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Environmental Policies in the Transportation Sector: Taxes, Subsidies, Mandates, Restrictions, and Investment

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Keywords
environmental policy, transportation policy, externalities, taxes, subsidies, mandates, restrictions, investment

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1. Introduction

The transportation sector is associated with many negative externalities, including air pollution, global climate change, and traffic congestion. Vehicular emissions are an important source of air pollution and a major environmental concern in urban areas (Lin and Prince, 2009; Lin Lawell, 2017). Motor vehicles are the primary source of carbon monoxide (CO), and an important source of volatile organic compounds (VOC) and nitrogen oxides (NO_x, which consist of both nitrogen oxide (NO) and nitrogen dioxide (NO_2)) responsible for the formation of photochemical smog and ground-level ozone (O_3). Vehicular emissions also contribute to the ambient air concentrations of sulfur dioxide (SO_2) and particulate matter (PM_{10}) (U.S. EPA, 1994).

In addition to local air pollution, a second environmental concern to which the transportation sector contributes is global climate change. The transportation sector is responsible for over a quarter of U.S. greenhouse gas emissions (Auffhammer et al., 2016). If annual greenhouse gas emissions worldwide continue unabated, global temperatures are estimated to rise about 2 degrees C in less than 40 years, with the potential of pushing the climate to a regime unlike any that has been witnessed in the last million years (Ramanathan et al., 2016).

A third externality arising in the transportation sector is traffic congestion. Traffic congestion and long travel times are undesirable because they discourage future economic growth, increase vehicular emissions, increase fuel expenses, increase operating costs for both private and freight vehicles, decrease economies of agglomeration, heighten the psychological burden of travel, create a need for more emergency services, decrease the reliability of travel, and impose an opportunity cost on time (Morrison and Lin Lawell, 2016). The external costs of congestion – which include increased operating costs for both private and freight vehicles, increased fuel usage and emissions, and, most significantly, the delay costs and uncertain travel times confronting motorists – are substantial and have been steadily increasing (Beaudoin and Lin Lawell, 2018). Congestion can be particularly costly if individuals exhibit preferences for urgency owing to time constraints, schedule constraints, and possible penalties for being late (Bento, Roth and Waxman, 2017).

In this paper we discuss several possible policies for addressing the emissions and other environmental externalities from the transportation sector, including taxes, subsidies, mandates, restrictions, and investment. Although most economists generally recommend that policy-makers use incentive- (or market-) based instruments as opposed to command and control policies whenever possible, various economic and political constraints can preclude policy instruments that would in theory achieve a first-best outcome from being employed, and policy-makers have often implemented alternative policies such as subsidies, mandates, restrictions, and/or investment instead. Our discussion and analysis of these policies draws upon and synthesizes research using theoretical models, behavioral and experimental economics, empirical analyses, and structural econometric modeling.

2. Taxes

Most economists generally recommend that policy-makers use incentive- (or market-) based instruments as opposed to command and control policies whenever possible (Auffhammer et al., 2016; Lade, Lin Lawell and Smith, 2018a). Whenever unpriced emissions are the sole market failure, incentive-based instruments such as a carbon tax or cap-and-trade program are more likely to achieve the social optimum and maximize social net benefits (Pigou, 1920; Coase, 1960).

One incentive- (or market-) based instrument that many economists recommend for addressing the emissions and other environmental externalities from the transportation sector is a gasoline tax. Gasoline consumption contributes to air pollution, global climate change, and traffic congestion, all of which are critical environmental issues. According to Mankiw (2006), higher gasoline taxes are "the most direct and least invasive policy to address environmental concerns". As Stavins (2004) explains: "A gas tax increase – coupled with an offsetting reduction in other taxes, such as the Social Security tax on wages – could make most American households better off, while reducing oil imports (read dependence on Middle Eastern regimes), local pollution, urban congestion, road accidents, and global climate change". Davis (2015) enjoins us to join the "Pigou Club" (Mankiw, 2009) and support higher gasoline and diesel taxes.

Since gasoline is a relative complement to leisure, the optimal gasoline tax is significantly higher than the marginal damages from gasoline consumption (West and Williams, 2007). Economists have calculated the optimal gasoline tax to be $1.01/gallon in the United States (Parry and Small, 2005); $1.34/gallon in the United Kingdom is $1.34/gal (Parry and Small, 2005); $1.58/gallon in China (Lin and Zeng, 2014); $1.37 in the state of California (Lin and Prince, 2009); and 40.57 cents per litre in 2006 Canadian dollars in Ontario and the Greater Toronto-Hamilton Area in Canada (Wood, 2015).

A recent study by the International Monetary Fund estimates energy taxes for more than 150 countries (Parry et al., 2014a). The efficient set of fuel taxes for developed and developing countries would include charges on fuel use for carbon and local pollution (with credits for emissions capture during combustion) and additional charges on motor fuels for road congestion and accidents (though the latter should transition to distance-based charges). For most countries, efficient fuel taxes could yield considerable fiscal, health, and carbon benefits (Parry et al., 2014b).

One incentive- (or market-) based instrument that many economists recommend for addressing global climate change is a carbon tax. Carbon taxes efficiently reduce greenhouse gas emissions (Williams et al., 2015). An efficient carbon tax would be one that is imposed on the carbon content of fossil fuels at a rate equal to the social cost of carbon, and would rise slowly over time, reflecting the projected rise over time in the social cost of carbon (Williams, 2017).

Although a carbon tax would likely slow economic growth, its adverse effect on economic growth is very small, especially if the tax revenue is used in ways that promote economic growth, such as cutting marginal rates of other taxes, reducing the budget deficit, or financing growth-enhancing public goods (Williams, 2017).

Similarly, although a carbon tax would also be mildly regressive, imposing a slightly higher burden on lower-income households than on higher-income households, it is much less regressive than it is widely perceived to be. Moreover, as the incidence of a carbon tax depends on how the tax revenue is used (Williams et al., 2015), the regressivity of a carbon tax could be overcome if some of the revenue is used in a progressive way (Williams, 2017). Recycling revenues to cut capital taxes is efficient but exacerbates regressivity. Lump sum rebates are less efficient, but much more progressive, benefiting the three lower income quintiles even when ignoring environmental benefits. A labor tax swap represents an intermediate option, as it is more progressive than a capital tax swap and more efficient than a rebate (Williams et al., 2015).

