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Market Power, Taxation and Product Variety in the Brazilian Automobile Industry*

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Abstract

This paper empirically assesses the impact of a discontinuous tax schedule on prices, markups and product assortment in the Brazilian automobile industry. To this end, I estimate a structural, equilibrium model of demand and supply for over a hundred different models and engine sizes of automobiles. With the model estimates of price elasticities and marginal costs I quantify how market power impacts the progressivity of the discontinuous tax schedule. I also examine how firms would reposition their products to avoid the tax and quantify the impact of this repositioning on equilibrium outcomes.

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1 Introduction

A notched commodity tax schedule - where a small change in a product's attribute creates a discontinuous change in tax liability - is often used in differentiated goods markets as policy tool to discourage the purchase of goods with a particular attribute (Slemrod, 2010; Sallee and Slemrod, 2012; Ito and Sallee, 2018). Examples include the U.S. guzzler tax and automobile taxes in many countries. At the same time, differentiated goods markets usually feature a small number of multi-product firms. In these settings, prices and product assortment are the equilibrium outcome of firms' oligopolistic competition. Yet, the empirical public finance literature typically studies notched taxes within the perfect competition framework. Therefore, the impact of product differentiation and market power on the efficacy of notched taxes as a policy instrument remains largely unknown.

This paper is an empirical study of the impact of a notched tax schedule on equilibrium product assortment and prices in a market that is differentiated and concentrated. The effects of a notched tax schedule in an oligopolistic industry with multi-product firms can be complex. A notched tax schedule raises all prices and reduces total demand. However, the notches also change the relative prices of products in different areas of the product space. These changes in relative prices shift demand away from products facing higher tax rates to products facing smaller tax rates. In a setting in which firms have market power, the shift in demand affects the markups firms can earn and their incentives to supply products in each area of the product space.

My setting is the Brazilian automobile industry. Brazil is ranked as the 7th largest producer of automobiles and 4th largest consumer market for automobiles in the world. The market is relatively closed; most of the automobiles sold in Brazil are domestically produced. The market is highly differentiated; there are over a hundred different models and engines sizes that consumers can choose. The market is highly concentrated; the market share of the largest four firms is over 80%.[1] The market is also heavily taxed. Consumers in Brazil pay two kinds of taxes when they purchase a new car: a sales tax of 25% and an engine tax with ad-valorem rate that

[1] Chevrolet (GM), Fiat, Ford and Volkswagen.

increases with car engine displacement.[2] The rate is 7% for engines up to 1L, 11% for engines between 1L to 2L and 18% for engines above 2L.

The engine tax has been used to address distributive and environmental concerns. It is a luxury tax; cars with larger engines are also more expensive and presumably purchased by high-income consumers. It is also a way to promote the purchase of smaller cars which are more fuel efficient and pollute less. To quantify how firms' pricing and product assortment responses affect the government's ability to achieve its distributive and environmental goals, I build a structural model of market demand and supply of cars in Brazil.

I model demand for different cars using the random coefficient logit model proposed by Berry et al. (1995) (hereafter BLP). The BLP framework is flexible enough to generate elasticities that depend on vehicle attributes and the distribution of consumer incomes. It does so while accounting for car characteristics known to both consumers and firms but not observed to the econometrician. The model also allows me to obtain price elasticities for cars that were not offered, which is key to study how firms choose product assortment.

In the supply model, I assume that in each year the multi-product firms play a two-stage non-cooperative game. In the first stage, firms simultaneously choose the subset of products they will offer in Brazil, taking as fixed the set of available models and engines sizes that they produce worldwide. In the second stage, given the products chosen in the first stage, firms simultaneously choose prices. The equilibrium of the Bertrand-Nash pricing game played in the second stage is characterized by a system of first order conditions in which firms equate their residual marginal revenues to marginal costs. As a result, the demand estimates and observed prices imply estimates of marginal cost for each product offered. Given these estimates and a parametric assumption on how the cost function depends on attributes of the automobiles, I estimate the marginal cost function.

The model is estimated using a detailed dataset on product sales, prices,

[2]Engine displacement is the combined volume of the pistons inside the cylinders of an engine. It is a commonly used measure of engine size. The aforementioned rates are for automobiles that run on gasoline, ethanol or both, i.e, bifuel cars. For gasoline automobiles, the displacement bins are the same, but the rates are 7%, 13%, and 25% respectively.

and characteristics. A product is defined at the model and engine displacement level. For example, the VW Golf (model) 1.6L (engine displacement) is a product and the VW Golf 2L is another product. The data spans the 2005-2012 period. The preference parameters are estimated using the Generalized Method of Moments (GMM) proposed by Berry (1994), Berry et al. (1995) and Nevo (2001).

