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Using patents and prototypes for preliminary evaluation of technology-forcing policies: Lessons from California's Zero Emission Vehicle regulations☆

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ABSTRACT

Technology-forcing policies are one of several measures that governments have at their disposal in order to address market failures arising from knowledge spillover and pollution externalities. However due to uncertainty and information asymmetry, pre-commercial evaluation of these policies can be difficult, especially for radically novel technologies. We use a case study of California's Zero-Emission Vehicle (ZEV) regulations and their impact on electric vehicle technology development by the 21 largest auto manufacturers 1991–2013 to determine whether patents and prototypes are valid preliminary indicators to evaluate the effectiveness of technology-forcing policies. In order to better understand automaker R&D activity, it was necessary to include a global perspective. The results show that patents, when embedded within a global industrial perspective, can be used to analyze technology-forcing policies, which provides a helpful tool for policy makers gauging the effectiveness of these types of regulations in pre-commercial or early market environments.

1. Introduction

Technology-forcing policies are one of several regulatory measures that governments have at their disposal in order to advance innovation (Ashford et al., 1985; Rennings, 2000). These regulations mandate performance levels above current technological capabilities or the adoption of specific innovations that are not yet fully developed (Jaffe et al., 2002; Lee et al., 2010). They "can be used to encourage all varieties of technological innovation as well as diffusion for both product and process change" (Ashford et al., 1985, p.463). The rationale for their use is when, "… a technological fix of the problem can only be brought about by applying regulatory pressure on firms" (Gerard and Lave, 2007, p. 3). Market failures arising from knowledge spillover and pollution externalities provide justifications for policymakers to use this type of regulation (Rennings, 2000). One result of knowledge spillover is that companies engage in reduced levels of early-stage innovation when they are not fully compensated for the benefits of their efforts. (Jaffe et al., 2005). Technology-forcing policies can be used to overcome this barrier while also helping correct for underpriced environmental externalities if the innovation being pushed creates fewer pollution externalities than the alternative.

The automotive sector in particular has seen a great deal of environmental innovation based on technology-forcing emissions legislation (Gerard and Lave, 2005; Gerard and Lave, 2007). As a case in point, US Corporate Average Fuel Economy (CAFE) standards and EU vehicle emissions regulations have helped drive the auto industry toward the use of more efficient combustion engines (EPA, 2010; European Commission, 2009; Nemet, 2014). Similarly, the 1970 US Clean Air Act led to the development of the catalytic converter in 1975 and three-way catalyst in 1981, reducing vehicle emissions (Hackett, 1995).

Researchers have engaged in extensive ex post analysis of the costs and merits of technology-forcing legislation relative to other measures e.g., subsidies or tax credits[1] (Freeman and Haveman, 1972; Ashford et al., 1985; Jaffe et al., 2003), but these studies provide limited normative guidance for decision makers who are crafting policy. The primary issue is one of uncertainty; because technology-forcing policies address innovations whose future dynamics are inherently unknowable these innovations are associated with high levels of ambiguity for policymakers. Regulators do not know what levels of technological improvements are likely without a policy or what levels are feasible with such legislation. Thus, regulation innovation targets risk being either too weak to lead to meaningful change, or too ambitious to be achievable (Freeman and Haveman, 1972). Given the technical information

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[1] This article is not meant to compare the relative merits of innovation policies, but in general, researchers have found technology-forcing policies to have a relatively higher cost than other measures such as subsidies or tax credits (Jaffe et al., 2003).

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required, technology-forcing legislation entails constant interaction between regulators and firms to determine investment; levels of technological progress; and how those two factors relate to established goals (Hackett, 1995). Policy stringency may have to be adjusted, as it was for California's ZEV regulations, depending how the target technology is developing (Collantes and Sperling, 2008).

Increased levels of uncertainty are specifically associated with technology-forcing policies when they influence pre-commercial development. Once an innovation is available on the market regulators can look at sales volume, prices, and consumer acceptance to help adjust policy, but before commercialization there are limited ways for policymakers to gauge the progress of a technology. This issue is compounded by information asymmetries between regulators and firms, specifically when innovations have lengthy development cycles. For example, in order to reduce the cost of a technology-forcing policy firms may downplay progress or exaggerate the level of resources necessary to reach a stated goal (Gerard and Lave, 2005). As a result, regulators often do not have a good understanding of how well companies are progressing toward the policy's targets. This leaves the period of time while an innovation is being developed where policymakers have limited means to analyze the effectiveness of a technology-forcing regulation.

An additional limitation in the understanding of technology-forcing policies is that studies have traditionally confined analyses to individual countries (Freeman and Haveman, 1972; Ashford et al., 1985; Jaffe et al., 2003). Consequently, they do not incorporate important global market dynamics, such as R&D by multi-national firms. This can become especially problematic when regulatory impacts are determined by firm size and companies are involved in markets outside the policy reach. Thus, including global market dynamics should lead to a better understanding of the general impact of technology-forcing policies.

