Experiments in technology forcing: comparing the regulatory processes of US automobile safety and emissions regulations

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Abstract: Technology forcing is a strategy where a regulator mandates a standard that cannot be met with existing technology to internalise external costs associated with the production and/or use of a product. We argue that the implementation process for these policies has a pronounced effect on how regulations affect the development and diffusion of new technologies. To examine this proposition, we look at two case studies of technology forcing policies targeting US automakers: The 1969 Department of Transportation airbag mandate and the 1970 Clean Air Act emissions requirements for new vehicles by 1975. The results of these two mandates were quite different. EPA successfully forced the adoption of catalytic converters, while airbags did not become compulsory for nearly 20 years. We demonstrate that these results did not stem from differences in complexity or costs of adopting the technologies, but instead were a product of political and regulatory variables that influenced the implementation process.

Keywords: technology forcing; regulation and technological change; automobile regulations.

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1 Introduction

As its name suggests, a technology-forcing strategy specifies a regulatory standard that cannot be met with currently available technology, forcing firms to develop and adopt a viable compliance strategy. The promise of this approach is that a new technology will emerge, drastically improving performance. Implementing technology-forcing policies places considerable pressure on firms, regulators, legislators, the courts, and other stakeholder groups. Regulators must exert pressure on firms to conduct R&D, evaluate technological progress, and decide whether to implement the standards on time. Firms must make research and product development decisions in an uncertain regulatory environment. If firms cannot meet the standards, regulators have to determine whether it was because recalcitrant firms did not try hard enough to develop the technology, or whether good-faith efforts simply failed to elicit necessary technological breakthroughs. On this basis regulators must decide whether to delay the standards, levy fines or even shut down the industry. If standards are put in place, firms could be forced to adopt unproven or unreliable new technological fixes. Consequently, firms are likely to appeal for regulatory relief from legislators and the courts.

There is a growing literature examining the extent to which regulations can induce technological change (Jaffe *et al*., 2003). Many economists believe that market mechanisms are more likely to spur technological advance than command-and-control regulations.[1] Yet, little attention is paid to the role of the implementation process. The thesis that we advance in this paper is that the regulatory implementation process is a central element in the relationship between regulations and technological change. Regulators and firms are each attempting to change the actions of the other party, and the dynamics of this process shape both technological and regulatory outcomes.[2] As a result, the nature of the implementation process itself can be as important as instrument choice in whether regulations effectively induce firms to develop and adopt new technologies.

To examine this proposition, we turn to the US automobile industry, where regulation often targets technological fixes as a means to internalise external costs. Specifically, we compare two episodes that played out during the 1970s. The first was the Secretary of Transportation's 1969 decision to force the automakers to develop and install airbags on their vehicles to protect unbelted passengers. The second was the 1970 Clean Air Act Amendments, requiring automakers to reduce new-vehicle emissions by 90% within a four- to five-year period.[3] The comparison is apt for a number of reasons. First, these regulatory processes occurred simultaneously. Second, the costs and complexity of the necessary technologies appear to be within the same range. Third, in both cases firms were able to develop and adopt the targeted technologies.

Despite the similarities, the results of these two regulatory efforts were quite different. The initial airbag mandate was drawn out and ineffective. GM demonstrated that technology worked by installing airbags on several thousand of its vehicles in 1973. Nevertheless, the regulatory agency – the National Highway Traffic Safety Administration (NHTSA) – did not require airbags, and consequently regulations played a limited role in airbag adoption. Rather, the adoption of airbags was predominantly a market-driven phenomenon (Mannering and Winston, 1995). The story for emissions-control technologies is much different. Although automakers failed to meet the performance targets by the statutory deadlines, two marquee technologies emerged and diffused across the US fleet – the catalytic converter in 1975 and the three-way catalyst in 1981. These technologies led to significant emissions reductions, though US automakers did not meet the standards set in the 1970 statute until 1993.