With the demand and marginal cost estimates I perform a series of counterfactuals to quantify the distortions caused by the engine tax and market power on equilibrium outcomes. The first counterfactual holds the set of products offered fixed and investigates how market power affects price levels and tax pass-through. The second counterfactual examines how firms would reposition their products to avoid the tax and quantify the impact of this repositioning on equilibrium outcomes.

The results obtained in the first counterfactual indicate that market power is the main factor distorting market outcomes. I find that markups over marginal cost account for 85% of the price increase and 78% of the sales decrease relative to the perfectly competitive benchmark without the engine tax. Furthermore, firms' strategic price responses generate heterogeneous and incomplete pass-through of the engine tax: average pass-through is 85% for products in the first tax bin, 97% for products in the second tax bin and 96% for products in the third tax bin.

The markups over marginal costs and the incomplete and heterogeneous tax pass-through have direct policy implications. Using the value of the taxes paid by consumers and choice probabilities obtained under different competitive conduct assumptions, I construct different Suits indexes (Suits, 1977). The Suits index is a Gini coefficient that associates the cumulative share of taxes to the cumulative share of consumers, ranked from lowest to highest income. It ranges from -1 to 1, with negative values indicating a regressive tax, positive values indicating a progressive tax and 0 indicating a proportional tax.

With marginal cost pricing and the engine tax, the index is 0.71. In contrast, with Bertrand-Nash pricing and the engine tax, the index is 0.76. Hence, market power increases the progressivity of the engine tax. It does so through two channels. First, tax pass-through is smaller for the vehicles in the first tax bin and these vehicles are more likely to be purchased by consumers with lower income. Second, market power increases all prices and thus reduce the market participation of consumers at the bottom and middle of the income distribution.

The second counterfactual examines how firms would reposition their products to avoid the discontinuities of the engine tax and quantify the impact of this repositioning on equilibrium outcomes. In contrast to the previous counterfactual, for which I only needed to compute equilibrium prices for a fixed set of products, I now need to compute equilibrium prices and product assortment. Obtaining this equilibrium is computationally challenging as firms have a large set of actions to choose from. To address this issue, I use the algorithm proposed by Fan and Yang (2020). I find that the discontinuities of the engine tax lead firms to choose engine sizes away from the thresholds defined by the tax schedule. This movement decreases the variety of engine sizes observed in the market and this reduction in variety plays an important role in reducing total sales. Not accounting for this variety effects would understate the ability of the engine tax in reducing CO_2 emissions.

This paper is related to several strands of the literature. Recently, the insights of Berry et al. (1995); Pakes et al. (2015) have been extended to study how policy changes impacts equilibrium product assortment. Examples include the impact of mergers on product positioning (Fan, 2013; Fan and Yang, 2020), the effect of bailing out truck manufacturers on truck offering (Wollmann, 2018) and the impact of competition on product assortment (Eizenberg, 2014; Nosko, 2014; Sullivan, 2020). Furthermore, a growing empirical literature has focused in quantifying how market power impacts the ability of taxation as a tool to achieve a determined policy goal (e.g revenue, CO_2 abatement, etc). Examples include Miravete et al. (2018); Preonas (2019); Fowlie et al. (2016). I add to both literatures by studying not only equilibrium price responses to a notched tax but also by documenting and showing the empirical relevance of product assortment responses.[3]

[3]Kroft et al. (2021) provide a theoretical framework to contrast specific and ad-valorem commodity taxes in settings with imperfect competition and entry/exit of firms. We depart from them in two aspects. First, I consider a notched tax schedule and thus I am not able to cast the analysis in terms of infinitesimal changes in taxes. Second, instead of considering firms' entry/exit decisions I consider the assortment decisions of

The second contribution of this paper is to the empirical literature that investigates the distributional impact of regulation in a variety of industries. Miravete et al. (2020); Stolper (2021) investigate the interaction between market power and the distributional impact of regulation in the Pennsylvania market for spirits and the Spanish gasoline market, respectively. Durrmeyer (2022) quantifies the equilibrium effects of the bonus/malus policy in the French automobile industry and analyzes the distributional impact of the policy. I add to this literature by studying a developing country where the high degree of income inequality makes the distributional impact of regulation a key policy object, and by quantifying the role of market power in affecting the progressivity of the regulation.