Standard economic theory predicts that, when regulating externalities, incentive- (or market-) based price (tax) and quantity (cap-and-trade) instruments will produce identical outcomes when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator (Adar and Griffin, 1976; Stavins, 1995; Weitzman, 1974). Uncertainties regarding marginal abatement costs generate different policy prescriptions depending on the relative slopes of the marginal damage and marginal abatement cost curves; a relatively flat marginal damage curve would make a price instrument relatively more attractive and vice versa (Adar and Griffin, 1976; Weitzman, 1974).

While uncertainties regarding marginal abatement costs may matter, the literature largely agrees that uncertainty over marginal damages alone has no impact on the equivalence of incentive- (or market-) based price (tax) and quantity (cap-and-trade) instruments: according to standard economic theory, even in the presence of uncertainty over marginal damages, both price instruments and quantity instruments perform equally in terms of their *ex post* efficiency. Stavins (1996) finds that uncertainties in marginal damages only matter if uncertainties in marginal damages and uncertainties in marginal abatement costs are simultaneous and correlated with each other.

For many environmental externalities, marginal damages are uncertain; a stark example of an environmental externality with uncertain marginal damages is global climate change (Weitzman, 2014; Rudik, 2018). Even though uncertainty over marginal damages may not matter in theory, it may be important in practice since such uncertainty may lead to behavioral responses, or what Shogren and Taylor (2008) call "behavioral failures". Such behavioral responses include endowment effects, fairness concerns, attitudes towards risk deviating from the expected utility framework, and cognitive costs. If the behavioral responses of market participants differ under price and quantity instruments, then incentive- (or market-) based price (tax) and quantity (cap-and-trade) instruments instruments may lead to different outcomes. Owing to behavioral responses, and in contrast with standard economic theory, price instruments and quantity instruments may lead to different outcomes even when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator (Heres and Lin Lawell, 2018).

Heres and Lin Lawell (2018) examine the effects of uncertainty in marginal damages on the outcomes of incentive- (or market-) based price (tax) and quantity (cap-and-trade) instruments. They develop a theory model to compare the equilibria under price and quantity instruments with and without behavioral responses. They then conduct a laboratory experiment to evaluate the equivalence of price and quantity instruments when marginal damages are uncertain but marginal abatement costs are known with certainty. According to their results, in terms of aggregate emissions, the quantity-equivalence of quantity and price instruments cannot be rejected when marginal damages are known with certainty. However, when marginal damages are uncertain, the implementation of an optimal tax leads to more emissions compared to those achieved with a tradable permit system capped at the optimal amount of emissions. The results from their analysis of individual decisions and permit prices provide evidence for behavioral responses from endowment effects and risk attitudes proposed by prospect theory which cause price and quantity instruments to lead to different outcomes (Heres and Lin Lawell, 2018).

If price and quantity instruments are no longer equivalent when marginal damages are uncertain because of behavioral responses, policy-makers should consider the possibility of behavioral responses in the design of policy and in their choice of whether to use a price or quantity instrument (Heres and Lin Lawell, 2018).

3. Subsidies

Gasoline taxes have been touted by many economists as an efficient and relatively simple tool to address environmental concerns and other problems associated with gasoline consumption. However, rather than removing subsidies and increasing gasoline taxes, many countries still subsidize gasoline (Lin Lawell, 2017), which may have the opposite effect of exacerbating the environmental concerns and other problems associated with gasoline consumption.

Recent estimates show that global post-tax fossil fuel subsidies have reached a staggering $4.9 trillion worldwide in 2013 and $5.3 trillion in 2015, representing 6.5% of global GDP (Coady et al., 2017). According to detailed measurements of net gasoline taxes and subsidies, 33 countries subsidized gasoline for at least one 12-month period from 2003 to 2015, and 9 countries subsidized gasoline for the entire period. Moreover, while two-thirds of these 33 countries increased their net gasoline taxes from 2003 to 2015, the global mean gasoline tax fell by 13.3 percent due to a shift in consumption towards states that maintain gasoline subsidies or that have low taxes (Ross, Hazlett and Mahdavi, 2017).

There is variation in net gasoline taxes and subsidies across different regions of the world. Europe and North America have the highest net taxes, while oil-rich countries in the Middle East and North Africa have the lowest net taxes. Countries that subsidize gasoline also keep their gasoline prices fixed and are economically dependent on oil or natural gas exports, perhaps due to political pressure to distribute resource revenues (Ross, Hazlett and Mahdavi, 2017).

The prevalence of gasoline subsidies worldwide and the fall in the global mean gasoline tax may exacerbate air pollution from the resulting increase in gasoline consumption. This is particularly the case for oil-rich countries in the Middle East and North Africa that have the lowest net taxes (Kheiravar and Lin Lawell, 2018).

In Iran, domestic energy prices, including gasoline prices, are set administratively rather than by the market. The Iranian government has heavily subsidized petroleum products, utilities, as well as a few food products for over three decades since the early 1980s. These subsidies were originally introduced to manage the economic challenges during the war against Iraq. The energy subsidies in particular turned Iran into one of the most energy intensive countries due to the over-consumption resulting from artificially low national energy prices, and over the past two decades different administrations have tried to cut back on the energy subsidies (Kheiravar and Lin Lawell, 2018). Kheiravar and Lin Lawell (2018) evaluate the effects of transportation fuel subsidies and the Iranian energy subsidy reform on air quality, and find that reforms that have cut back on transportation fuel subsidies have improved air quality in Tehran.