Our interest is in determining the characteristics of the implementation process that make it more or less likely that technology-forcing policies will lead to adoption and diffusion of new safety and environmental control technologies. Thus, there are two questions of interest. First, did the regulatory process foster technological change? And, second, what are the factors that lead regulators to implement the standards? We do not attempt to evaluate the efficiency of these technology-forcing attempts. Instead, we take it as given that regulators are interested in pursing a technology-forcing strategy. It may well be the case that other policy approaches would have met the desired policy goal more efficiently.

We begin by reviewing several theories of technology-forcing regulations, and the factors that could lead firms to increase or reduce their R&D into safety features and emissions control technologies. In the following two sections, we draw on these theories to inform our case studies of safety and emissions technologies. To sharpen the connections between theory and practice, we conducted interviews with a number of individuals, representing the automakers and the regulatory community, who were involved in the regulatory process through the 1970s. The interview material augments a considerable body of evidence contained in published histories, court decisions, and economic analyses related to the safety and emissions regulations. Next, we compare the results and offer possible explanations for the different regulatory outcomes. Finally, we offer some tentative conclusions about technology-forcing regulations lessons from our case studies, and offer some directions for future research.

2 Economic theories of technology-forcing

In the case of automobiles, we would expect technological change to be driven by market forces, including consumer demand and product liability concerns. If consumers are not willing to pay more for a vehicle with superior environmental or safety attributes, then the market will underprovide these amenities. For example, the consumer incurs the full cost of reducing emissions, but the marginal benefits are spread across the entire population. Thus, it is unlikely that unfettered markets will bring about superior emissions control systems. In contrast, consumers are likely to capture a significant share of the benefits of improved safety, and might be willing to pay more for the superior safety features. However, consumers might systematically underestimate the effectiveness or value of these attributes, resulting in socially sub-optimal levels of safety.[4] The rationale for instituting a technology-forcing policy is that the preferred outcome of the government/regulator is a technological fix of the problem that can only be brought about by applying regulatory pressure on firms.

There is the potential for confusion distinguishing technology forcing measures from technology standards. A technology standard specifies the process to be used, and is usually based on an existing technology that has been developed and adopted in some form. In contrast, a performance standard requires firms to meet a mandated target, but the standard does not specifying the use of any particular technology. Technology forcing can take either form: it can mandate performance levels that are not currently technologically feasible, or mandate the development of a specific technology that is not currently viable. A regulator can also identify a preferred technology, and set performance standards that are likely to force the development of that technology.

A salient feature of the technology-forcing process is that firm R&D decisions and regulator enforcement decisions are each endogenous to the implementation process. To motivate firms to conduct R&D, regulators must be able to credibly assert that regulations will be enforced. However, firms often have greater information about their own technological development than regulators. Firms might be able to exploit this asymmetry by deliberately missing the standard – hiding their innovative capabilities, under-investing in R&D, and claiming that the standards cannot be met. If industry participants argue that meeting a standard is impossible, and regulators have no foundation to contradict them, then it is unlikely that regulators will be able to enforce the standards (Yao, 1988; Kleit, 1992).[5] To be effective, regulators must be able to limit or erase these information advantages. The regulatory agency can establish its own technical division to conduct research, contract out the research, or rely on competing stakeholder groups to supply it with information. In the USA, for example, congress often commissions the National Academy of Science to study technically challenging policy issues.

Regulators can also provide incentives for industry participants to reveal information voluntarily by promoting a competitive dimension. Competition can emerge in a number of forms. If a firm believes that it can *raise its rivals' costs* and operationalise a cost advantage, it might be willing to share information with the regulator (Hackett, 1995; Puller, forthcoming). Similarly, firms might share information to persuade an agency to tailor regulations to the specifications, especially if there is a pending technology standard. The strategy can fail if regulators fail to reward a firm that successfully innovates by actually implementing the regulations. Foreign firms and components providers can also supply a competitive push. A regulator might not have the political support to levy heavy fines or shut down a domestic firm, which undermines regulator credibility. However, this constraint likely will not apply with equal weight to shutting down foreign competitors. As a result, foreign firms might have greater incentives to develop compliance strategies. Regulators benefit if foreign firms successfully innovate because the success undermines claims by domestic firms that standards are unattainable. Similarly, components providers have the incentive to demonstrate the effectiveness of new control technologies as a means to expand the market for their products. For the competitive element to be effective, participants must believe that standards will be enforced.