Lastly, this paper adds to a literature using structural models of supply and demand to study the impact of hypothetical and factual environmental regulation in the automobile industry. Examples include Goldberg (1998); Klier and Linn (2012); Huse and Lucinda (2013); Adamou et al. (2013); Grigolon and Verboven (2014); Durrmeyer and Samano (2017); Reynaert (2020). These papers have restricted their attention to the U.S. and European countries (e.g. France, Germany and Sweden) and have mainly evaluated the aggregate impact of CAFE policies, taxes, fees and rebates on consumers decision to purchase more fuel efficient automobiles. I add to this literature by studying the progressivity of the engine tax and by addressing not only the impact of the engine tax on consumers choice, but also the impact of the engine tax on the composition of cars offered.

The next section presents an overview of the Brazilian automobile industry and describes the data. Section 3 describes the behavioral model. Section 4 discuss the identification and estimation of the model. Section 5 presents the estimates of the demand and marginal cost parameters. It also discusses the substitution patterns implied by the model. Section 6 presents the counterfactual analysis. Lastly, section 7 concludes.

multi-product firms which requires obtaining own and cross price elasticities.

2 Institutional Background and Data

2.1 Overview

In 2012, Brazil was the 7th largest producer of automobiles and the 4th largest consumer market for automobiles in the world. The automobile industry in Brazil was worth $94 billion, which is roughly 19% of its industrial GDP. Most of this production, roughly 90%, was sold domestically. These sales account for approximately 86% of total automobile sales in Brazil. Thus, the automobile market in Brazil is not only large, but also relatively closed.

Brazil levies a high import tariff on automobiles. The tariff is 35%. Automobiles produced in Mexico are exempt from this tariff due to a trade agreement between the two countries. Also exempt are automobiles produced in Argentina, Paraguay, Uruguay and Venezuela who are members of Mercosur, the South American common market. The high import tariff is an important factor explaining why Brazil's automobile market is so closed. Import tariffs and domestic production shares are much lower in the United States and in major European countries (Belgium, Germany, Great Britain, Spain, France and Italy) are much lower.[4]

In addition to being relatively closed, the automobile market in Brazil is also relatively concentrated. The main manufacturers in Brazil are foreign firms. They include GM and Ford from the United States; Citroen, Peugeot, and Renault from France; Mercedes-Benz and Volkswagen from Germany; Fiat from Italy and Honda and Toyota from Japan. Using data that I will describe in more detail in the next section, Table 1 reports their market shares in 2012. Fiat is the largest manufacturer and has 25.6% of the market. The market share of the top 4 firms is 80%. By contrast, the market share of top 4 firms in the United States is 53% and it ranges between 44% to 65% for the major European countries.[5]

Table 1 goes here

[4] See Cosar et al. (2018).
[5] See Cosar et al. (2018).

2.2 Automobile Taxes

The government levies several kinds of taxes on the sale of new automobiles. All but one have uniform rates and I treat these as equivalent to a sales tax of 25%. The non-uniform tax is known as IPI, which is the Portuguese acronym for *tax on industrialized products*. This tax is the focus of this paper and hereafter will be referred as the *engine tax*.

The engine tax is a discontinuous function of engine displacement, a measure of engine size.[6] For automobiles that run on gasoline, the tax is 7% when engine displacement is 1L or less; 13% when engine displacement is between 1L and 2L; and 25% when engine displacement exceeds 2L. For automobiles that can also run on ethanol (bifuel), the displacement bins are the same, but the rates are 7%, 11%, and 18% respectively.

An important feature of the engine tax schedule is the "jumps" or discontinuities in the rates (in the public finance literature, they are called notches). Notched tax schedules based on engine size are present not only in Brazil but also in other major automobile markets like China and Japan; and midsize markets like the UK and Turkey. Historically, the Brazilian government rationale for the engine tax is that it works as a luxury tax. Automobiles with larger engines are more expensive and likely to be purchased by high income consumers. Furthermore, automobiles with larger engines also emit significantly more CO_2 than automobiles with smaller engines. Therefore, another likely rationale for the engine tax is that government wanted to reduce CO_2 emissions.

The schedule of rates is mostly fixed throughout my sample period of 2005 to 2012. However, in response to the world financial crisis, the government did temporarily reduce the rates in 2009, the first quarter of 2010, and in 2012. These reductions did not affect the tax thresholds determining the engine displacement bins. Since these changes were the result of a counter-cyclical macroeconomic policy intended to stimulate automobile sales, I will treat them as exogenous variation in prices.