Another transportation-related subsidy are emissions-based car subsidies and taxes. Alberini et al. (2018) analyze whether subsidies (taxes) that reward (penalize) low (high) emitters induce changes in the retirement of existing and inefficient vehicles. They exploit natural experiment conditions in Switzerland to analyze the impact of three different "bonus"/"malus" annual registration fee schemes implemented at the cantonal level. In the three schemes, the bonus rewards new, fuel-efficient vehicles. The malus is retroactive in canton Obwalden (i.e., it is charged on both new and existing high-emitting cars), but prospective in Geneva and Ticino. Alberini et al. (2018) find that while the bonus/malus in Obwalden hastens the retirement of existing high-emitting vehicles (by around 5%), the scheme in Geneva postpones retirement (by some 3%), and there are no statistically significant effects in Ticino.

The development of the ethanol industry in the U.S. has historically been accompanied by government subsidies. Ethanol production subsidies were implemented by the federal government in order to promote ethanol as a way to reduce dependence on imported oil (Pear, 2012). The launch of the ethanol industry was initiated in part by a production subsidy of 40 cents per gallon provided in the Energy Policy Act of 1978. Since then, the level of the subsidy has been modified a couple of times (Tyner, 2007). Most recently, the federal ethanol production subsidy was reduced from 51 cents per gallon to 45 cents per gallon in the 2008 Farm Bill, and subsequently eliminated on December 31, 2011.

According to conventional wisdom, an output subsidy is more efficient than an input subsidy as a means of encouraging output of a good, because an input subsidy distorts the choice of inputs away from the least-cost combination, while an output subsidy does not (Parish and McLaren, 1982). Schmalensee (1980) argues that if some commodity is more valuable to society than its market price indicates, then the best remedy is to use an output subsidy to increase its market value. Because other types of subsidies are less direct and build in extraneous incentives, they are strictly inferior in cost and efficiency terms (Schmalensee, 1980).

In their analysis of the choice between using investment and output subsidies to promote socially desirable production, Aldy, Gerarden and Sweeney (2018) find from their theory model that output will be greater under the output subsidy, though the extent of the difference in output depends on the convexity of the production costs. They find empirically that, owing to subsidy incentives, wind farms choosing the investment subsidy produce 10 to 11 percent less power per unit capacity than wind farms selecting the output subsidy, and that investment subsidies cost more to the Federal government per unit of output from wind farms than an output subsidy (Aldy, Gerarden and Sweeney, 2018).

Parish and McLaren (1982) analyze the relative cost-effectiveness of input and output subsidies using a static model. They observe that subsidy payments to inframarginal units of input or output are wasted from the point of view of encouraging expanded production. Subsidies may differ in their cost-effectiveness if they differ in the amounts absorbed by inframarginal units of the item subsidized, and these differences arise in the presence of increasing of decreasing returns to scale, and because of changes in input intensities as production expands. In particular, Parish and McLaren (1982) find that with decreasing returns to scale, inputs are more productive on the average than at the margin, and thus total payments made under an input subsidy, if spread over the total output, would represent a lower rate of subsidy per unit output (and a lower total payment) than under the output subsidy.

Yi, Lin Lawell and Thome (2018) develop a stylized theory model to provide intuition on which types of subsidies are more cost-effective for inducing investment in firm capacity, and how the presence of a mandate affects the relative cost-effectiveness of different types of subsidies. They build on the insight of Parish and McLaren (1982) that subsidy payments to inframarginal units of input or output are wasted from the point of view of encouraging expanded production.

Yi, Lin Lawell and Thome (2018) extend the analysis of Parish and McLaren (1982) along several dimensions. First, Yi, Lin Lawell and Thome (2018) use a dynamic model rather than a static model. As the input whose potential subsidy they analyze is capital, and as capital investment is inherently a dynamic problem involving incurring investment costs in the present for future gain, a dynamic model is more appropriate than a static model for analyzing capital investment, and may capture additional nuances a static analysis may overlook. For example, one nuance that arises with a dynamic model is that when multiple periods of time are considered, the government must pay any production subsidy for each unit of production in all periods of time, including each unit of production in periods even before any investment has taken place, even though these units of production are inframarginal. Whereas a static model assumes that any investment is made right away, a dynamic model recognizes that investments are dynamic decisions that may take time to occur, and that firms may additionally account for the option value to waiting before making any investment. A dynamic analysis would therefore consider as a drawback of production subsidies that the government would need to pay the production subsidy for every unit of production that takes place before any investment is made, even though these units of production are all inframarginal.

A second extension Yi, Lin Lawell and Thome (2018) make to the Parish and McLaren (1982) analysis is to model an industry in which production is highly correlated with capacity. Such a model is well-suited for describing industries such as ethanol and oil where there is little or no idle capacity, so that output is highly correlated with capacity. In the oil industry, for example, production is essentially determined by the number of wells drilled, as once a well is drilled, there is a high opportunity cost of shutting in a well (Anderson, Kellogg and Salant, 2018; Boomhower, 2016). As Yi, Lin Lawell and Thome (2018) show and explain in their empirical analysis, for the ethanol plants in their data set over the time period of their analysis, production is highly correlated with capacity. When production is highly correlated with capacity, the objective of encouraging expanded production can be reformulated as an objective of inducing investment in firm capacity.

A third extension Yi, Lin Lawell and Thome (2018) make to the Parish and McLaren (1982) analysis is to analyze the relative cost-effectiveness of different types of subsidies for inducing investment in firm capacity. While Parish and McLaren (1982) compare input and output subsidies, Yi, Lin Lawell and Thome (2018) compare output (or production) subsidies with investment subsidies and entry subsidies.

A fourth extension Yi, Lin Lawell and Thome (2018) make to the Parish and McLaren (1982) analysis is to allow for strategic interactions and oligopolistic behavior among firms. While Parish and McLaren (1982) model a static firm in isolation, Yi, Lin Lawell and Thome (2018) develop an econometric model of a dynamic game among incumbents and potential entrants in the ethanol industry.

Parish and McLaren (1982) find in their static analysis that input subsidies are more cost-effective than output subsidies when there are decreasing returns to scale. In the model of Yi, Lin Lawell and Thome (2018), decreasing returns to scale similarly makes an investment subsidy relatively more cost-effective than production subsidies in inducing investment that otherwise would not occur. However, in the dynamic model of Yi, Lin Lawell and Thome (2018), owing in part to dynamic considerations, strategic interactions, and a high correlation between production and capacity, whether production subsidies are more cost-effective than investment subsidies depends on the parameters, even under decreasing returns to scale, and is therefore an empirical question.

