The Implications of Heterogeneity for the Regulation of Energy-Consuming Durable Goods

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Abstract

Many of the most important policies that aim to reduce greenhouse gas emissions and other environmental externalities do so by regulating the energy efficiency of energy-consuming durable goods. We document a hitherto unexplored connection between heterogeneity in the utilization of such durable goods and the economic efficiency of this class of policies. Inefficiency arises because products with the same energy efficiency rating have different lifetime utilizations, and hence different lifetime emissions, are given equal policy treatment. We develop a model that characterizes sufficient statistics for the deadweight loss from using these second-best policies in lieu of efficient Pigouvian taxes in the presence of such utilization heterogeneity. Most notably, under some plausible assumptions, the R^2 from a regression of the lifetime emissions of products on their energy efficiency ratings is equal to the fraction of the first-best welfare gain that can be achieved by energy efficiency regulations, like Corporate Average Fuel Economy standards, that impose an (implicit) linear tax on energy efficiency. We explore the quantitative importance of heterogeneity for the case of automobile fuel economy regulations using data on vehicle mileage shortly before scrappage. We document significant dispersion in lifetime mileage of different types of vehicles that share a common fuel economy rating. We estimate that this heterogeneity implies that fuel-economy regulations can achieve only about one quarter of the welfare gain from an optimally designed policy.

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1 Introduction

The consumption of energy, which is both a tremendous engine of economic growth and the principal driver of global climate change, is nearly always achieved through the operation of some durable good. Motor vehicles combust gasoline; appliances use electricity; furnaces burn natural gas; and so on. To correct the market failures caused by the pollution that attends energy consumption, economists typically advocate the pricing of emissions. As argued by Pigou (1932), if externalities can be taxed directly, then market efficiency can be fully restored. Such policy prescriptions are indifferent to the durables that act as an intermediary between fuel inputs and emissions outputs.

Policies that directly target emissions are, however, relatively rare. Instead, a proliferation of policies focus on these durable intermediaries, often through the regulation of their energy efficiency. Examples include fuel economy regulations, appliance efficiency mandates, and building codes. Energy efficiency policies are known to suffer from inefficiencies due to the "rebound effect"; by lowering the cost of using a durable good, energy efficiency regulations induce additional use on the margin.[1] The aim of this paper is to establish another inefficiency of such policies, one that stems from heterogeneity in how durables are used.

To see the logic of our inquiry, note that two goods with the same energy efficiency rating may have very different total lifetime emissions because they may have different realized utilizations. One refrigerator may last longer than another. Or, consumers may drive certain types of cars more than others. A policy that directly taxed emissions would account for differences in realized utilization; e.g., someone who drives their car more will pay more under a carbon tax. But, policies that regulate the durables themselves, rather than emissions, are almost always limited in their ability to account for such heterogeneity in utilization. This limitation implies a substantial inefficiency, and this is the subject of our investigation.

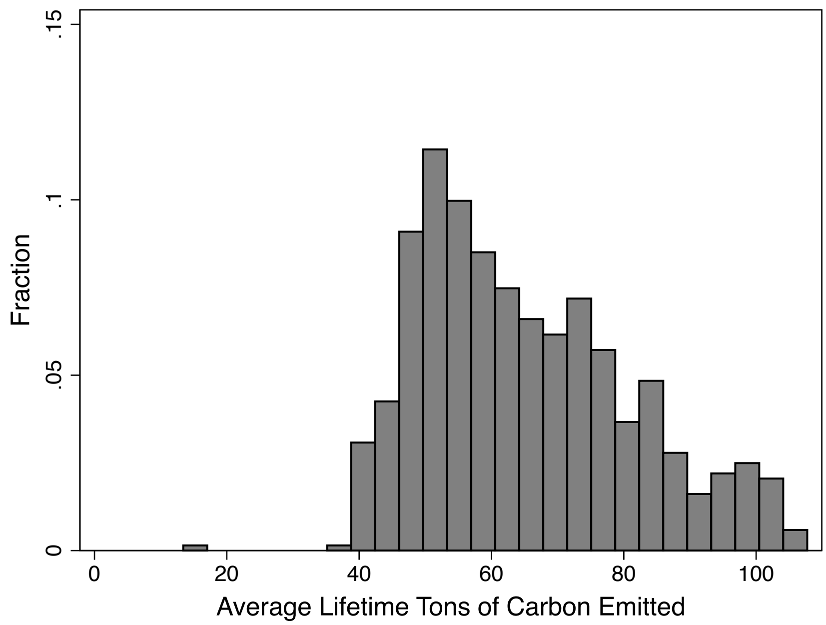
Most commonly, energy efficiency regulations must give the same policy treatment to two products that have the same official energy efficiency rating. For example, Corporate Average Fuel Economy (CAFE) standards require automakers to sell vehicles that meet or exceed a specified sales-weighted average fuel economy. This creates an implicit tax or subsidy (a shadow price) on each car sold that is a linear function of its fuel consumption rate. Thus, all vehicles that share a fuel economy rating will have a common implicit tax or subsidy.[2] But, vehicles with a common fuel economy rating in fact vary widely in their lifetime emissions, because some types of cars last longer than others.