The engine tax schedule may have shifted supply away from large engine automobiles towards lower engine automobiles. Figure 1a and 1b displays

[6]Engine displacement is the combined volume of the pistons inside the cylinders of an engine. More information on what is engine displacement can be found at https://www.yourmechanic.com/article/what-is-engine-displacement

the fraction of automobiles offered by engine size and fuel type. The plots are constructed by pooling the data over the sample period. For both fuel types, most of the automobiles offered have engines that are either 1L or between 1L and 2L. A striking feature of the plots is the bunching at the tax thresholds, especially for gasoline-powered engines. Note that there are no bifuel automobiles with engines larger than 2L. At first glance, this result may seem surprising since the engine tax rate on these automobiles is 7% higher for gasoline engines than for bifuel engines. However, most of the automobiles in this bin are made in Mexico, not in Brazil.

Figure 1 goes here

2.3 Data

The data on the automobile market in Brazil come from a variety of sources. The quantity data are provided by the national department of traffic (DENATRAN).[7] These data are at the model/engine displacement/trim level (e.g., Honda Civic 1.8L LX and Honda Civic 1.8L EX) and covers the period from 2005 to 2012.

The data on manufacturer's suggested list retail prices are obtained from Quatro Rodas, a Brazilian magazine specializing in automobiles. This magazine is also the source of information on a set of automobile characteristics: horsepower, safety features such as airbag and ABS, and comfort features such as air conditioning and automatic transmission. Information on automobile weight and fuel consumption is obtained from Molicar, a consulting firm specializing in the automobile industry, and *Carros na Web*, a specialized website that reports technical specifications of almost every car sold in Brazil.

I constructed measures of fuel efficiency using annual retail prices of ethanol and gasoline from the National Agency of Petroleum (ANP). I use data from the National Bureau of Statistics (IBGE) to construct a measure of market size. My measure is the number of households in the middle and upper income classes, i.e., with monthly income equal to or greater than

[7] In Brazil, one is required to pay a fee when registering a new car and also to pay a yearly ownership tax that depends on the market value of the car. Therefore, I expect the government to keep an accurate record of the number of new vehicles registered.

three times the minimum wage. To estimate the distribution of income in Brazil, I use the average income reported in IBGE and the Gini coefficient reported by the World Bank.

The sample is an unbalanced panel containing every car made in Brazil, Mexico, and members of Mercosur and sold in Brazil during the period 2005 to 2012. The data excludes SUVs and trucks and covers 89% of all registrations in Brazil during that period.[8]

A model often comes with different engine sizes (e.g., Honda Civic 1.8L, Honda Civic 2L). The literature on automobile demand (e.g., Berry et al. (1995)) has typically aggregated across engine sizes and defined a product as a model (e.g Honda Civic). However, my data on quantities and prices are more detailed and, as a result, I can define a product as a model and engine-displacement combination (e.g., VW Golf 1.6L, Honda Civic 1.8L, Honda Civic 2L). This is especially important in my case since the tax rate of a model can vary substantially depending upon the size of its engine.

Table 2 reports the number of products and models offered in each year of the sample period. The first two columns establish that the number of products and models are increasing over time. Column 3 demonstrates that the mean number of different engines-displacement offered per model is relatively stable around two. Column 4 demonstrates that the average number of models across firms that is made in Brazil is relatively stable over time. It then follows that the increase in the number of products is coming from an increase in the number of imported models offered every year and not from an increase in the number of engines offered per model. Column 5 reports the number of models that come with engine displacements of 1L and more than 1L. Column 6 shows that these models account for a sizeable share of sales. These data underscore the importance of defining products at the model-engine displacement level and highlight the stability of firms' domestic production lines.

Table 2 goes here

Table 3 reports total automobile sales and product market shares by tax bin. Total sales rose steadily from 1.34 million in 2005 to 2.6 million in

[8]As highlighted by the high coverage, SUVs were still in their infancy during our sample period.

2012. The information on product shares establish some interesting trends in the composition of cars bought. First, models with medium-size engines (1L to 2L) become more popular over the sample period. Their sales share increased in 12.3 p.p while their share in the total number of products offered increased only 4.2 p.p. Second, the popularity of models with small engines (1L) declined. Their sales share decreased 12.4 p.p while their share of the total number of products offered decreased only 4.1 p.p. The sales and product shares of models with large engines exhibit no trend. These patterns suggest that models with small and medium size engines are closer substitutes with each other than with models of large engines. It is also consistent with the hypothesis that the substantially higher tax rates on models with large engines drive consumers and firms away from this area of the product space

Table 3 goes here

Table 4 displays the sales-weighted averages of the variables used in the demand model. All monetary variables are in 2010 Reais ($), the Brazilian currency. Prices are post-tax. The characteristic variables consist of horsepower (Hp), the number of kilometers one can drive with one Real (Km/$), horsepower per 100Kg (HPW), a dummy variable that is equal to 1 if the car is bifuel and 0 otherwise (Bifuel), a dummy variable that is equal to 1 if automatic transmission is a standard feature and 0 otherwise (At), a dummy variable that is equal to 1 if air-conditioning is a standard feature and 0 otherwise (Air), a dummy variable that is equal to 1 if either ABS airbags are standard features and 0 otherwise (Safety), and the trunk volume measured in liters.