This study is meant to address the above literature gaps and policy problems in two ways. First, it will determine whether pre-commercial development, in the form of patents and prototypes, might provide useful preliminary measures of the effectiveness of technology-forcing policies. Second, it will analyze how these types of regulations influence firm R&D where companies have different approaches to innovation commercialization. Our paper accomplishes these two goals by testing the following hypotheses:

1. Technology-forcing policies will result in firms increasing a) the number of prototypes that they develop and b) patents that they receive.
2. Firms that pursue mass market commercialization of an innovation will have higher levels of patents and prototypes than companies seeking to meet regulation requirements, which in turn will have higher R&D levels that those refraining from market introduction.

To test these hypotheses, we analyze of the impact of ZEV regulations on the development and market introduction of electric vehicles (EVs) in California.

1.1. Research case

The effect of ZEV regulations on EV commercialization is a good case to analyze indicators of technology-forcing policies for three reasons. First through David Vogel's “California effect” (1995) ZEV regulations, which govern about 30% of the US market (Mui and Baum, 2010), have the potential to influence auto maker activity around the world. The California effect has shown how environmental policies in large markets can drive firms to meet more stringent regulatory requirements. For example, California's vehicle emissions requirements have been an important contributing factor to increases in US national emissions standards. (Vogel, 1995). Second, auto makers have chosen several different approaches to the introduction of commercial EVs with some companies taking a mass market tack; others seeking to only meet the regulatory minimum; and a third group eschewing commercialization all together. And third, the electric vehicle case offers an opportunity to analyze the relationship of patents and prototypes to a technology-forcing policy because auto makers use both innovation indicators when developing alternative-fuel vehicles (Oltra and Saint Jean, 2009; Sierzchula et al., 2012a). Patents have been a frequently-used measure for studying basic research in automobile innovation (Oltra and Saint Jean, 2009; Bakker, 2009; Wesseling et al., 2014a). Prototypes, meanwhile, offer a better R&D indicator for technological progress that is closer to commercialization (Suarez, 2004). They have recently been incorporated in systematic analysis of the development of alternative fuel vehicles such as hybrid-electric vehicles and hydrogen fuel cell vehicles (Bakker et al., 2012; Sierzchula et al., 2012a), and are particularly useful when examining early or pre-commercial situations (Suarez, 2004), such as the electric vehicle industry 1990–2010. And while some concept car prototypes could be considered primarily marketing tools, several have heralded commercial introduction of important EVs such as the Nissan LEAF, Chevy Volt, and BMW i3 (Sierzchula et al., 2012a).

In addition, this study provides the prospect of influencing the evolution of ZEV policies. The electric vehicle industry offers extensive historical data while EV development and early adoption is still in a formative period. Thus, analysis provided by this study could be of particular relevance to regulators that are updating ZEV regulations.

1.2. ZEV policy origins

The California Air Resources Board's (CARB) 1990 ZEV regulations were designed to encourage development and diffusion of new powertrain technologies (Bedsworth and Taylor, 2007). They forced auto makers to include a percentage of zero-emission vehicles, e.g. fuel-cell electric vehicles (FCEVs) or EVs, in their annual sales to maintain access to section 177 state auto markets[2]; otherwise, the firms would face financial penalties[3] (DMV CA, 2014; Wesseling et al., 2014b). This legislation led automakers to introduce several electric vehicles in the mid to late 1990s (Sierzchula et al., 2012a). However, based on a 2002 legal challenge from the auto industry, ZEV regulations were weakened as they were eventually determined to mandate compliance based on options that were unrealistic (Collantes and Sperling, 2008). After several years of weak incentives, the policy's stringency increased for 2009 model year vehicles. This change resulted in auto makers having to produce ZEV credits in order to meet the policy's minimum requirements. These can be acquired through sales of EVs/FCEVs or purchased from other manufacturers. Sales of ZEVs prior to 2009 are included in auto manufacturer credits. A timeline of important ZEV regulation events is available in Fig. 1, while a more complete summary can be found in Wesseling et al. (2014a).

Due to changes in ZEV regulations identified in Fig. 1, automakers have only recently actually had to produce ZEV credits. From 2009–2014, Large Volume Manufacturers (LVMs) have needed to acquire ZEV credits equal to 0.79% of their annual sales, increasing to 3% in 2015, and 22% in 2025 (CARB, 2014a; CARB, 2014b). Credits are determined based on the type of fuel a vehicle uses, emissions, zero-emission driving range, and presence of advanced components. For example, if Tesla sold a Model S in 2012, it would receive seven ZEV credits; if Toyota sold a Prius it would receive 0.35 ZEV credits. There is also a phase-in multiplier that increases the ZEV credits earned for a vehicle sold prior to 2011. It should be noted that the ZEV requirements themselves are much more detailed and include multiple types of vehicles e.g., plug-in hybrids and neighborhood electric vehicles, than what is noted in this section. For the complete regulations, please see the CARB website (CARB, 2014a,b).

[2] This term specifically refers to the authorizing section of the clean air act, and covers states that have chosen to adopt California's emissions standards instead of federal requirements, including: Connecticut, Maryland, Massachusetts, New Jersey, New York, Oregon, Rhode Island, Vermont, Washington, which represent approximately 30% of the US auto market (Mui and Baum, 2010).

[3] Each section 177 state determines its own penalty level for noncompliance. For instance, California penalizes auto makers $5000 for each ZEV credit not produced.