Regulating Untaxable Externalities: Evidence from Vehicle Air Pollution and Exhaust Standards

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The general objective of this project is to advance knowledge on the effectiveness and efficiency of air pollution emission policies for passenger transportation. Vehicle transportation is an important potential setting for regulating air pollution. US vehicle transportation accounts for 40 percent of total US emissions of two major air pollutants, carbon monoxide and nitrogen oxides, creates $72 billion in annual pollution-related health and other damages, and causes about 37,000 annual premature deaths (Fann et al. 2013, USEPA 2014).

Economics textbooks describe optimal policy to address such emissions—a corrective or Pigouvian tax equal to the marginal external cost of emissions, or a comparable quantity mechanism (e.g., cap and trade). Taxing vehicle air pollution emissions, however, is technologically infeasible. While governments have directly taxed many other types of pollution, no level of government, anywhere in the world, at any time, has directly taxed air pollution emissions from vehicles. Motor fuel taxes provide a direct tax on greenhouse gas emissions but are a poor proxy for a tax on air pollution (Knittel and Sandler 2018).

Vehicle air pollution taxes are nonexistent in part because no economically viable technology can accurately measure individual pollution emissions at scale. Real-time air pollution monitoring technologies for vehicles exist, but their substantial cost has limited their use to a few test vehicles and prescribed driving sequences. Roadside remote sensing of pollution has considerable measurement error. Some governments use scheduled emissions tests (i.e., "smog check"). When these tests are paired with high-stakes incentives, they can lead vehicle owners to engage in avoidance behavior like short-term repairs or cheating that make taxes based on such tests potentially inaccurate (Mérel et al. 2014). The most accurate scheduled test, the Federal Test Protocol, takes over 6 hours and costs over $1,000 per vehicle. Even abstracting from avoidance behavior, accurate scheduled tests would not permit a Pigouvian tax since they abstract from behaviors like driving speed and acceleration.

Instead, the US, EU, Japan, China, India, Brazil, and most other countries rely heavily on new vehicle exhaust standards to regulate air pollution from vehicles. Exhaust standards set a maximum emissions rate per mile that applies to every vehicle. More recent standards also impose fleet-wide average requirements. These standards are separate from the Corporate Average Fuel Economy (CAFE) standards that are the subject of much economic research.

Exhaust standards have been controversial for decades due to their substantial costs and potential inefficiencies. Congress has issued three separate requests to the National Academies of Science

to provide advice on the standards. The Trump Administration has challenged California's policy to enforce its own tighter exhaust standards. Many manufacturers have cheated on these standards, including the recent diesel pollution scandal involving Volkswagen, Fiat Chrysler, and other auto makers. This scandal has already produced $22 billion in penalties – the largest auto settlement in US history – leading to questions about the standards' basic effectiveness. Such cheating is not new; the Environmental Protection Agency has found "defeat devices" in many manufacturers' vehicles over the last 40 years.

Research Questions

This paper carefully assesses the effectiveness and efficiency of exhaust standards. It also analytically and quantitatively assesses potential social welfare gains from feasible counterfactual policies. Specifically, the paper investigates four questions.

First, how has air pollution from vehicles changed over time? We measure long-term declines in pollution emissions for the new and used US vehicle fleets, then decompose emission trends into three channels—changes in the scale of vehicle miles traveled, changes in the composition of driving across vehicle classes, and change in emissions per mile within a vehicle class. Second, to what extent have exhaust standards caused these declines? We exploit four sources of variation in exhaust standards – across classes of vehicles, between California and federal standards, across model years, and across pollutants – to assess the causal effects of these standards on emissions. Third, are these standards cost-effective? We report several stylized facts on the extent to which these standards equate the marginal cost of abating pollution across vehicles, which is a necessary condition for cost-effectiveness. Fourth, to what extent would counterfactual policies increase social welfare? We develop analytical and quantitative models of the new and used vehicle fleets to study how feasible alternative policies would affect vehicle pollution emissions and consumer choices.