Column 2 of Table 4 shows that automobiles prices are declining over time. Prices are roughly constant during the first four years of the sample but fall substantially over the next four years. A key factor behind this decline is the temporary cuts in engine tax rates. Columns 3 and 4 indicate that cars are becoming more powerful as both Hp and HPW increase over time. Column 5 shows that automobiles are also becoming cheaper to drive. In 2005, the average car drove 3.7 Km per Real, whereas in 2012 the average care drove 4.5 km per real. This decrease in the cost of driving is likely driven by the rising fraction of bifuel automobiles reported in Column

6.[9] The last four columns show that automobiles are becoming safer, more comfortable to drive and larger. The share of automobiles with ABS and/or airbags as a standard feature increases over time, as does the share of automobiles with automatic transmission and air-conditioning as standard features. Lastly, average trunk size is consistently increasing over time.

Table 4 goes here

2.4 Potential Products

To study how the engine tax schedule affects the set of products offered, I require not only data on the products that firms supplied in Brazil but also data on the set of products that firms could have supplied. To construct this set of products, I first use the data previously described to identify the set of models and engine sizes that each firm sold in Brazil in 2005 (e.g Clio 1L, Clio 1.6L Astra 2L). For each of these models, I identify the set of engine sizes that the firm produced and offered outside of Brazil (e.g Clio 1.1L, Clio 1.4L, Astra 1.6L and Astra 2.2L).[10] The union of these two sets gives me the set of products that firms could have chosen to produce in Brazil in 2005 but did not. I then impute the characteristics of these alternative products based on a flexible regression model that predicts Km/L and Weight as a function of HP, engine displacement, model fixed effects and year fixed effects for the sample of products sold in Brazil. For AT, AIR and Safety, I assign the characteristic of the best seller product within that model.

Table 5 displays summary statistics for the set of alternative products. There is a total of 66 products that firms could have offered in Brazil but did not. Every firm except Audi had products that they did not offer in Brazil but sold elsewhere in the world. Chevrolet had by far the largest set of alternative products. They could have offered 24 products based on 6 different models. One interesting feature of the set of alternative products is the number of small engines with 1.1L or 1.2L displacement. Outside

[9]By allowing cars to run with any mixture of ethanol and gasoline, bifuel cars provide more flexibility to consumers and thus may reduce the cost of driving.

[10]The list of the engines available outside Brazil can be found in Wikipedia and specialized websites like https://www.auto-data.net/en

of Brazil, models with these engines displacements seem quite popular. However, during my sample period they were not offered in Brazil.

Table 5 goes here

Figure 2 displays the average Km/$ and HPW by engine displacement for the set of products offered in Brazil in 2005 and the products that could have been offered. The figures indicate that the alternative products with 1.1L and 1.2L engines have on average similar Km/$ and HPW to the offered products with 1L. It also indicates that the alternative products with 1.1L and 1.2L engines have on average similar Km/$ and HPW to the products offered with 1.4L and 1.6L engines. The absence of any models with 1.1L and 1.2L engines in Brazil despite being not substantially different in observed characteristics (e.g. Km/$ and HPW) than the 1L models is further evidence that the tax thresholds affected product assortment.

Figure 2 goes here

3 Model

This section presents the behavioral model used to formalize the industry environment described in the previous section. I describe how consumers make choices, the firms' problem and define the equilibrium.

3.1 Demand

There are T markets, defined as Brazil in a given year. In each market there are M_t potential consumers that choose to buy one product or none. The indirect utility of a product j for consumer i in year t depends on the price and characteristics of the product:

$$\begin{gathered} u_{ijt} = x_{jt}\beta_i - \alpha_{it} p_{jt}^d + \phi_m + \phi_t + \xi_{jt} + \epsilon_{ijt} \\ i = 1, ..., M_t; \quad j = 0, ..., J_t; \quad t = 2005, ..., 2012 \end{gathered} \tag{1}$$

where x_{jt} is a K-dimensional vector of observed characteristics, p_{jt}^d is the post-tax price paid by consumers, ϕ_m is a car model fixed effect, ϕ_t is a year fixed effect, ξ_{jt} is a scalar characteristic which is observed by consumers and firms but not to the econometrician and ϵ_{ijt} captures idiosyncratic shocks on consumers' i taste for car j.