The starting point for thinking about regulator-firm interaction is that firms conduct R&D in order to comply with regulations. R&D is costly, but it can lead to innovations that will reduce costs of regulatory compliance. In this framework, firms will conduct R&D up to the point where the marginal benefit and the marginal costs are equal. There are three common modelling scenarios. The first is that regulations are exogenous; that is, firms take regulations as given and regulator-firm interactions have no bearing on regulatory standards. A second is the regulated monopoly. Here regulator-firm interactions and strategic behaviour are important, but there is no competition among firms. Finally, the general case is where regulations are a product of firm and regulator interactions, and there are multiple firms, the possibility of entry, and/or participation by components parts providers or other industry interests.

Puller (forthcoming) develops a model that includes these cases, along with the generalised case. Table 1 sketches basic theories of the relationships between regulations and firm incentives to conduct R&D under these conditions. In each case, a primary motivation for firms to innovate is to reduce the costs of complying with innovation, and R&D costs are decrease the incentive to innovate in each case. A monopolists by definition do not have competitors, and therefore raising rivals' costs and spillovers are not central to its decision (except to the extent that entry is possible). The monopolist is concerned that a regulator will respond to successful innovation by demanding further improvements, and therefore the ratchet effect is a concern. If regulations are exogenous, then firms cannot influence regulatory stringency, nor will regulators respond strategically to successful innovation. Therefore, neither the ratchet effect nor raising rivals' costs will affect firm incentives. However, even in a competitive environment where regulations are exogenous, firms will be concerned about the extent to which they can capture the full value of their innovations.

Table 1 Generalised model of R&D incentives

Variables affecting firm incentives	*Generalised model*	*Regulated monopolist*	*Regulations exogenous*
Reduce compliance costs	+	+	+
Raise rivals' costs	+		
R&D costs	–	–	–
Spillovers	–		–
Ratcheting, regulator credibility	–	–	

Source: Puller (forthcoming)

Uncertainty enters the technology-forcing process in a number of forms. The link between R&D and technological breakthroughs is not deterministic, and therefore regulators must assess whether firms made good-faith efforts to comply. In addition, there will be uncertainties pertaining to the costs of adopting a new technology, the reliability and effectiveness, unintended consequences of its use, as well as potential lock-in of inferior technologies. If technology-forcing efforts target an accelerated timetable for adoption, short time horizons reduce possibilities of resolving some of these uncertainties, and make the system vulnerable to economic or political shocks. Finally, an adversarial regulatory process fosters litigation, and court decisions are both unpredictable, and can have lasting impacts on present and future regulations.

3 Regulating the US automobile industry

The two pieces of enabling legislation guiding our case studies are the 1966 Motor Vehicle Safety Act and the 1970 Clean Air Act Amendments. Both of these statutes passed with overwhelming support. In each case, the statute ushered in a new area of regulation. The original safety regulations were to be handled by the Department of Commerce before the Department of Transportation opened in 1967. Similarly, the initial air pollution control was handled by the Department of Health, Education and

Welfare (which largely followed the lead of California regulators) before EPA was established in 1970. As we will see, these statutes provided very different directives to the regulatory agencies. These differences resulted in different regulatory processes, and, we argue, to differences in regulatory outcomes.[6]

4 Case 1: safety

The Motor Vehicles Safety Act in 1966 required the National Highway Safety Board (NHSB) to put standards in place by 31 January 1968. The legislation provided a broad mandate to improve automobile safety by establishing standards that were 'reasonable, practicable and appropriate'. For the most part, the agency issued technology standards, designed to get all new vehicles to have state-of-the-art safety features. However, the agency took a bolder, technology-forcing approach for airbags and for antilock braking systems.