This paper utilizes the most comprehensive and high quality data on new and used vehicle pollution emissions ever constructed. It includes 50 years of directly comparable pollution data using the same high-quality measurement method covering every US light-duty vehicle and light-duty truck sold since 1972, and many over the period 1957-1971. These data provide identical measurement methods—the test procedure, down to the second of the test and the exact chemical composition of fuel used in this Federal Test Procedure, is listed in the US Code of Federal Regulations. We believe this is the longest-lasting high-quality dataset on pollution emissions rates from any country or sector.

We supplement these with 65 million vehicle test records from eight states and three separate types of tests, including consumer used vehicle inspections, official regulatory "in-use" tests, and road-side remote sensing. We have obtained these data from a series of Freedom of Information Act and Open Record requests and from extensive conversations with government staff. The remote sensing measures are believed to be impervious to manufacturer "defeat devices" used to cheat on emissions tests, and in fact a subset of our remote sensing data were used to document Volkswagen's cheating on its diesel vehicles.

Preliminary Results

Preliminary results reveal several surprising findings. First, we show that the emissions rate of the US new vehicle fleet has fallen by more than 99 percent since regulation began in 1968. We find similar patterns for the three main regulated air pollutants—carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x). While used vehicle emissions are less comparable over such long time periods, we find suggestive evidence that they have followed similar patterns since 1990.

Second, exhaust standards have caused a substantial share of these declines. We find that a 1.0 gram-per-mile decrease in exhaust standards causes new and used vehicle emission rates to fall by between 0.5 and 1.0 grams per mile. Equivalently, exhaust standards have caused between 50 and 100 percent of the decrease in new vehicle emissions rates.

These results come from differences-in-differences regressions that use several sources of variation in exhaust standards. We provide evidence on the effectiveness of each of the four major sets of vehicle exhaust regulation since the 1960s, which are generally referred to as Tier 0 (1968-1993), Tier 1 (1994-2003), Tier 2 (2004-2016), and Tier 3 (2017-2025). While the identifying assumptions underlying these regressions cannot be tested directly, several indirect pieces of evidence support the research design. Event study graphs show that changes in emissions correspond in time with changes in exhaust standards. Additionally, we report estimates including rich controls for several of the most important potential confounding policies: inspection and maintenance ("smog check") standards, Corporate Average Fuel Economy standards, gasoline hydrocarbon standards, gasoline sulfur content standards, ethanol blending, and gasoline prices (including gasoline taxes). As further evidence on the potentially confounding role of fuel economy standards, we also report results in terms of emissions per gallon of gasoline, and we separately show direct effects on official fuel economy ratings and on used vehicle tailpipe measures of CO_2 emissions. These alternative estimates help rule out other explanations for the long-term downward trend in vehicle emissions.

We also study many other specifications, including subsamples of data with less measurement error. Moreover, we show that a new vehicle's certified emissions, which is what exhaust standards regulate, strongly predicts its future emissions as a used car. Using lists of the exact engine configuration of the Volkswagen vehicles with defeat devices from the consent decree of the Volkswagen litigation, we confirm that remotely sensed used vehicle NO_x emissions are dramatically higher for these than for other vehicles. Finally, we examine mechanisms by which exhaust standards may affect emissions. We find that exhaust standards do not change basic vehicle attributes (size, horsepower, torque, fuel economy, etc.) but do lead manufacturers to install cleaner engines.

Third, the analysis provides several stylized facts suggesting that tailpipe standards and vehicle property taxes are not cost-effective: (1) a small share of vehicles account for most pollution; (2) age and mileage explain large differences in emissions rates; (3) initially identical new vehicles have very different on-road emissions rates; and (4) existing registration fees and property taxes are higher on cleaner vehicles. These facts are not true for fuel economy and CO_2 emissions, suggesting that existing research on fuel economy may not extrapolate well to air pollution.

Fourth, to study efficiency, the analysis builds a quantitative equilibrium model of new and used vehicle markets. The model describes manufacturers that produce new vehicles and engage in Bertrand competition within different vehicle classes; households with preferences across vehicle classes; and competitive vehicle resellers that purchase vehicles from manufacturers then rent them to households. Each period, vehicles age and incur maintenance and depreciation costs; when these costs exceed a vehicle's rental value, the vehicle is scrapped. Air pollution damages vary by vehicle type, and are calibrated to match our microdata and 65 million pollution readings. The social planner chooses from a menu of feasible policy tools, including exhaust standards, registration fees, and CAFE standards, to maximize social welfare. A competitive equilibrium is a vector of vehicle prices and scrap decisions such that consumers choose vehicles to maximize utility, auto manufacturers choose vehicles to supply to maximize profits, vehicle resellers choose prices and scrap to maximize profits, and the new and used vehicle markets clear.