The vector x_{jt} contains dummy variables that capture the presence of air-conditioning (Air), automatic transmission (At) and ABS/Airbags as standard safety equipment ($Safety$). These variables are included to provide a measure of how comfortable and safe the car is. Possibly, they also provide a proxy for how luxurious the car might be. The year fixed effect capture macroeconomic events that affect the value of buying a car relative to the outside option of not buying a car. Lastly, the model fixed effect captures unobserved characteristics that are common among all different engine size versions of the same model (e.g. prestige, style, advertising, etc) across years.

I incorporate individual heterogeneity in price sensitivity and in the taste for vehicle characteristics by assuming that,

$$\alpha_{it} = \frac{\alpha}{y_{it}}$$

$$\beta_i = \beta + \Sigma\eta_i, \quad \eta_i \sim N(0, I)$$

where y_{it} is the income of consumer $i \in I_t$ and η_i is a random draw from a multivariate normal distribution which is also independent of consumer's income. Lastly, ϵ_{ijt} has an extreme value type-I distribution and is iid across consumers and alternatives.

The income draws y_{it} are simulated from a truncated log-normal distribution. This log-normal distribution is constructed to fit the mean and the Gini coefficient of the true Brazilian income distribution and the truncation is made at the 50th percentile which implies that I will only simulate households that belong to the mid-class or above.[11] The decision to truncate the income distribution has a straightforward rationale behind it. Brazil is a low-income country and many households do not have enough income to pay the monthly installment of even the cheapest car in the market.[12]

[11]The mean of the Brazilian income distribution is obtained from the National Survey of Households (PNAD) and the Gini coefficient is obtained from the World Bank database.

[12]In fact, approximately 13 million households are enrolled in *Bolsa Familia* which is

The vehicle characteristics that consumers have heterogeneous taste for are Km/\$, HPW and $Trunk$. Km/\$ is kilometers per Real (Brazilian currency) and provides a measure of cost of driving; HPW is horse-power divided by weight and provides a measure of automobile performance. $Trunk$ is the trunk space in 100L and provides a measure of the cargo space of the vehicle, which can be seen as a proxy for vehicle size.

With this specification, the demand model allows for flexible substitution patterns with respect to prices, measures associated with different dimensions of engine performance (cost of driving and power) and cargo space, which is a proxy for vehicle size. These are key inputs driving the firms decisions of what engines they will equip their cars.

The indirect utility u_{ijt} can be decomposed in two parts. Let,

$$\begin{aligned} \delta_{jt} &= x_{jt}\beta + \phi_m + \xi_{jt} \\ \mu_{ijt} &= -\ \alpha_{it} p^d_{jt} +\ x'_{jt}\Sigma\eta_i \end{aligned} \tag{2}$$

be the mean utility of car j and an individual-specific deviation from the mean utility, respectively.

In each period t, M_t consumers choose among one of the many new cars available (define J_t as the set of all cars offered) or the outside option of not buying a new car (defined as choice 0):

$$c_i = \underset{j \in J_t \cup 0}{\arg\max}\, u_{ijt}$$

The indirect utility of the outside option is normalized to be $u_{i0} = \epsilon_{i0}$. Integrating out the Type-I Extreme Value shocks, we obtain the probability of each consumer i buying car j:

$$s_{ijt} = \frac{\exp(\delta_{jt} + \mu_{ijt})}{1 + \sum_{k \in J_t} \exp(\delta_{kt} + \mu_{ikt})}$$

The predicted aggregate market share of car j in market t is obtained by integrating over the distributions of consumer income and unobserved heterogeneity, denoted by $F_y(y)$ and $F_\eta(\eta)$, respectively:

a government program that makes direct cash transfers to extremely poor/poor families.

$$s_{jt}(\mathbf{p}_t^d, \boldsymbol{\xi}_t, J_t) = \int_y \int_\eta \frac{exp\big(\delta_{jt} + \mu_{ijt}\big)}{1 + \sum_{r=1}^{J_t} exp\big(\delta_{rt} + \mu_{irt}\big)} dF_\eta(\eta) dF_y(y) \qquad (3)$$

3.2 Supply

The automobile industry is comprised of multi-product car makers that behave as oligopolistic, non-cooperative profit maximizers in the different geographical markets. To model firms' product choices, I make two assumptions on the set of products offered. The first imposes restrictions on the set of products offered worldwide by car makers. The second imposes restrictions on the set of products offered in Brazil.