One of the major issues in the debate on vehicle restraints was the choice of active versus passive restraints, and the political debate and the regulatory process treated the two as substitutes, not complements. Seat belts are considered active restraints because the passenger would have to fasten the seatbelt; whereas, an airbag is a passive restraint because a consumer is protected automatically. Many safety advocates argued that relying on passengers was not good enough, and therefore pressed for passive restraints.

In July 1969, with the support of Secretary of Transportation, John Volpe, the Department of Transportation issued an advanced notice of Rule 208, calling for mandatory adoption of inflatable restraints. The standard did not specify a deadline, but suggested target dates of 1971 or 1972. In Spring of 1970, NHSB firmed up the deadline for implementation, mandating passive restraints on all vehicles by 1 January 1973, but the final rule issued in November pushed the deadline back to July 1973.

In contrast to the conventional wisdom, the auto manufacturers did not reflexively oppose the proposed rule. Instead, there was considerable heterogeneity of opinions. The Ford Motor Company revealed plans to put airbags on some of its 1971 vehicles, while at the same time GM quietly launched its own programme under the assumption that the strength of its R&D division gave it the edge in any technology race. There was also a push from components parts providers, which were very optimistic about the prospects for rapid development and adoption. There was considerable dissent from the position. The dominant opinion at Chrysler, for example, was that airbags were not cost effective, that they diverted resources from other safety research, and created liability issues. Volkswagen and Mercedes-Benz also opposed the rule. As GM's technological advantages became apparent, Ford also backed off its support of the mandate (Graham, 1989).

If consumers are willing to cover the costs of airbags, then producers should have adopted airbags (in theory, at least) whether the regulations are put in place or not. However, if consumers are not willing to pay for the full costs, the adoption depends both on the technological development of airbags and enforcement of the regulations. The behaviour of the firms and components providers suggests that competition to meet the expected regulatory standard, not competition to satisfy consumer demand, was the primary driver of R&D into airbag technology. Firms that opposed mandatory adoption took a number of routes to block the regulations from going through.

As the opinion at Ford shifted to oppose airbags, the company shopped a technological alternative to the airbag – an interlocking belt system that would not allow the vehicle to start unless the passenger seat belts were fastened. In addition to the technology alternative, in April 1971 Henry Ford II and Lee Iacocca went to the White House to lobby for a delay in the passive restraint requirement. In response, the White House encouraged regulators to delay the standards, and in October NHTSA pushed back the implementation date until 1975. When the final rule was issued in February 1972, automakers had the option to use interlock devices or airbags to satisfy the requirements.

While Ford lobbied the executive branch, Chrysler sued the agency directly. Chrysler argued that NHTSA lacked the authority to issue technology-forcing standards. In December 1972, the court found that NHTSA had the authority to set technology-forcing standards, but needed better performance criteria. However, the court found that the crash-test dummies did not allow for consistent and reliable measurement of performance and therefore the agency had no way to objectively certify any devices. In effect, the technical problems paralysed the agency because its staff lacked the expertise to satisfy the information demands that the court established (Mashaw and Harfst, 1990).

GM demonstrated its commitment to the airbag by equipping 1973 model year Chevys with air bags and no belts, and GM's technical staff worked with NHTSA to improve measurement. Because GM was a technology leader in the field, the technical assistance essentially eliminated any regulator information disadvantage, and allowed NHTSA to issue a revised dummy standard in April 1973. The technology-forcing regulatory process was essentially over at this point: the technology had been proven, and the debate concerned whether regulators could force the adoption. This is essentially the domain of a technology standard.[7]

Meanwhile, car companies had been given the option to satisfy the passive restraint requirement with interlock system on 1973 and 1974 vehicles. The interlock systems were plagued with mechanical problems, and even when (or, especially when) the system worked flawlessly, consumers found the system irritation. In response to the public outcry, congress rescinded the regulation. In addition, congress established a legislative veto that gave it the authority to vote down any regulation coming out of NHTSA. The legislative veto was later found unconstitutional, but it underscores the unpopularity of the interlock systems.