To illustrate this heterogeneity, we plot the average lifetime carbon emissions for different types

[1] For example, fuel economy regulations that spur consumers to buy more efficient cars implicitly lower the cost of driving an additional mile, which induces people to drive more. For reviews of the literature on the efficiency of fuel economy regulation and taxation, see Anderson, Parry, Sallee, and Fischer (2011) and Sallee (2011), respectively. See Borenstein (Forthcoming) for a recent treatment of the economics of the rebound effect.

[2] Note that this is a stylized representation of CAFE, which requires each automaker to meet the standard separately. Until recently, there was no trading of compliance credits across firms, so each firm had a unique shadow price. In addition, cars and light-duty trucks are regulated separately. We also abstract from a recent policy change in which a vehicle's fuel-economy standard is conditioned on a vehicle's footprint – a measure of vehicle size determined by multiplying the vehicle's wheelbase by its average track width.

Figure 1: Distribution of Lifetime Carbon Emissions for Vehicles with EPA Average Rating of 23 Miles per Gallon



of cars that have the same fuel economy rating in Figure 1. The figure uses data, which we describe in detail below, on the odometer readings of vehicles shortly before they are scrapped, which we convert into tons of carbon using the vehicle's fuel economy rating and the average carbon content of gasoline. The graph suggests a wide dispersion in lifetime emissions among vehicles with a common 23 miles per gallon rating (the median in our data); the standard deviation is 20% of the median. At $39 per ton, which is the current federal guideline for the social cost of carbon, the standard deviation in damages across cars with the same fuel economy rating is over $600. Thus, a policy like CAFE that must give all cars with the same fuel economy rating the same shadow price is necessarily imprecise; it places the same implicit tax or subsidy on products that in fact have substantially different lifetime externalities. The goal of our paper is to understand how this imprecision affects the welfare properties of policies that regulate durables goods, as compared to efficient policies that target emissions.

To achieve this goal, we use both theory and data. We first develop a model with a representative consumer that allows us to derive sufficient statistics for the deadweight loss of using energy efficiency regulations in lieu of an efficient emissions tax. In this model, which we describe in section 2, consumers are all alike, but there is heterogeneity in lifetime utilization of goods due to differences in product durability. In this setting, product-based policies can be fully efficient if they assign a unique (implicit) tax or subsidy to each product according to both its energy efficiency rating and its average lifetime durability. Energy efficiency policies are, however, generally limited in that they must impose regulatory treatment that is a function of only energy efficiency ratings.