Yi, Lin Lawell and Thome (2018) then develop and estimate a structural econometric model of a dynamic game to empirically examine whether it costs more to the government to induce marginal investment via a production subsidy, an investment subsidy, or an entry in the context of the ethanol industry in the United States. While conventional wisdom and some of the previous literature favor production subsidies over investment subsidies, and while historically the federal government has used production subsidies to support ethanol, the empirical results of Yi, Lin Lawell and Thome (2018) show that, for the ethanol industry, investment subsidies and entry subsidies are more cost-effective than production subsidies for inducing investment that otherwise would not have occurred.

4. Mandates

Politicians and regulatory agencies in the U.S. have passed or considered a suite of policies to decrease emissions in the transportation sector, including carbon taxes, fuel economy standards, renewable fuel mandates, and regional or federal emissions trading programs. If unpriced emissions are the sole market failure, a carbon tax or cap-and-trade program can achieve the first-best market allocation (Pigou, 1920; Coase, 1960), while renewable fuel mandates are strictly second-best (Helfand, 1992; Holland, Knittel and Hughes, 2009; Lapan and Moschini, 2012; Lade and Lin Lawell, 2018). This is because fuel mandates implicitly subsidize renewable fuels even if the renewable fuel still generates some emissions (Lade and Lin Lawell, 2018). Despite this, typically favor renewable fuel mandates over taxes and cap-and-trade programs to reduce greenhouse gas emissions from transportation fuels.

The most prominent fuel mandates in the U.S. currently are the federal Renewable Fuel Standard (RFS), a renewable fuel share mandate; and California's Low Carbon Fuel Standard (LCFS), a carbon intensity standard. To comply with renewable fuel mandates, both upstream firms and downstream consumers must invest in new technologies. For example, the RFS requires 36 billion gallons (bgals) of ethanol to be blended into the U.S. fuel supply each year by 2022, of which 16 billion gallons must be biofuel derived from cellulosic feedstocks. Meeting these targets will require tremendous investments in the research and development, commercialization, and production of cellulosic biofuels. In addition, consumers must purchase millions of vehicles capable of using high-ethanol blend fuels (Lade and Lin Lawell, 2018).

Delays in the development and deployment of new technologies when binding mandates exist for their use may lead to situations with high short-run compliance costs. The problem compounds if compliance credits are bankable, in which case the anticipation of high future compliance costs may lead to significant increases in credit prices in the present. This situation has already borne out under the RFS. In 2013, the fuel industry anticipated that the statutory mandates would become increasingly difficult to meet beyond 2014. This caused RFS compliance credit prices to increase from $0.10/gal to $1.40/gal over the course of only a few months. The large and sudden increase in compliance costs set off a prolonged period of regulatory uncertainty and delay as the EPA considered how to best address these challenges, and eventually led to the Agency relaxing the mandates, thereby reducing the incentive to invest in the technologies required to meet the future objectives of the RFS (Lade, Lin Lawell and Smith, 2018b).

There is an extensive literature studying fuel mandates. These include papers that study the market effects of carbon intensity standards and renewable fuel mandates (de Gorter and Just, 2009; Holland, Knittel and Hughes, 2009; Lapan and Moschini, 2012; Moschini, Lapan and Kim., 2017; Just, 2017); explore channels of mandate compliance (Korting and Just, 2017); compare the relative performance of fuel mandates to more traditional policy instruments such as carbon taxes (Holland et al., 2014; Chen et al., 2014), or subsidies for production, investment, or entry (Yi, Lin Lawell and Thome, 2018); study unintended consequences of the policies and their relative efficiency when markets are imperfectly competitive (Holland, 2012) or open to trade (Rajagopal et al., 2011); examine ways policy-makers can increase the efficiency fuel mandates through strategic policy choices (Lemoine, 2016); and analyze how well mandates perform as innovation incentives (Clancy and Moschini, 2018).

There is also a literature studying the effects and efficiency of hybrid price-quantity policies. Roberts and Spence (1976) first proposed pairing a fixed non-compliance penalty and abatement subsidy with a tradable credit policy to bound compliance costs and reduce the expected social cost of a policy when costs and benefits are uncertain. A large literature has subsequently studied similar proposals, primarily in the context of emission trading programs (see e.g., Pizer, 2002; Newell, Pizer and Zhang, 2005; Burtraw, Palmer and Kahn, 2010; Fell and Morgenstern, 2010). In addition, it has been shown in the previous literature that a rate-based standard can achieve the first-best if it is coupled with an emissions tax (Holland, Knittel and Hughes, 2009) or a consumption tax (Holland, 2012).

Lade and Lin Lawell (2018) build on this work by analyzing if one can improve the efficiency of renewable fuel mandates, including volumetric standards, by coupling the mandate with a cost containment mechanism. To this end, they formalize, expand upon, and synthesize the previous literature studying renewable fuel mandates by developing a model of mandates under perfect competition that incorporates both a renewable share mandate and a carbon intensity standard, both with and without a cost containment mechanism. The extant literature has traditionally considered cost containment mechanisms as tools for increasing program efficiency and decreasing compliance cost uncertainty (Newell, Pizer and Zhang, 2005; Nemet, 2010; Fell et al., 2012; Fell, 2016). In contrast, Lade and Lin Lawell (2018) show that cost containment mechanisms may substantially increase the efficiency of a policy even in settings with no uncertainty.

In particular, Lade and Lin Lawell (2018) show that whenever the marginal cost of renewable fuels is high relative to fossil fuels, cost containment mechanisms have the benefit of both constraining compliance costs and limiting deadweight loss. If both the mandate and cost containment mechanism are set optimally, the efficiency of the policy increases substantially over optimally setting the fuel mandates alone. In a limiting case, an LCFS with an optimal cost containment mechanism can achieve the first-best outcome. Using a numerical model of the U.S. gasoline market, Lade and Lin Lawell (2018) show that the efficiency gains from strategically including a credit window offering with a fuel mandate are economically significant.