I assume that, in every year, firm's worldwide set of products is fixed and exogenously defined. Specifically, the worldwide line-up of models, the engines produced and offered per model, and the comfort and safety attributes of the models are predetermined. This assumption is motivated by the observation that there is substantial engineering effort and R&D investment into the development of a car model and into development of an engine (Blonigen et al., 2017). Thus, it is unlikely that firms' can immediately respond to global or specific market changes by creating a new model or engine.

I also assume that, in every year, the models offered in Brazil are exogenously defined. This assumption is motivated by the observation that most cars sold in Brazil are also made in Brazil, and that changing the models offered requires firms to change the plant internal processes, adapt the line of production, change inventory and advertise the changes. These are presumably costly actions that take time to happen.[13] Thus, the assumption that the models offered in Brazil are exogenously defined seems like a reasonable (though imperfect) simplification.

Given these assumptions, on the first stage, firms choose the combination of engines they will use to equip their models. To summarize, the

[13] An example is the case of Volkswagen Brazil. Recently, it took then an investment of US$ 800 million to adapt one of their Brazilian plants to receive the production of three additional car models. For more on it check: https://carros.uol.com.br/noticias/redacao/2017/11/13/fazer-carro-e-tao-caro-que-ate-google-e-apple-desistiram-uol-carros-conta.htm

events of the two-stage game played by car makers in every year unfolds according to the following:

1. Car makers observe the tax rates imposed by the government and the fixed cost of each product. Then, they simultaneously choose what products they will offer by choosing the engines they will equip their models; lastly, they incur the fixed cost.

2. Car makers observe demand and marginal cost shocks (unobserved to the econometrician) for each product chosen in the 1st stage of the game and they simultaneously choose the prices they will charge.

At the 1st stage of the game, firms are assumed to know the distribution of marginal cost and demand shocks but not their realizations. This is a strong assumption but often made in the literature to rule out selection effects. Firms solve the game backwards and so do I.

Stage 2: Pricing

Products are indexed by j, firms are indexed by f, car models are indexed by m and markets are indexed by t. In any market t, let J_{ft} be the set of products that firm f chose to produce in the first stage of the game. In addition, $J_t \equiv \cup_f J_{ft}$ is the set of products offered in market t by all firms.

The marginal cost of each car j, $mc(.)$, is assumed constant and heterogeneous across products. In particular, it is a function of a K_s-dimensional vector of car attributes, W_{jt}, and a cost shock, ω_{jt}, which at this stage is observed to the firms.

The pre-tax price of a product j is defined as,

$$p_j^s = \frac{p_j^d}{1.25 \times (1 + \tau_{ipi})} \tag{4}$$

where p^d is the post-tax price. Firms simultaneously choose the pre-tax prices of their products, $\mathbf{p}_{ft}^s$, in order to maximize their profits:

$$\pi_f^\star(J_{ft}, J_{-ft}, \boldsymbol{\omega}_t, \boldsymbol{\xi}_t) = \max_{\mathbf{p}^s} \; M_t \sum_{k \in J_{ft}} \big(p_{kt}^s - mc(W_{kt}, \omega_{kt})\big) \times s_{kt}(\mathbf{p}_t^d, \boldsymbol{\xi}_t, J_t) \tag{5}$$

where $s_{jt}(\mathbf{p}_t^d, \boldsymbol{\xi}_t, J_t)$ is the market share of product j and M_t is the market size. Note that since firms observe all of the cost shocks in the market as well as all of the demand shocks, they determine equilibrium prices. Thus, we have that they are the source of bias into the price coefficient.

