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Analysis

Picking Winners: Modelling the Costs of Technology-specific Climate Policy in the U.S. Passenger Vehicle Sector

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ABSTRACT

Researchers debate the cost-effectiveness of technology-specific versus technology-neutral climate policies, but few quantify the differences. Using the case of low-carbon vehicle technologies in the US passenger vehicle sector (ethanol, plug-in electric and hydrogen), we develop a technology adoption simulation model that represents increasing returns to adoption in both financial costs and consumer preferences, representing uncertainty through Monte Carlo analysis. We compare the policy costs ($/tonne CO_2 out to 2050) of: i) a technology-neutral carbon tax, ii) a somewhat neutral vehicle standard requiring low carbon vehicle sales, but allowing competition among technologies, and iii) technology-specific vehicle standards requiring sales of just one technology. On average across simulations, the carbon tax is twice as cost-effective as the best vehicle standard, in part because the tax more substantially affects vehicle use rates. Among the vehicle standards, a technology-specific standard that selects the right "winner" (plug-in electric vehicles) is more cost-effective than the neutral standard, as it more quickly stimulates technology improvement. However, there is risk in a technology-specific approach; mistakenly forcing a "loser" technology (hydrogen) results in policy costs that are 2 to 5 times higher than other policies. Results can help policymakers trade-off the costs and risks of different climate policy options.

1. Introduction

1.1. Technology-neutral versus Technology-specific Climate Policy

This study uses a dynamic technology adoption model to explore the potential long-term cost-effectiveness of certain technology-neutral versus technology-specific climate policies, under technological uncertainty. We focus on the case of low-carbon fuel vehicle technology entering the US passenger vehicle sector, namely plug-in electric vehicles (PEVs), hydrogen fuel cell vehicles (HFCV), and biofuel vehicles (85% ethanol). These technologies have failed to substantively displace fossil fuels despite several decades of intermittent media hype, optimistic government goals and innovation activity—largely due to a lack of effective climate policy (Melton et al., 2016).

In the passenger vehicle sector, a more technology-specific climate policy would choose a "winner" (e.g. supporting only PEVs and PEV-related infrastructure) whereas a more technology-neutral policy would address greenhouse gas emissions more broadly (e.g. a carbon tax), allowing market forces to determine the "winner" or combination of winners among low-carbon fuel technologies. Some economists argue that "technology-specific" climate policies are too costly or risky for society and thus should not play a significant role in climate abatement strategies (Jaffe et al., 2005; Nordhaus, 2010). The main reasoning behind this argument is that the policymaker is not well-equipped to choose the right low-carbon technology "winner". Consider the example of a vehicle regulation that forces automakers to develop and sell PEVs. There is considerable uncertainty regarding future cost reductions in the technology, the evolution of consumer preferences, and the rollout of recharging infrastructure. With imperfect information about the future, there is risk that a transition to PEVs might end up being more costly for society than a transition to another low-carbon technology, such as biofuel or hydrogen-fuel cell vehicles. According to neoclassical economic theory, technology-neutral policies instead allow firms and consumers to select the lowest-cost technologies, effectively moving society onto the lowest cost marginal abatement curve, that is, assuming that other market failures do not exist. In the transportation sector, a carbon tax also has an advantage in potentially prompting a wider variety of abatement actions, including mode switching and decreased travel demand, in addition to switching to low carbon vehicle technologies.

However, several researchers argue that technology-specific policies could play an important role in effective climate change mitigation, likely as a complement to carbon pricing (Azar and Sandén, 2011;

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Carrillo-Hermosilla, 2006; Stern, 2007). One practical argument is that the stringent carbon pricing needed to achieve deep GHG reductions is unlikely to be politically acceptable in most countries, particularly North America, whereas sector or technology-specific regulation seem to be more acceptable (Eggert and Sperling, 2014; Rhodes et al., 2015). Further, Weber and Rohracher (2012) identify twelve "transformative failures" that prevent major technological transitions in general—most of these failures are highly relevant to the transportation sector. For example, while a stringent enough carbon tax can effectively "internalize" the negative externality of GHG emissions, the carbon tax does not address knowledge spillover effects which lead to underinvestment among firms regarding pro-environmental innovations. Several of the transformative failure categories identified by Weber and Rohracher—infrastructural failure, institutional failure, and directionality failure—all indicate that technology transformations can be blocked by a lack of shared understanding of what technologies society will transition towards. That is, different firms and stakeholders may lack a shared expectation for the direction of future technology development, and in effect may simultaneously invest too little into the development of too many low-carbon technologies, delaying breakthroughs in any one technology. Although a technology-neutral carbon tax might provide enough incentive for firms and stakeholders to organize and agree upon a direction of transition, e.g. towards PEVs rather than hydrogen, it is arguable that a technology-specific policy can send a stronger signal and assure that such a direction is collectively known.