Our model characterizes the deadweight loss of utilizing such restricted second-best policies using a parsimonious set of parameters (sufficient statistics). We emphasize results relating to policies, like CAFE, that impose a linear tax on products according to their efficiency ratings. In the simplest case, the fraction of the welfare gain achieved by the first-best policy—as compared to a baseline policy that sets a single tax rate on all products—that can be achieved by a linear tax on energy efficiency is equal to the R^2 from a regression of the lifetime emissions of products on their energy efficiency ratings. The intuition for this is that the first-best policy charges each product a tax equal to its lifetime damages, and the ability of the linear tax to mimic this policy differentiation is determined by the degree to which the efficiency ratings predict lifetime emissions. This result links directly to graphs like Figure 1; when such figures show a greater spread in lifetime emissions for a given energy efficiency rating, the R^2 of a regression of lifetime emissions on energy efficiency ratings will be lower and the policy's deadweight loss will be greater. Under alternative assumptions, terms other than this R^2 will also influence welfare, but the R^2 remains an important factor.

In turn, the sum of squared residuals from this regression, along with an estimate of the marginal damages of emissions, can be used to express the deadweight loss of using second-best policies (as compared to the first-best benchmark) in terms of dollars. To demonstrate the quantitive importance of our theoretical results for actual policy, we investigate the case of automobile regulation using data on the lifetime mileage of different types of cars. We describe our data in section 3. In section 4 we use these data to quantify the efficiency of a policy that puts a linear tax on fuel consumption as compared to an efficient policy. We find that CAFE-style policies recover only about 25% of the welfare gains (compared to a zero-policy baseline) that are achieved by the efficient policy.[3]

We then generalize our model to account for heterogeneity across types of consumers, who may use durable goods differently, in section 5. In this setting, the first-best allocation is achievable (assuming no rebound effect) when each consumer has a unique set of taxes on all products. Such a policy is infeasible, and we focus our study on policies that cannot discriminate across consumers and admit only a single tax rate on each product. We derive the second-best tax rates in this case. Our results demonstrate that a vast amount of information is required in order to formulate optimal policy; the second-best rates depend on a matrix of interactions between cross-product price elasticities and marginal external damages. In some sense, our formulas provide a negative result: to implement the second-best product-based policy, policymakers would need to know a

[3]Throughout the paper, we focus on the question of how heterogeneity in utilization affects the welfare properties of two policies that are optimally designed, one of which faces a constraint, in the absence of a rebound effect. Actual policies, including CAFE, suffer from additional inefficiencies compared to the ideal both because of the rebound effect and because they are not necessarily second-best, even given the constraints we consider here. In particular, CAFE gets the average implicit tax to vehicles wrong because it taxes some vehicles, but subsidizes some others. This means that CAFE gets the extensive margin wrong—that is, it should raise the price of all cars on average (because all produce externalities), but it does not necessarily do so. This is similar to the extensive margin problem of performance standards considered in Holland, Hughes, and Knittel (2009). CAFE could be combined with a sales tax on all cars so as to achieve the second-best rate. Our focus is on the role of heterogeneity, because that is our contribution in this paper, but a full assessment of real-world policies, including CAFE, must also consider these other factors.

great deal of information that is not readily available. An advantage of direct taxes on emissions is that they do not require this information. Our analysis in this section is related to Diamond (1973), which considers the second-best tax rates for a single consumption good that causes a different externality when consumed by different individuals. Our model generalizes the results of Diamond (1973) to the case of many interrelated goods (e.g., types of cars) that each cause externalities. Doing so highlights the vast informational requirements for implementing second-best policies. We plan to develop simulations to assess how much welfare is lost by resorting to optimal product-based standards.

Our analysis points to inefficiencies of product-based policies that have largely gone undiscussed in the energy policy literature. In some cases, product-based policies may be chosen because emissions cannot be taxed or regulated directly. In such cases, our analysis shows the cost of second-best policies compared to an unobtainable first-best. But, policies that target durables, rather than emissions, often persist even when more direct and efficient policies are feasible. For example, it would be technologically challenging to monitor the greenhouse gas emissions emitted from the tailpipe of individual automobiles. It is straightforward, however, to tax motor fuel according to its carbon content, and thus a policy very similar to an efficient tax on carbon emissions can be easily mimicked by a gasoline tax. Nevertheless, we rely on CAFE. In cases such as this, our results point to the welfare costs of preferring one form of regulation, perhaps because of political economy or equity considerations, over other feasible instruments.