We use the model to study several counterfactual policies. Preliminary results suggest that the largest welfare gains come from redesigning annual registration fees. Making registration fees proportional to the pollution damages from a given type of vehicle decreases the present value of pollution damages by $50 billion and increases social welfare by $30 billion. A central mechanism

for such fees is to encourage scrap of the oldest vehicles. Even in the absence of such drastic reforms, merely charging similar property taxes and registration fees for clean and dirty vehicles, rather than the current higher fees on cleaner vehicles, would decrease the present value of pollution damages by $20 billion.

Innovations Relative to Existing Literature

This paper builds on several literatures. We provide the first comprehensive analysis of exhaust standards, which are informally believed to be among the most important environmental policies for transportation in the US, EU, China, India, and elsewhere. Most economic research on environmental policies for transportation focuses on fuel economy standards, smog check, gasoline taxes, or fuel content standards. While many papers describe the existence of exhaust standards, existing work largely does not directly analyze their effects (e.g., Bresnahan and Yao 1985, Bishop and Stedman 2008). While we focus on US standards, the analysis is potentially relevant in the dozens of other countries that either copy US standards with a several-year lag or use their own standards that have similar structure.

Additionally, this research provides the first economic analysis of vehicle property taxes. Research has carefully analyzed property taxes for real estate but has not exploited the fact that many of these property taxes also apply to vehicles. We create a new dataset listing the precise rules of all vehicle registration fees and property taxes imposed by US states, cities, counties, and special districts. We show that lower-value vehicles emit more pollution, so these vehicle property taxes send consumers a perverse price signal by discouraging ownership of more-valuable and cleaner vehicles.

This research is also uniquely able to attribute a large share of national, long-term changes in pollution to a single policy—exhaust standards. While many countries and sectors have had large decreases in pollution over time, and most of this decrease reflects cleaner production within an industry or product rather than reallocation across products, studies have struggled to assess which economic forces have caused most of that decline (Shapiro and Walker 2018). This research provides a unique setting where a single regulation accounts for most of a long-term national decrease in pollution emissions rates.

This analysis also shows that air pollutants like carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x) (sometimes called "criteria" or "local" pollutants), which exhaust standards regulate, have starkly different patterns than fuel economy and associated CO_2 emissions. Much existing literature focuses on fuel economy standards and their inefficiency relative to gasoline taxes (e.g., Goldberg 1998, Bento et al. 2009). In part the difference between CO_2 and local pollutants arises because "end-of-pipe" or "post-combustion" abatement technologies like catalytic converters can remove local pollutants after gasoline is burned, while no such economically viable post-combustion abatement technology exists for CO_2 emissions. These air pollution abatement technologies vary in effectiveness across vehicles and time, suggesting that policies efficient for CO_2 emissions may not be optimal for air pollution.

This research also adds to existing work that uses quantitative equilibrium models to study the impact of vehicle taxes and standards on pollution emissions. The model adapts fuel economy analyses (Goulder et al. 2012, Jacobsen and van Benthem 2015) to study vehicle air pollution. Our setting is just one case of a more general problem where due to information asymmetries, political economy constraints, or other forces, directly taxing an externality is infeasible. It is widely acknowledged that taxing a good or product attribute which is imperfectly correlated with an externality is inefficient. Economics has a clear prescription for optimal first-best policy, but guidance on optimal second-best policy in such settings is unavailable. One of our goals is to provide

such guidance for regulation of pollution from vehicles when optimal first-best taxes are infeasible.

Conflict of Interest Statement

The authors are receiving a $25,000 grant from the Environmental Protection Agency to support this research, and otherwise declare they have no financial or other interests that might bear on the proposed work, including no financial or other ties to the transportation industry.

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