Following the interlock debacle, the rulemaking process became much more politicised along party lines. The lame duck administration of President Gerald Ford brokered an agreement with several automakers to install devices on 500 000 vehicles in 1980 and 1981. Under the Carter Administration, NHTSA decided to terminate this agreement and re-established the passive restraint rulemaking process. By July 1977, NHTSA promulgated a rule requiring passive restraints on all cars.

Carter, however, was a one-term president, and the lead-time for the requirement bled over into the Reagan Administration. Less than a month into office in 1981, NHTSA delayed the standard another year. This prompted insurance companies to enter the fray and sue the agency, and in July 1983 the Supreme Court found that the agency had no basis for such a delay *State Farm Automobile Insurance v. Dole*, 802 F.2d 474 (D.C. Cir. 1986). Although the airbag proponents had won the day, the process had been pushed back another several years, and NHTSA did not issue a final rule on the matter until July 1984. The rule required a phase-in of airbags between 1986 and 1989 unless mandatory seat belt laws were put in place.

At this point the rulemaking procedure was 15 years old, and airbags were still not required equipment. However, for reasons that are not altogether clear, firms began to think about safety differently. One explanation is that domestic firms thought it was a good dimension to compete against Japanese producers. For whatever reasons, Ford and Chrysler began to offer airbags, and consumer willingness to pay was soon higher than the marginal installation costs, fostering rapid diffusion of airbags across the fleet (Mannering and Winston, 1995). The popularity of airbags made it much easier for the agency to make them required equipment.

5 Case 2: emissions technology

Unlike the safety legislation, the legislative directives of the 1970 Clean Air Act were very explicit both with respect to performance targets and the implementation process itself. Congress mandated 90% reductions in tailpipe emissions, to be enforced for HC and CO in 1975, and for NOx in 1976. EPA was to assess a $10,000 fine (current dollars) for each car sold that was not certified to meet these standards, effectively prohibiting sale of any car that could not comply (the average new vehicle price of a 1975 vehicle was $5,000). EPA could grant a single, one-year delay of the standards if the necessary technology and hardware did not become available. As a means to assess the industry's progress, congress directed the National Academy of Sciences (NAS) to evaluate the technological feasibility and costs of implementing the standards.

The competitive pressures driving the development and diffusion of catalytic converters were not particularly robust. Before the enactment of the Clean Air Act Amendments, GM President Ed Cole promised to put catalytic converters on all GM vehicles if EPA took steps to make unleaded gasoline available. The initial compliance cost estimate was $860 per vehicle (Mondt, 2000), which translated into a $5 billion per year industry savings for each year the standards were delayed (current dollars). GM and Ford investigated catalyst technologies and continued to set up production facilities to manufacture the equipment, it does not appear that the two companies were competing to meet the standards as a means to raise their rivals' costs. By 1973, GM was expressing public opposition to implementation of the 1975 standards.

Japanese producers developed the stratified-charge engine that would be able to meet the HC and the CO targets by the 1975 deadline. The introduction of this technology did not provide a very robust competitive dimension to meet the standards, however. For example, Ford was familiar with the technology, but reluctant to adopt it for a variety of reasons, notably because it increased NOx emissions.[8] Chrysler did not have an R&D programme to develop the catalytic converter, and the company did not secure commitments from parts suppliers.

EPA was confident that modest improvements in catalyst technology would be enough to meet the HC and CO targets.[9–10] The EPA technical staff equipped its own vehicles built with carburettors and no on-board electronics that met the standards for 50 000 miles, erasing any major information advantage enjoyed by the industry. As a result, the agency was in a favourable position to contend that the technology was available, and the standard would go into place on time.[9]

NAS questioned the technological effectiveness and availability in its 1 January 1972 report, casting doubt on catalyst availability by 1975 (though its estimated compliance costs were down to \$288). Based on the NAS report, automakers petitioned for a delay. Unlike NHTSA, EPA rebuffed the industry and rejected these petitions. As a result, the automakers sued EPA. After two iterations through the court process, the appellate court, citing continued questions about technological availability, continued to favour a delay of the 1975 standards. The court was reluctant to enforce standards that were likely to have serious impacts on the industry, and particularly on Chrysler. At the same time, however, the court counselled EPA that the agency could set interim standards, and it discussed the precedent for doing so (*International Harvester v. Ruckelshaus*, (D.C. Cir. 1973) 478 F. 2d 615).