Transformative failures are particularly important for emerging technologies, such as low-carbon vehicles, where further development and production experience could result in substantial cost reductions and performance improvements. In such cases, technological adoption can be driven by increasing returns to adoption, a process in which the technology becomes more attractive to consumers as more consumers adopt it (Arthur, 1989). The concept describes how the private costs of production and adoption (and thus the policy costs of GHG abatement) can be significantly reduced through several observed processes including manufacturers learning by doing (Arrow, 1962; Loschel, 2002; Nykvist and Nilsson, 2015), economies of scale (Taleb et al., 2014), and changes in consumer preferences (Axsen et al., 2009; Mau et al., 2008). For example, PEVs would become more attractive as production costs decrease, as consumers get more exposure to the technology, and as recharging infrastructure becomes more widespread—all of which are likely to increase as PEV sales increase in a given region and globally. A more technology-specific policy could stimulate increasing returns to adoption for PEVs and potentially reach a threshold where societal GHG abatement costs are substantially reduced in the passenger vehicle sector—in turn triggering a more cost-effective low-carbon transition than would occur under a more technology-neutral policy. Due to the potential of such thresholds, some researchers argue in favour of using technology-specific instruments instead of relying solely on an economy-wide carbon tax and broad-based subsidies for research and development (Sandén and Azar, 2005; Sierzchula et al., 2012). However, it is difficult to compare the cost-effectiveness of technology-neutral versus technology-specific policies, in part due to the enormous uncertainty inherent to the future cost reductions and breakthroughs that may occur for various emerging technologies.

1.2. Previous Research Efforts

Several recent studies have explored the social costs of technology-neutral versus technology-specific policies to reduce GHG emissions, using general equilibrium models (Acemoglu et al., 2016; Kalkuhl et al., 2012), partial-equilibrium models (Fischer et al., 2014; Lehmann and Söderholm, 2016) endogenous growth models (Acemoglu et al., 2012) and energy-economy simulation models (Small, 2012). In most cases, the technology-neutral policy is a carbon tax, while the technology-specific policy is either a research (R&D) subsidy to develop low-carbon substitutes (Acemoglu et al., 2012; Kalkuhl et al., 2012), or a deployment-related policy such as a renewable portfolio standard for electricity generation (Fischer et al., 2014) or fuel economy standards for transportation (Small, 2012). Some of these studies find that compared to a carbon tax alone, a carbon tax implemented in combination with technology-specific policies can be more cost-effective if strong market and transformative failures are present—namely technology path-dependency, knowledge and innovation spillover failures, lack of R&D investment due to perceptions of risk, or a lack of common understanding or shared vision about what technology and infrastructure is to be included as part of the transition. For example, Kalkuhl et al. (2012) use a general equilibrium model to find that the combination of a carbon price with technology-specific subsidies would impose less welfare costs (measured as lost consumption in a global economy) than a carbon price on its own. In contrast, Fischer et al. (2014) assert that a renewable portfolio standard is unlikely to be any more cost-effective than a carbon tax alone.

Lehmann and Söderholm (2016) argue that the appropriateness of technology-specific versus technology-neutral polices may vary by sector. While most studies focus on the electricity sector, Small (2012) provides one of the few explorations of this debate within the case of the passenger vehicle sector, using the US-based National Energy Modeling System (NEMS) model to simulate the cost-effectiveness of a fuel tax relative to a Corporate Average Fuel Economy (CAFE) standard. Simulating the cost-effectiveness of GHG abatement out to 2020 and 2030, the author finds that the fuel tax is the most cost-effective, though a fuel tax and CAFE standard seem to be complementary in that their combination provides the greatest overall emissions reductions and only slightly higher policy costs.

Important gaps remain in this literature. Most of the above studies model technology in the abstract, namely as the substitution between "dirty" versus "clean" inputs. In reality, many "clean" or low-carbon technologies are competing with each other, and with incumbent technologies. In the case of alternative-fuel vehicles, for example, PEV, HFCV and ethanol (E85) vehicles (among others) could all play roles in a low-carbon transition, with each having different present day attributes, technology learning curves, and consumer preferences. Having such a wide array of low-carbon options presents further risk and uncertainty for technology-specific policy, where a policymaker must prioritize support for the different low-carbon options. Although Small (2012) does simulate adoption of ethanol (E85) and hybrid vehicles in his model, his study excludes PEV and HFCV vehicles that are more likely to be affected by increasing returns to adoption in the long-run. In short, we are aware of no study that explores the cost-effectiveness of technology-specific policies in a specific sector where multiple low-carbon technologies could compete, and the risks and uncertainty therein.

1.3. Present Contribution and Research Objectives

We seek to fill this literature gap by using a technology adoption model that endogenously simulates consumer adoption of passenger vehicles in the long term (from 2015 to 2050), including increasing returns to adoption through learning by doing and changes in consumer preferences. Our approach is novel in several ways. First, our model is technology specific, representing gasoline vehicles as well as PEVs (plug-in hybrid and pure electric vehicles), HFCVs and biofuel powered vehicles, while endogenously representing overlaps in learning curves between related technologies (e.g. hybrid, plug-in hybrid and pure electric vehicles). Second, we also model the "neighbour effect" using empirical data on how a new technology becomes more desirable as its new market share increases (Axsen et al., 2009; Mau et al. 2008)—a consumer preference dynamic that is rarely represented in energy-economy or technology adoption models. Third, we model three types of policies that represent a continuum between technology-neutral and technology-specific, namely a carbon tax (most neutral), a general vehicle emissions standard (allowing PEVs, HFCVs and biofuels to compete), and vehicle emissions standards that require sales of only one of these