Renewable energy mandates for new technologies exist in contexts other than the transportation fuel sector as well. Many states have ambitious renewable portfolio standards that require significant investments in renewable electricity generation. If they are used instead of incentive-based instruments, quantity-based mandates such as the federal Renewable Fuel Standard, California's Low Carbon Fuel Standard, renewable portfolio standards, and the Clean Power Plan should be combined with a cost containment mechanism. However, incentive-based instruments should be used instead of mandates whenever possible.

There is also a literature on analyzing mandates and standards related to vehicles (Sallee and Slemrod, 2012; Klier and Linn, 2016; Anderson and Sallee, 2016; Levinson, 2016; Kellogg, 2017; Bento, Gillingham and Roth, 2017; Leard, Linn and McConnell, 2017; Huse and Koptyug, 2017; Ito and Sallee, 2018). Despite widespread agreement that a carbon tax would be more efficient (Williams, 2017), and although an increase in gasoline prices could result in a sizable increase in fleet fuel economy, presenting opportunities for the development and diffusion of fuel-saving technological advances in the form of favorable consumer sentiment and political environment (Li, Timmins and von Haefen, 2009), many countries use fuel economy standards to reduce transportation-related carbon dioxide emissions.

Davis and Knittel (2016) pair a simple model of the automakers' profit maximization problem with unusually-rich nationally representative data on vehicle registrations to estimate the distributional impact of U.S. fuel economy standards. The key insight from the model is that fuel economy standards impose a constraint on automakers which creates an implicit subsidy for fuel-efficient vehicles and an implicit tax for fuel-inefficient vehicles (Davis and Knittel, 2016).

Jacobsen (2013) employs an empirically estimated model to study the equilibrium effects of an increase in the US corporate average fuel economy (CAFE) standards, and finds that the overall welfare costs are regressive.

Klier and Linn (2012) analyze the medium-run effects of the U.S. Corporate Average Fuel Economy (CAFE) standard by employing a novel empirical strategy that accounts for the endogeneity of vehicle characteristics by exploiting the variation in engine models used in vehicle models. According to their results, the regulatory costs of an increase in the CAFE standard are significantly smaller in the medium run than in the short run (Klier and Linn, 2012).

An issue that arises with fuel economy standards for passenger vehicles is the possibility of a rebound effect: higher fuel economy reduces per-mile driving costs and may increase miles traveled. Using data from the 2009 National Household Travel Survey and simultaneously relaxing several assumptions employed in previous studies using micro data, Linn (2016) estimates that the change in miles traveled for a one percent increase in the fuel economy of all vehicles belonging to a household is 0.2 to 0.4, which suggests that the rebound effect could erode roughly one-third of the fuel savings caused by the regulated increase in US passenger vehicle fuel economy between 2005 and 2014.

China introduced its first fuel economy standard (GB 19578-2004) in September 2004. The fuel economy standard was a fuel consumption of 6.9 L per 100 km by 2015, which translates to an estimated 167 grams of CO_2 emissions per kilometer. In addition to the fuel economy standard, China also has a Corporate Average Fuel Consumption (CAFC) standard (GB 27999-2011), which went into effect in 2012. The CAFC standard is a target level for a firm's sales-weighted average fuel consumption, where the target is a sales-weighted average of individual fuel consumption targets for each vehicle model (Chen, Lin Lawell and Wang, 2018).

By developing and estimating a structural econometric model of China's automobile market as a mixed oligopolistic differentiated products market in which different consumers may vary in how much they like different car characteristics on the demand side, and in which state-owned automobile companies may have different objectives than private automobile companies on the supply side, Chen and Lin Lawell (2018) find that China's Corporate Average Fuel Consumption (CAFC) standard is inefficient, and that the alternative vehicle market share, consumer surplus, private firm profits, and state-owned firm utility would all increase if China removed its CAFC standard and made its fuel economy standard more stringent instead.

The intuition is as follows. Chen and Lin Lawell (2018) find that, all else equal, a more stringent fuel economy standard favors vehicles whose fuel efficiency exceed their respective target, lowering their relative prices, which has the possibility of increasing alternative vehicle market share; consumer surplus, particularly for consumers of fuel efficient and/or alternative vehicles, and those who can now switch to fuel efficient and/or alternative vehicles as a result of their lower relative price; average private firm profit; and/or average state-owned firm utility. In contrast, China's CAFC standard is inefficient, in part because the CAFC standard does not require that each vehicle model achieve a minimum fuel efficiency target, but instead allows firms to average across all the vehicle models that they produce; in part owing to the compliance cost and computational cost burden to firms of having to average across all the vehicle models they produce; and also in part because there is already a fuel economy standard in place. Thus, removing the CAFC standard and making the fuel economy standard more stringent will best ensure that all cars meet a stringent minimum fuel efficiency target (Chen and Lin Lawell, 2018).

5. Restrictions

Another type of policy that has been implemented to address the emissions and other externalities associated with the transportation sector is a driving restriction. A typical driving restriction prohibits drivers from using their vehicles on given weekdays, based on the last digits of their vehicles' license plates (Zhang, Lin Lawell and Umanskaya, 2017).

License plate-based driving restrictions have been widely used as a method to reduce urban air pollution and traffic congestion in developing countries. Santiago, Chile introduced a license plate-based driving restriction in 1986 and Mexico City, Mexico introduced a driving restriction, *Hoy No Circula*, in 1989. Following these two, several more Latin American cities have introduced license plate-based driving restrictions, including Bogotá, Colombia and São Paulo, Brazil. Other Colombian cities that have implemented license plate-based driving restrictions include Bucaramanga, Cartagena, Manizales, Pereira, Barranquilla, Armenia, Cali, and Medellín. Beijing and its neighboring city Tianjin also implemented license plate-based driving restrictions during the 2008 Olympic Games and a modified version of the restriction continued in Beijing after the Olympics. Driving restrictions have also been implemented in cities of some developed countries as well, including Paris in 2015 (Zhang, Lin Lawell and Umanskaya, 2017).