Interim standards were not an option contemplated by congress, which provided an all-or-nothing menu for the agency. Nonetheless, in April 1973, EPA granted a one-year delay of the 1975 HC and CO standards, while setting interim standards that required roughly 50% reductions relative to the standards in place in 1970. GM and Ford could only meet these standards with catalyst technologies, and both companies were forced to adopt the devices. EPA did not induce the emissions performance that congress had mandated, but it did force massive industry expenditures and rapid adoption of a new pollution control device. Industry capital expenditures jumped from \$630 million in 1974 to \$3.73 billion in 1975 (EPA, 1997). As a result, aggregate HC and CO emissions dropped sharply despite continued increases in vehicle miles travelled.

Although the catalytic converter led to sharp emissions reductions, meeting the full 90% reductions would require required further reductions in HC and CO, along with the full reduction of NOx. To this point firms had made almost no progress reducing NOx emissions. In July 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). There were also two subsequent delays of the HC and CO standards stemmed from exogenous changes in the economic environment (the 1973 oil embargo) and potential unforeseen environmental impacts of the catalytic converter (excessive sulphate emissions) illustrate further hitches with the technology-forcing process (Stork, 1977). These delays pushed the target deadlines to 1978.

There were several major differences from the first stage, both with respect to technology and the institutional setting. First, unlike the catalytic converter, the three-way catalyst required significant engine improvements and computer technology to function properly. 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. These challenges, however, did not seem to spur increases in R&D efforts. After firms had developed the catalytic converter and committed to installing it, there was an industry-wide lull in R&D intensity. It is not possible to tell whether this was because the industry faced severe economic pressure or because firms sensed that further emissions reductions were not politically viable. In either case, it appears that there was less R&D, and there was certainly no technological breakthrough that allowed firms to meet the impending 1978 standards.

As the 1978 deadline approached, EPA lacked discretion to delay the standards, and the lack of industry progress forced the hand of congress. In 1977, congress enacted the further amendments to the Clean Air Act, pushing the HC and CO standards back to 1980 and 1981, respectively, and setting the NOx standard at one gram per mile – two and a half times higher than the requirement from the 1970 statute. The failure of firms to meet the targets was likely due to some combination of reduced R&D efforts and difficulties with the complexities of the enabling technologies.

Despite continued technological challenges, a contentious adversarial process did not result for the period between 1978 and 1981. The legislation provided firms with a target date for the initial instalment and in 1981, US 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% of the new US vehicles were equipped with the devices in 1981 (Bresnahan and Yao, 1985). There were numerous problems with the new technologies, leading to massive recalls (Doyle, 2000).[11–12] However, through the 1980s companies refined the technology, significantly reducing all of the criteria pollutants. By 1993, GM was certifying cars that could meet the 1970 statutory requirements for HC, CO and NOx.[11]

6 Issues in technology-forcing: comparing the safety and emissions cases

EPA successfully pushed development and implementation of the catalytic converter in the 1970s. At the same time, however, NHTSA failed to push through its airbag mandate. GM wanted to have the standards enforced, but NHTSA did not accommodate these wishes. In each case, the major auto producers were able to develop suitable technologies within the time period allotted by the technology-forcing mandates. The key question addressed in this paper, therefore, is what accounts for these different regulatory outcomes? Table 2 contains a summary of the salient comparisons.

