INNOVATION IN AUTOMOTIVE EMISSION CONTROL TECHNOLOGIES: GOVERNMENT ACTIONS AND INVENTIVE ACTIVITIES

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ABSTRACT

The primary aim of this investigation is to understand the impact of government regulations on innovation in the development of automotive emission control systems. Analysis of regulatory measures and a longitudinal study of patenting indicate that governmental actions in the form of “technology-forcing” standards have stimulated innovations.

INTRODUCTION

Innovation processes for automotive emission control technologies are particularly interesting since innovation took place under “technology-forcing” regulation, laws which impose emission standards above the technical capabilities of emission control devices at the time that laws are passed. Effectiveness of environmental regulation on technological innovation is not clearly understood (Jaffe, Newell et al., 2002). Proponents of regulation claim that greater stringency of environmental regulation provides incentives for firms to develop new and less costly ways of reducing pollutants (Jaffe and Palmer, 1997). Yet, more systematic assessments of the impact of regulation on innovation necessitate more systematic empirical evidence.

This research aims to contribute to the literatures in environmental policy and management of innovation by providing empirical analyses of the effect of technology-forcing policy interventions on innovation using automotive emissions control technologies as a case. Prior studies on technology-forcing on automobile emission control technologies have typically relied on qualitative judgments by examining relationships between the introduction of new technologies by industry and the onset of regulations by government (NESCAUM, 2000). This study extends prior work by analyzing quantitatively the automobile industry’s patenting behavior in emission control technologies. This study focuses on the period from 1968 to 1998. The technologies covered for this study include not only technologies related to catalysts, first used in 1975, but also other technologies such as electronic controls, thermal management systems, and advanced engine controls with integrated catalytic converters that comprise modern automotive emission control systems.
TECHNOLOGY-FORCING REGULATION AND INNOVATION

The technology-forcing approach is generally believed to be a more efficient way to bring about technological innovation (McGarity, 1994; Kemp, 1997). Unlike a technology-based standard, which relies on existing technologies to bring about pollution reductions, technology-forcing standards essentially require innovation to meet the standards by setting performance levels that are beyond known existing technical capabilities of the manufacturers, thus “forcing” technological innovation.

Innovation in automotive emission control technologies provides a very interesting case for understanding the impact of technology-forcing regulation on technological responses from the regulated industry primarily because automotive emission control technologies represent a more complex set of technologies than previously studied cases of CFC phase out or flue gas desulfurization systems used for SO₂ control for electric power plants (Taylor, 2001). The research question is whether technology-forcing government regulations have influenced innovative activities by the automobile manufacturers and their suppliers. And if so, the second question is whether increasing stringencies of technology-forcing regulation have led to more advanced technologies. These research questions address whether technology-forcing regulation could be an effective policy instrument in inducing technological innovation in environmental control.

DATA AND MODEL SPECIFICATION

I performed three analyses to investigate the impacts of government actions on innovation in automotive emission control technologies: regulatory action analysis, patent analysis, and econometric regression analysis. I used patenting activities in automotive emission technologies as indicators of innovative activity and developed the relevant patent set using patent data from the U.S. Patent and Trademark Office (USPTO). I used both an abstract-based keyword search and a class-based search method. I also adopted citation-weighted patent counting in addition to simple patent counting (SPC) to account for values Inset patent set have on subsequent innovation. As for a citation-weighting scheme, I adopted a linear weighting scheme used by Trajtenberg (Trajtenberg, 1990). The relevant governmental regulations considered are the 1970 Clean Air Act (1970CAA), 1977 Clean Air Act Amendments (1977CAAA), 1990 Clean Air Act Amendments (1990CAAA), and National Low Emission Vehicle Program (NLEV). To build robustness into the model, I adopted two control variables, total innovation activity in automotive technologies (TOTAL_PATENT) and market share for cars (MARKET_SHARE) by major contributing countries into the model. The logic in employing these two control variables is as follows: patenting activities in emissions control technologies could just as well reflect the portion of overall innovation activity in automotive technologies, and competitive pressures, especially from foreign makers, could have driven innovation activities in emission controls.

For regression, I employed a panel negative binomial regression model with fixed (country) effects. I incorporated the fixed effect into the model to account for factors that differ across countries but that are relatively stable over time. Such factors that may influence patenting activities include the propensity to patent and organizational cultures (Benner, 2001). In order to account for fixed effects, I disaggregated magnitudes of yearly patent counts by patenting activities of each contributing country: U.S., Japan, Germany, and other countries.
RESULTS

Have Technology-Forcing Government Regulations Influenced Innovative Activities by the Automobile Manufacturers and their Suppliers?

The regression coefficients indicate that regulatory measures, especially the 1970CAA and the 1990CAAA, have significantly influenced innovation in automotive emissions control technologies. Moreover, impacts of regulations on innovative activities are found to be stronger one or two years prior to phase-in dates than innovation activities in the on-set year. This reflects firms’ higher propensity to innovate one or two years prior to the phase-in date. The average lag between file and grant dates for patents related to automobile emissions control was approximately 2.0 years. Regression result also suggests that firms, once they realized that Congress would probably pass the 1977CAAA, reduced the intensity of their innovative activities. Hence, we see reduced patenting activity from 1975 to 1981. Given that the 1977CAAA was enacted to delay the imposition of the 90% emissions reduction requirements, this observation becomes hardly surprising. The industry probably had been developing three-way catalysts (TWC) technologies in the mid-1970s, before the passage of the 1977CAAA, but believed strongly that while a TWC system would ultimately meet the more stringent terms of the 1970CAA, it could not be perfected in time to meet the original schedule.

