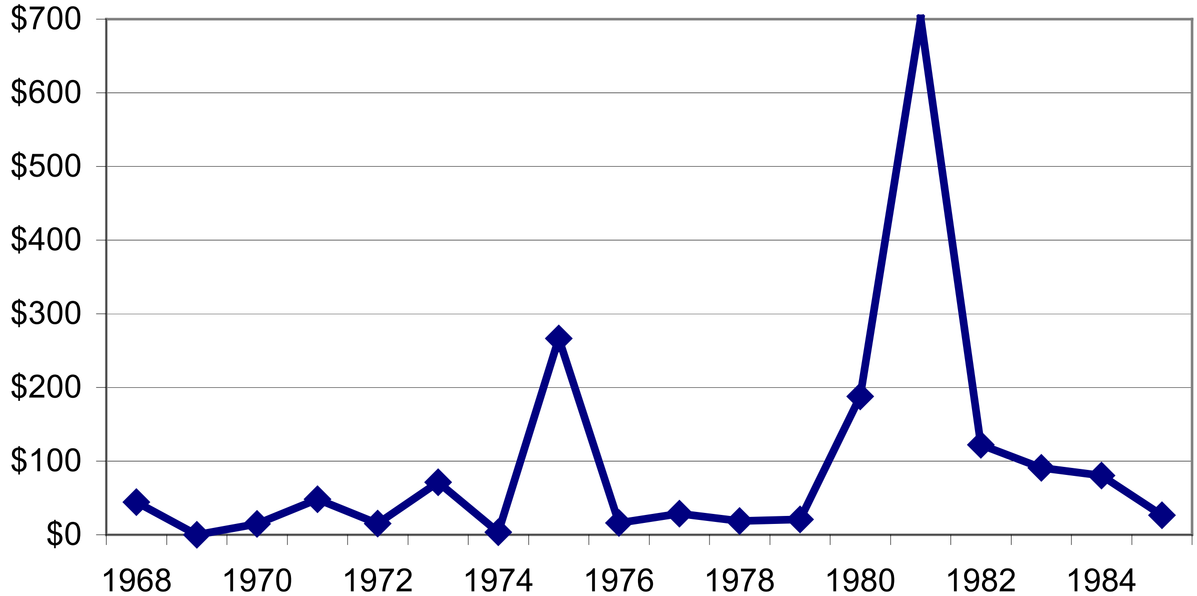

Figure 2: Estimated Aggregate Emissions of CO, NOx, and HC from Light-Duty Gas Vehicles, 1970-1985

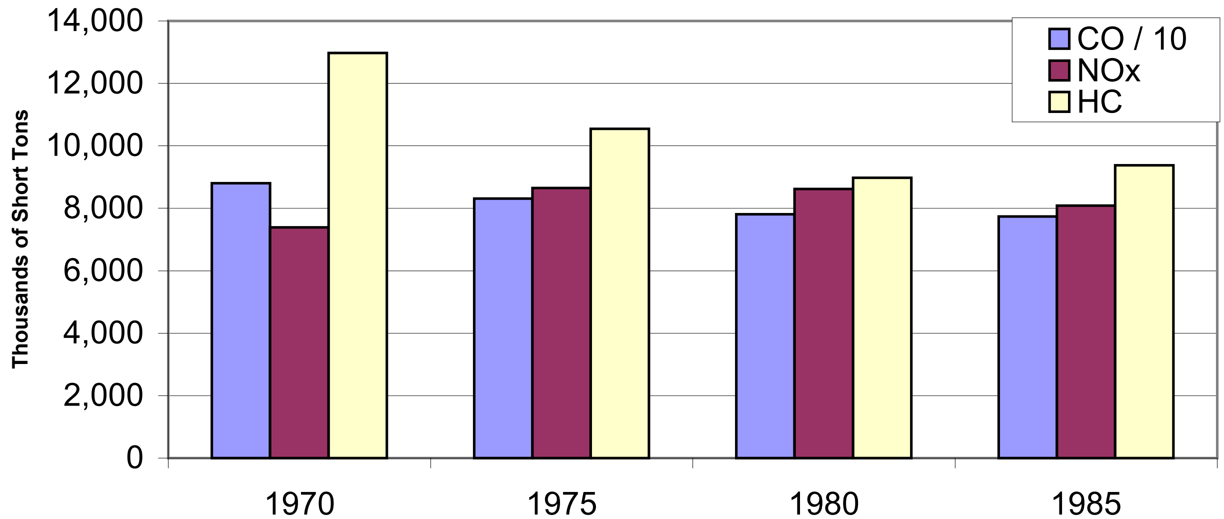

Table 1: Federal Emissions Standards, 1968-1981

Model Year	HC	CO	NOx
Uncontrolled Vehicle	8.7	87	4.4
1968	6.2	51	--
1970	4.1	34	--
1972	3.0	28	--
1973			3.1
1975	1.5 (0.41)	15 (3.4)	
1976			(0.41)
1977			2
1980	**0.41**	7	
1981		**3.4**	1

Notes: Measurements are in grams per mile. Numbers in parentheses are the 1970 Clean Air Act standards. Numbers in bold indicate that the standards in place satisfied the 90 percent requirement.

Table 2: Timetable of Delays

December 31, 1970	Clean Air Act Amendments direct EPA to set standards and federal test procedure
June 23, 1971	EPA sets standards for 1975 Model Year
January 1, 1972	NAS issues report suggesting technology to meet standards is not yet available.
March 13, 1972	Volvo requests delay of standards. Other automakers follow suit, including the Big Three on April 5.
May 12, 1972	EPA denies extension
December 18-19, 1972	D.C. Court of Appeals hears automakers appeal and remands the case back to EPA for further investigation (I.H. v. Ruckelshaus)
December 30, 1972	EPA issues supplement to Decision of the Administrator,
February, 1973	D.C. Court of Appeals again remands (I.H. v. Ruckelshaus)
April, 1973	EPA delays in HC, CO standards
June, 1973	EPA delays NOx standards
June, 1974	Congress extends interim HC, CO standards to 1977 and NOx to 1978
February, March 1975	EPA extends interim HC, CO standards to 1978 in response to concerns about sulfate levels
August, 1977	Clean Air Act Amendments push interim HC to 1980 and CO, NOx standards to 1981