In the first-best, driving during each hour of each day would be charged a fee or tax per vehicle mile traveled, equal to the marginal damages of an additional vehicle mile traveled during that hour of that day, so that individual households will each choose the socially optimal choice of when and how much to drive during the week. In contrast to the first-best, a license plate-based driving restriction restricts a household from driving during certain hours of the day for certain days of the week (Zhang, Lin Lawell and Umanskaya, 2017).

In addition to license plate-based driving restrictions, another type of driving restriction are low emission zones, which define areas that vehicles may enter only if they are classified as low emission vehicles (Wolff and Perry, 2010). Another form of driving regulation are congestion charges (Leape, 2006; Gibson and Carnovale, 2015). Cropper et al. (2014) evaluate the costs and emissions reductions of a program that requires people to buy permits to drive on high-ozone days.

In the previous literature on the effects of license plate-based driving restrictions, Eskeland and Feyzioglu (1997) examine the effect of *Hoy No Circula* on gasoline demand and car ownership in Mexico City during the period 1984-1993. Davis (2008) measures the effect of *Hoy No Circula* on air quality during the period 1986-1993 by using a regression discontinuity design to control for possible confounding factors. These two studies find no evidence that *Hoy No Circula* improved air quality in Mexico City.

Gallego, Montero and Salas (2013a,b) find in their analysis of *Hoy No Circula* that policies that may appear effective in the short run can be highly detrimental in the long run, after households have adjusted their stock of vehicles. Blackman et al. (2018) use a contingent valuation method to measure the costs of Mexico City's *Hoy No Circula*, and find that the Mexican program's costs are substantial: up to $130 per vehicle per year, which represents 1-2 percent of drivers' annual income and implies total costs of $617 million per year.

Zhang, Lin Lawell and Umanskaya (2017) build upon and synthesize the existing literature by developing a theoretical model of license plate-based driving restrictions that incorporates three behavioral channels highlighted by the literature that may affect the effectiveness of a license plate-based driving restriction. One behavioral channel that may affect the effectiveness of license plate-based driving restrictions is the possibility that households may intertemporally substitute their driving during restricted hours with driving during unrestricted hours. Davis (2008) finds that estimates for the effects of *Hoy No Circula* on air pollution during nonpeak weekdays and weekends tend to be positive, consistent with intertemporal substitution toward nighttime and weekend driving when the driving restrictions are not in place.

Two other behavioral channels that may affect the effectiveness of license plate-based driving restrictions that Zhang, Lin Lawell and Umanskaya (2017) incorporate in their theory model are the possibility that households may purchase a second car and the possibility that households may take an alternative mode of transportation. Davis (2008) explains the lack of an improvement in air quality resulting from *Hoy No Circula* with data from vehicle registrations and automobile sales which indicate that the program led to an increase in the total number of vehicles in circulation as well as a change in the composition of vehicles toward used, and thus higher-emitting, vehicles. In addition, Davis (2008) finds no evidence of an increase in public transportation ridership.

In addition to identifying substitution, the purchase of a second car, and the use of alternative modes of transportation as three behavioral channels through which license plate-based driving restrictions may be ineffective or even potentially increase air pollution, the theoretical model of Zhang, Lin Lawell and Umanskaya (2017) also incorporates insights from differences in the sources and atmospheric chemistry of different air pollutants. Zhang, Lin Lawell and Umanskaya (2017) show that the complex atmospheric chemistry of ozone smog formation may further cause driving restrictions to be ineffective or even have perverse consequences. The difficulty of regulating ozone smog in particular is also examined by Auffhammer and Kellogg (2011), who find that federal gasoline standards, which allow refiners flexibility in choosing a compliance mechanism, do not reduce ozone pollution because minimizing the cost of compliance does not reduce emissions of those compounds most prone to forming ozone; and by Salvo and Wang (2017), who find that increased ethanol use in the gasoline-ethanol vehicle fleet leads to higher ozone concentrations in urban São Paulo's ambient air.

After developing a theoretical model of license plate-based driving restrictions that incorporates substitution, the possibility of purchasing a second car or taking public transit, sources of air pollutants, and atmospheric chemistry, Zhang, Lin Lawell and Umanskaya (2017) examine the hypotheses of their model in light of suggestive empirical evidence from the license plate-based driving restriction implemented in Bogotá, Colombia. Consistent with their theory model, Zhang, Lin Lawell and Umanskaya (2017) find suggestive empirical evidence that under certain circumstances, due to substitution, the purchase of a second car, the use of alternative modes of transportation, and/or atmospheric chemistry, it is possible for license plate-based driving restrictions to increase air pollution. Also consistent with their theory, Zhang, Lin Lawell and Umanskaya (2017) find that license plate-based driving restrictions may have different effects on different air pollutants, reflecting heterogeneity in the sources and atmospheric chemistry of the pollutants. In particular, owing to atmospheric chemistry, it is possible for a license plate-based driving restriction to cause a significant decrease in NO and a significant increase in NO_2, NO_x, and O_3 (Zhang, Lin Lawell and Umanskaya, 2017).

6. Investment

The government has two potential roles in the surface transportation sector. The first potential role for government is to provide transportation infrastructure in the form of roads and public transit systems; and also to operate public transit services. Once the infrastructure is in place, a second potential role for government is to employ policy instruments (such as taxes and other forms of regulation relating to safety, environmental standards, travel demand management policies, and so forth) in order to address the market failures that are inherent to unregulated transportation activity; and also to determine the operational aspects of public transit service (Beaudoin, Farzin and Lin Lawell, 2015; Beaudoin, Farzin and Lin Lawell, 2018).

A contentious issue currently confronting transportation analysts and policy-makers is what the effects of public transit investment on congestion and on air quality are, and therefore what the appropriate level of public transit investment should be (Beaudoin and Lin Lawell, 2017; Beaudoin and Lin Lawell, 2018b). While public transit receives plenty of political support for its "green" reputation and its contribution to sustainability, there is also an ongoing debate in policy circles regarding the efficacy of public transit investment as a means of addressing traffic congestion: some display skepticism regarding the congestion-reduction possibilities of public transit (Rubin, Moore and Lee, 1999; Stopher, 2004; Rubin and Mansour, 2013), while others advocate for transit investment (Litman, 2014). Similarly, while several studies have considered the relationship between automobile travel and air quality, and although there is generally a consensus that auto travel leads to adverse health outcomes, there is very little empirical evidence on the incremental effect that public transit supply may or may not have on air quality (Beaudoin, Farzin and Lin Lawell, 2015).