Table 2 Comparison of safety and emissions cases

Variable affecting technology-forcing process	*Catalytic converter*	*Airbag*
Technological complexity/costs	$200–$250	$235 (for GM)
Asymmetric information	EPA erases advantage	GM reveals information
Regulatory mandate	Legislative (congress)	Regulatory (agency)
Raising rivals' costs	Maybe	Yes
Courts	Disruptive/Accommodating	Accommodating/Disruptive
Dealing with non-compliance	EPA winks at Chrysler	?
Liability concerns	Recalls	Yes

6.1 Technological complexity and costs

The different results of the two regulatory episodes do not appear to be driven by differences in costs or complexity of the technological solutions. GM installed airbags on several thousand vehicles in 1973, illustrating that the technology was workable. GM also offered airbags on a number of models between 1974 and 1976, at a price of $235.

However, by the end of the decade no US producer was equipping its vehicles with airbags. In contrast, GM and Ford each put catalytic converters on their vehicles in 1975 (at a unit cost of roughly $250 per vehicle), and by the end of the decade virtually all automobiles sold in the USA employed catalyst technologies.

6.2 Regulator pressure and credible commitment

Several factors affect whether a regulator can credibly commit to enforcing a standard. The first is information asymmetries. If regulators do not have good information about feasibility and costs of compliance, firms can use this information advantage to force a delay of the standards. Regulators can attempt to reduce this advantage by gathering information, or attempting to get firms to reveal it voluntarily. Information advantages do not account for the different regulatory outcomes. EPA certainly had its own test facilities and a highly competent technical staff, and the agency quickly erased the information advantage during its technology-forcing process. However, NHTSA was able to elicit information from firms about passive restraint technology, along with technical information about testing. Thus, the information asymmetry was not a decisive factor to explain these differences.

The second factor of credibility is the difference between congressional and administrative standard setting. Under the Clean Air Act, congress did not delegate authority to EPA and instead wrote explicit regulatory standards that circumscribed the regulatory process. EPA lacked the authority to push back standards, while NHTSA repeatedly delayed the standards. In April 1971, Henry Ford II and Lee Iacocca met with President Nixon and his domestic affairs advisor, John Ehrlichman. The automobile executives were facing two technology-forcing mandates – emissions control and passive restraints. However, this visit addressed only the passive restraints deadline. According to Mashaw and Harfst (1990):

> "They wanted relief from environmental requirements too, but they knew that was impossible. They had already talked to William Ruckelshaus at the Environmental Protection Agency (EPA) and had been given a lesson in statutorily mandated regulation. The Congress had put EPA emission control criteria under a strict statutory timetable that neither agency nor industry could evade for long. Under that statute manufacturers might get a year's relief, but only if they could demonstrate their own failure in good faith effort at compliance."

This passage suggests that congressional mandates supply considerable credibility to regulatory agencies. The evidence indicates EPA was determined to enact regulations on time, so congressional restraint does not explain EPA actions. It is not possible to assess whether congress would have delayed an airbag mandate if it had not delegated authority to NHTSA.

6.3 Competition

There are a number of potential sources of competition. Firms can try to establish a competitive advantage by developing a new technology and raising their rivals' costs; components providers are looking for a market for their wares; and foreign competitors are wary of being shut out of the market. Components providers were influential, but not decisive, in both the emissions and the safety cases. Foreign competitors did not seem to be the driver in either case. Although the stratified-charge engine met the 1975 emissions standards, neither EPA nor producers took this seriously as a compliance option. Competitive forces contribute to regulator commitment, by supplying information about feasibility and costs of compliance strategies. Firms that stand to gain from the adoption of regulations might voluntarily reveal information to regulators, erasing any extant information asymmetries. Although the competitive dimension appears to be theoretically and intuitively important, its impacts on regulatory outcomes in these two cases are dubious. Competition was not a major force in the development of the catalytic converter. At the same time, competitive pressures clearly drove GM to develop airbags, yet NHTSA failed to implement the airbag mandate.

6.4 Courts

The technology-forcing process is inherently adversarial, and therefore the courts are going to play a role. We have seen that in the safety case, the court decision essentially paralysed the regulatory process, making it almost impossible for regulators to enforce a standard (Mashaw and Harfst, 1990). In contrast, the appellate court that handled the initial adversarial process encouraged EPA to set an interim standard rather than delaying the standard. By setting the interim standards, EPA was able to force one set of producers to install catalytic converters, while essentially winking at Chrysler.