The effect of the NLEV is found to be insignificant. This can be attributed to its voluntary nature. Manufacturers agreed to participate in the NLEV program in return for regulatory stability with California’s LEV program. Manufacturers who joined the program probably knew that they could comply with it without committing themselves to further R&D investments.

Have Increasing Stringencies of Technology-Forcing Regulation Led to More Advanced Technologies?

This qualitative analysis compares the changes in magnitude of inventive activities with the timing of the enactments of federal regulations. For this analysis, I compared magnitudes of patenting activities with series of onset of automotive emission control regulations and corresponding stringencies for each of three major pollutants. Figure 1 shows emission standards from 1970 to 2004 for HC, CO, and NOx. The standards became notably more stringent in 1975 and 1980, reflecting the 1970CAA and 1977CAAA. Standards remained stable until 1994 when Tier I standards set by the 1990CAAA are phased in. The standards tightened again in 2001 reflecting phasing in of Tier II standards in 2004.

The phasing in of more stringent emission control standards drove innovation in emission control technologies: oxidation catalysts in 1975; three-way catalysts in 1980, and thermal management and onboard diagnostic systems in 1994. Further, advanced catalysts technologies, such as high-density and hexagonal cell-structured catalyst support, and advanced engine control systems, such as electronic exhaust gas recirculation and fuel injectors with improved fuel atomization, are being developed to satisfy stringencies of the Tier II standards (Bertelsen, 2001).
Analysis of emissions-control-related patenting activity and the stringencies of the automotive emissions control standards indicates a close relationship between them (Figure 2). Each increase in stringency led to increased patenting activity. The phasing-in of the 1975 intermediate emission standards and the 1980 emissions standards was followed by increased patenting in the early and mid 1970s. A similar phenomenon occurred in the late 1980s, when patenting activity rose steeply, coinciding with the phasing in of more stringent emission standards in 1994 as a result of the 1990CAAA. Interestingly, stable stringencies in the 1980s resulted in decreased patenting activity from the late 1970s, providing further evidence of the close relationship between stringency of government regulations and innovative activity in automotive emissions control technologies.

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CONCLUSIONS AND FUTURE RESEARCH

The analyses presented here show that technology-forcing regulations imposed upon automotive manufacturers have stimulated innovation by automobile manufacturers and their suppliers. The results from both regulatory action and patenting analysis support a view of the strong relationship between regulatory actions through technology-forcing standards and innovation in environmental technologies.

There are several policy implications of this research. First, the stringency of regulations appears to have driven the direction of innovative activities. Manufacturers had to redirect their emission control efforts from engine modification technologies such as transmission controlled spark and a thermovacuum switch to add-in catalytic converter systems to meet the stringency requirements. Moreover, as stringencies increased, notably in early the 1980s and 1990s, the automotive industry had to innovate--closed-loop control systems with sensors in the 1980s and advanced on-board monitoring systems and thermal management systems in 1990s, respectively--to satisfy the more exacting requirements. This result parallels what Taylor (2001) found in terms of SO2 control technologies.

Moreover, technology-forcing regulations in automobile emissions control led to innovation and diffusion of emissions control technologies for automobiles. In the 1970s, industry executives asserted that the 90% emissions reduction requirement “could prevent continued production of automobiles” and “do irreparable damage to the American economy” (Weisskopf, 1990). However, after 30 years of regulatory actions, new cars today are equipped with emission control devices capable of reducing CO, HC, and NOx by more than 90%.

I am expanding this research to identifying major innovators and sources of innovation in automobile emission control technologies by analyzing patent citations. Sources of innovation for automotive emission control technologies are not clearly understood. Ashford et al. (1985) claimed that the regulated industry and the pollution-control industry are the types of industrial sectors that respond to environmental regulations. It is expected that both regulated firms such as automotive manufacturers and components suppliers specializing in manufacturing pollution-control devices contributed a major portion of the total innovation. However, the degree to which firms from the regulated industry and pollution-control industry contribute to the total innovation is not clear. Further, the knowledge necessary for innovation could have originated
from other institutions such as private and government-funded research institutions, as well as universities.

Prior studies that rely on industry-level data are constrained by their aggregate nature of the data. Thus, firm-level analyses in focused industry studies such as studies of automotive emission control should provide a better understanding of the nature of the relationship between regulation and innovation. It is expected that characterization of historical development of emission control technologies under regulations, identification of sources of innovation and their technological capability as revealed by their patent portfolio will contribute to the literatures in management of innovation by providing a better understanding of how firms under heavily regulated industry respond to regulations.

REFERENCES


Figure 1. Federal Automotive Emission Standards for the Period 1970 to 2004


Figure 2. Patenting Activities in Automotive Emission Control Technologies, 1968 to 1998