In the first-best, a Pigouvian tax would be levied on auto travel, which generates a direct price for the emissions and congestion externalities, and not only limits the deviation from the socially optimal level of travel and helps utilize existing capacity more efficiently, but also results in a volume of travel that provides an appropriate signal for the optimal level of capacity investment in the future. However, if policy instruments that would in theory achieve a first-best outcome cannot be employed due to various economic and political constraints, then it is of interest to analyze potential second-best solutions available to policy-makers (Beaudoin, Farzin and Lin

Lawell, 2018). The general concept of subsidizing a substitute good in the presence of an uncorrected distortion has long been established (Baumol and Bradford, 1970).

Beaudoin, Farzin and Lin Lawell (2018) develop a theoretical model to analyze what role, if any, public transit investment should play in addressing traffic congestion in urban transportation networks. In particular, they evaluate the extent to which traffic congestion should be accounted for when determining the optimal second-best level of investment in public transit infrastructure in the absence of a first-best Pigouvian congestion tax on auto travel. Their model of second-best public transit investment contributes to the literature by allowing for both demand and cost interdependencies between the auto and transit modes. In particular, owing to cost interdependencies between the auto and transit modes when transit shares the right-of-way with auto traffic, "mixed traffic" transit investment can affect the equilibrium volume of auto travel through shifts in the auto travel cost function as well as the demand function (Beaudoin, Farzin and Lin Lawell, 2018).

The results of Beaudoin, Farzin and Lin Lawell (2018) indicate that the level of transit investment should be higher relative to that chosen when the congestion-reduction effects of transit are not accounted for, but the importance of this consideration is dependent upon the interaction of demand and cost interdependencies between the auto and transit modes, which may vary across regions. Beaudoin, Farzin and Lin Lawell (2018) calibrate their theoretical model with panel data from 96 urban areas across the United States over the period 1991 to 2011, and find that, due to differences in cost interdependence and cross-modal substitution, fixed guideway transit investments are expected to yield higher congestion-reduction benefits than mixed transit modes in dense regions. Their results suggest that urban mass transit may have a co-benefit of congestion reduction. As a consequence, prospective public transit projects should not be evaluated exclusively in terms of the forecasted net welfare generated by public transit users, but instead should also include interactions between auto and transit users in the cost-benefit analysis framework (Beaudoin, Farzin and Lin Lawell, 2018).

To empirically analyze whether public transit is a means to address traffic congestion within urban transportation networks, Beaudoin and Lin Lawell (2018b) estimate the effect of past public transit investment on the demand for automobile transportation by applying an instrumental variable approach that accounts for the potential endogeneity of public transit investment, and that distinguishes between the substitution effect and the equilibrium effect, to a panel dataset of 96 urban areas across the U.S. over the years 1991-2011. Their results show that, owing to the countervailing effects of substitution and induced demand, the effects of increases in public transit supply on auto travel depend on the time horizon. In the short run, when accounting for the substitution effect only, Beaudoin and Lin Lawell (2018b) find that on average a 10% increase in transit capacity leads to a 0.7% reduction in auto travel. However, transit has no effect on auto travel in the medium run, as latent and induced demand offset the substitution effect. In the long run, when accounting for both substitution and induced demand, Beaudoin and Lin Lawell (2018b) find that on average a 10% increase in transit capacity is associated with a 0.4% increase in auto travel. They also find that public transit supply does not have a significant effect on auto travel when traffic congestion is below a threshold level. Additionally, they find that there is substantial heterogeneity across urban areas, with public transit having significantly different effects on auto travel demand in smaller, less densely populated regions with less-developed public transit networks than in larger, more densely populated regions with more extensive public transit networks (Beaudoin and Lin Lawell, 2018b).

In recent decades, air quality in the U.S. has improved substantially. Over this time, there has been also been a steady increase in the volume of transit capacity supplied. Beaudoin and Lin Lawell (2018a) analyze whether any of the substantial improvement in air quality can be attributed to increased public transit supply. To do so, they develop an equilibrium model of transit and automobile travel volumes as a function of the level of transit supplied. They then empirically analyze the effects of the level of transit supply on observed ambient pollution levels by applying an instrumental variables approach that accounts for the potential endogeneity of public transit investment to a panel dataset of 96 urban areas across the U.S. In particular, they analyze the effects of the level of transit supply on the following criteria pollutants: carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), ozone (O_3), particulate matter (PM), and sulfur dioxide (SO_2).

Prospective public transit projects should not be evaluated exclusively in terms of the forecasted net welfare generated by public transit users, but instead should also include interactions between auto and transit users in the cost-benefit analysis framework. Nevertheless, while public transit investment may be able to play a complementary role, efficient pricing of auto travel remains necessary to address traffic congestion in the U.S. (Beaudoin, Farzin and Lin Lawell, 2018).

7. Conclusion

The transportation sector is associated with many negative externalities, including air pollution, global climate change, and traffic congestion. Most economists generally recommend that policy-makers use incentive- (or market-) based instruments as opposed to command and control policies (including quantity-based mandates) whenever possible (Auffhammer et al., 2016; Lade, Lin Lawell and Smith, 2018a). Whenever unpriced emissions are the sole market failure, incentive-based instruments such as a carbon tax or cap-and-trade program are more likely to achieve the social optimum and maximize social net benefits (Pigou, 1920; Coase, 1960).

Owing to behavioral responses, and in contrast with standard economic theory, incentive- (or market-) based price (tax) and quantity (cap-and-trade) instruments may lead to different outcomes even when transaction costs are negligible and marginal abatement costs are known with certainty by the regulator. If price and quantity instruments are no longer equivalent when marginal damages are uncertain because of behavioral responses, policy-makers should consider the possibility of behavioral responses in the design of policy and in their choice of whether to use a price or quantity instrument (Heres and Lin Lawell, 2018).