Liability concerns are a second reason why the courts might be important when thinking about technology-forcing. Damage awards related to death or injury are much higher than damage awards associated with a failed emissions system. As a result, a producer might be reluctant to adopt an unproven technology that creates liability exposure (Graham, 1991).

7 Conclusion

Technology-forcing has enjoyed considerable public support in the past, and legislators and regulators are likely to continue to forward the technology-forcing option. Therefore, an understanding of the machinations of technology-forcing is crucial to thinking about regulations designed to promote technological change. In this paper, we examine two case studies of technology-forcing policies directed at US automakers. Our interest is in determining the characteristics of the implementation process that make it more or less likely that technology-forcing policies will lead to adoption and diffusion of new safety and environmental control technologies. We conclude that the differential regulatory outcomes were not the result from differences in complexity or costs of adopting the technologies. Instead, political and regulatory factors of the implementation process were decisive.

These regulatory episodes led to major advances in environmental and safety technologies. Whether the regulatory efforts produced efficient results is a separate matter, and ultimately not central to our analysis. Congress and the state of California are likely to continue to pursue strategies to force improvements in environmental, safety, and fuel economy performance of new vehicles. This paper provides a framework for thinking about implementation of technology-forcing policies, and is a first step to an understanding of whether technology-forcing can provide an effective public policy choice.

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Notes

1 See Jaffe *et al.* (2003) for a thorough review. The empirical evidence generally favours market instruments over command-and-control, but the theoretical predictions are less clear cut.

2 Here we differentiate between technological and regulatory outcomes because it is possible that regulations will induce technological breakthroughs, yet regulations are delayed or withdrawn.

3 There are two other significant examples of ambitious policy goals affecting US producers. In 1975, congress directed companies to double their average fuel economy within a decade. This was not directly a technology-forcing effort, however, as these standards could be met by altering the mix of vehicle sales. More recently, a 1990 the California Air Resources Board regulation required that automakers make and sell zero emissions vehicles as 3% of their 1998 new car sales, and this percentage was to eventually increase to 10%. However, electric vehicle technology to compete with the internal combustion engine has not emerged, and automakers are abandoning their electric vehicle programmes.

4 In the case of fuel economy, for example, we argue show elsewhere that it is commonly assumed that consumers have discount rates that are far higher than social preferences for fuel conservation. If this assumption is valid, then consumers will systematically demand levels of fuel economy that are below social preferences for fuel conservation (Gerard and Lave, 2005).

5 Lewis (1996) reviews information issues in environmental policy.

6 The two case studies are necessarily abbreviated. For a more detailed examination of the technology-forcing process for emissions see Gerard and Lave (2003). For general historical accounts see Doyle (2000) and Krier and Ursin (1977). Two excellent accounts of the safety regulation are Graham (1989) and Mashaw and Harfst (1990).

7 After 1974 NHTSA, the rulemaking momentum within NHTSA lost steam. One of the major themes of the book by Mashaw and Harfst is that institutional changes brought about by judicial review transformed NTHSA from a rulemaking agency to an enforcement and recall agency. If the proposition is correct, then it should not be surprising that the agency had trouble implementing this technology standard.

8 Pestraukas, H., retired Vice-President of Environmental and Safety Engineering, Ford Motor Company, in a phone interview with David Gerard, 10 February 2003.

9 Austin, T., former Technical Analyst for EPA and Deputy Executive Officer for California Air Resources Board mobile source programme, in a phone interview with David Gerard, 27 November 2001.

10 Stork, E.O., former Deputy Assistant Administrator for Mobile Source Air Pollution Control at the US Environmental Protection Agency, in phone interviews with David Gerard, 27 November and 14 December 2001.

11 Leonard, S., retired Director of General Motors Public Policy Center, in personal interview with David Gerard, 8 November 2001.

12 Colucci, J., retired Head of the Fuels and Lubricants Division for GM Research Labs, in personal interview with David Gerard, 8 November 2001.