Gasoline taxes have been touted by many economists as an efficient and relatively simple tool to address environmental concerns and other problems associated with gasoline consumption. However, rather than removing subsidies and increasing gasoline taxes, many countries still subsidize gasoline (Lin Lawell, 2017), which may have the opposite effect of exacerbating the environmental concerns and other problems associated with gasoline consumption.

The development of the ethanol industry in the U.S. has historically been accompanied by government subsidies. While conventional wisdom and some of the previous literature favor production subsidies over investment subsidies, and while historically the federal government has used production subsidies to support ethanol, owing in part to dynamic considerations, strategic interactions, and a high correlation between production and capacity, whether production subsidies are more cost-effective than investment subsidies depends on the parameters, even under decreasing returns to scale, and is therefore an empirical question (Yi, Lin Lawell and Thome, 2018). Recent empirical results show that, for the ethanol industry, investment subsidies and entry subsidies are more cost-effective than production subsidies for inducing investment that otherwise would not have occurred (Yi, Lin Lawell and Thome, 2018).

Politicians and regulatory agencies in the U.S. have passed or considered a suite of policies to decrease emissions in the transportation sector, including carbon taxes, fuel economy standards, renewable fuel mandates, and regional or federal emissions trading programs. If unpriced emissions are the sole market failure, a carbon tax or cap-and-trade program can achieve the first-best market allocation (Pigou, 1920; Coase, 1960), while renewable fuel mandates are strictly second-best (Helfand, 1992; Holland, Knittel and Hughes, 2009; Lapan and Moschini, 2012; Lade and Lin Lawell, 2018). This is because fuel mandates implicitly subsidize renewable fuels even if the renewable fuel still generates some emissions (Lade and Lin Lawell, 2018). Despite this, typically favor renewable fuel mandates over taxes and cap-and-trade programs to reduce greenhouse gas emissions from transportation fuels.

However, quantity-based mandates are susceptible to large increases in compliance costs, particularly in the presence of capacity or production constraints that are inherent in energy markets. Given the experiences with the federal Renewable Fuel Standard in 2013, anticipating and designing climate policies in a way that can contain compliance costs is imperative (Lade, Lin Lawell and Smith, 2018). In the case of renewable fuel mandates, since the marginal cost of renewable fuels is high relative to fossil fuels, cost containment mechanisms such as a credit window have the benefit of both constraining compliance costs and reducing deadweight loss. In addition, when both a fuel mandate and cost containment mechanism are set optimally, the efficiency of fuel mandates can increase substantially over optimally setting fuel mandates alone (Lade and Lin Lawell, 2018). Thus, if they are used instead of incentive-based instruments, quantity-based mandates such as the federal Renewable Fuel Standard, California's Low Carbon

Fuel Standard, renewable portfolio standards, and the Clean Power Plan should be combined with a cost containment mechanism.

Similarly, despite widespread agreement that a carbon tax would be more efficient, many countries use fuel economy standards to reduce transportation-related carbon dioxide emissions. However, fuel economy standards impose a constraint on automakers which creates an implicit subsidy for fuel-efficient vehicles and an implicit tax for fuel-inefficient vehicles (Davis and Knittel, 2016), and are susceptible to a potential rebound effect (Linn, 2016). In addition, a corporate average fuel economcy standard that does not require that each vehicle model achieve a minimum fuel efficiency target, but instead allows firms to average across all the vehicle models that they produce, may impose additional compliance costs and a computational cost burden to firms of having to average across all the vehicle models they produce, and may be even less efficient than fuel economy standards that apply to each vehicle model (Chen and Lin Lawell, 2018).

License plate-based driving restrictions have been widely used as a method to reduce urban air pollution and traffic congestion in developing countries. However, under certain circumstances, due to substitution, the purchase of a second car, the use of alternative modes of transportation, and/or atmospheric chemistry, it is possible for license plate-based driving restrictions to increase air pollution (Zhang, Lin Lawell and Umanskaya, 2017).

The government has two potential roles in the surface transportation sector. The first potential role for government is to provide transportation infrastructure in the form of roads and public transit systems; and also to operate public transit services. Once the infrastructure is in place, a second potential role for government is to employ policy instruments (such as taxes and other forms of regulation relating to safety, environmental standards, travel demand management policies, and so forth) in order to address the market failures that are inherent to unregulated transportation activity; and also to determine the operational aspects of public transit service (Beaudoin, Farzin and Lin Lawell, 2015; Beaudoin, Farzin and Lin Lawell, 2018).

While public transit receives plenty of political support for its “green” reputation and its contribution to sustainability, a contentious issue currently confronting transportation analysts and policy-makers is what the effects of public transit investment on congestion and on air quality are, and therefore what the appropriate level of public transit investment should be (Beaudoin and Lin Lawell, 2017; Beaudoin and Lin Lawell, 2018b).

In the absence of a first-best Pigouvian congestion tax on auto travel, the second-best level of transit investment would account for the congestion-reduction effects of transit, and should be higher relative to that chosen when the congestion-reduction effects of transit are not accounted for, but the importance of this consideration is dependent upon the interaction of demand and cost interdependencies between the auto and transit modes, which may vary across regions (Beaudoin, Farzin and Lin Lawell, 2018). For example, due to differences in cost interdependence and cross-modal substitution, fixed guideway transit investments are expected to yield higher congestion-reduction benefits than mixed transit modes in dense regions (Beaudoin, Farzin and Lin Lawell, 2018). Moreover, owing to the countervailing effects of substitution and induced demand, the effects of increases in public transit supply on auto travel depend on the time horizon (Beaudoin and Lin Lawell, 2018b).

Although various economic and political constraints can preclude policy instruments that would in theory achieve a first-best outcome from being employed, policy-makers should use the first-best incentive- (or market-) based instruments as opposed to command and control policies whenever possible. In addition, when constrained to use alternative policies, policy-makers should strive to strive to increase their efficiency and implement second-best versions of these policies whenever possible.

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