The equilibrium prices are the outcome of a non-cooperative Bertrand-Nash game among the competing automakers and can be found as the solution of the system composed by firms first order conditions:

$$s_{jt}(\mathbf{p}_t^d, \boldsymbol{\xi}_t, J_t) + \sum_{k \in J_{ft}} \big(p_{kt}^s - mc_k(W_{kt}, \omega_{kt})\big) \frac{\partial s_{kt}(\mathbf{p}_t^d, \xi_t, J_t)}{\partial p_{jt}^s} = 0 \quad \forall j \in J_{ft}, \ \forall f \tag{6}$$

The first order condition for each product j can be rewritten in a way that relates its pre-tax price to its marginal cost and markup. In matrix notation:

$$\mathbf{p}_t^s = \mathbf{mc}_t + \underbrace{\Delta_t^{-1} \times \mathbf{s}\big(\mathbf{p}_t^d, \boldsymbol{\xi}_t, J_t\big)}_{markup} \tag{7}$$

$$\Delta_{(jt,kt)} = \begin{cases} \frac{\partial s_{kt}}{\partial p_{jt}^d} \times (1 + \tau_{jt}) & if \;\; j, \ k \in J_{ft} \\ 0 & otherwise. \end{cases}$$

To take the pricing equation to the data, I make the common assumption that marginal costs are an exponential function of the product attributes previously described. Rearranging terms and taking the logarithm:

$$log(mc_{jt}) = W_{jt}\theta + \psi_t + \psi_m + \omega_{jt} \tag{8}$$

Lastly, I assume that the marginal cost is a function of Km/L, HP, *Displacement*, *At*, *Air*, $Safety$, $\log(PriceSteel \times Weight)$, year fixed effects and car model fixed effects. Intuitively, these are characteristics that should have a positive impact on marginal cost. Moreover, the car model fixed effects that capture invariant cost attributes common across different versions of the same model.

Stage 1: Engine Choice

At this stage of the game firms simultaneously choose products. They observe the fixed cost of every potential product, FC_j, but they do not know the demand and marginal cost shocks (ξ and ω, respectively) that each product in the market will face. However, firms do know the distribution of these shocks, F_ξ and F_ω. As such, firms compare the expected variable profit accrued with changing the set of products offered with the change in fixed cost. Formally:

$$J^{\star}_{ft} \in \underset{J_{ft}\in\mathcal{J}_{ft}}{\arg\max} \left\{ \mathbf{E}_{(\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t)}\left[\pi^*_f\big(J_{ft}, J_{-ft}, \boldsymbol{\omega}'_t, \boldsymbol{\xi}'_t\big)\right] - \sum_{j\in J_{ft}} FC_j \right\}, \quad \forall f \tag{9}$$

where $\mathcal{J}_{ft}$ is the set of products available for firm f and $\mathbf{E}(.)$ is the expectation operator with respect to the joint distribution of marginal cost and demand shocks. $\mathcal{J}_{ft}$ for 2005 is defined as the union between the set of products observed being offered in Brazil with the set of products that firms could have supplied (described in section 2).

Equilibrium

The equilibrium concept of the game is Subgame Perfect Nash Equilibrium. Thus, an equilibrium is $\left\{\big(J^{\star}_{ft},\ \mathbf{p}^{\star}_{ft}(J^{\star}_t)\big)\right\}_{f\in F}$ such that prices satisfy equation 6 and the set of products satisfy equation 9.

4 Estimation

4.1 Outline

In this section, I outline the procedure used to recover demand and marginal cost parameters as well as bounds on fixed costs.

First, consider the estimation of the demand parameters which are defined to be $\theta_d = \big(\beta,\ \alpha,\ \Sigma\big)$. For any guess of the parameters $(\alpha,\ \Sigma)$ I can use the BLP contraction mapping to invert the demand system given by equation 3. Since there is no closed form solution for this integral I rely on simulation techniques and use 1000 Halton draws to approximate the integral.[14] Based on the definition of the mean utility δ, I construct the sample analogue of the structural demand error for each car j:

$$\xi_{jt}(\theta_d) = \delta_{jt} - x_{jt}\beta - \phi_m$$

The interaction of the vector ξ with a set of exogenous instruments Z generates the following GMM problem:

$$\min_{\theta_d} \ \xi(\theta_d)' Z \Omega Z' \xi(\theta_d) \tag{10}$$

where Ω is a weight matrix that is constructed in a 2-step procedure. In the first step the model is estimated assuming homoskedastic errors, i.e $\Omega = (Z'Z)^{-1}$. With the parameter estimates obtained in the first step I construct estimates of the error term and use them to obtain an estimate of the efficient weight matrix. In the second step, I re-estimate the GMM problem using the efficient weight matrix.[15]

The minimization problem involves a potentially large number of parameters (K-dimensional vector β, α, Σ). To reduce the computational burden, I rely on the fact that for any guess of α, and Σ the K-dimensional vector β enters the moment conditions on a linear fashion and hence they can be recovered with the following equation:

$$\hat{\beta} = (X'ZWZ'X)^{-1}X'ZWZ'\delta(\alpha, \sigma)$$

As it was pointed out by Knittel and Metaxoglou (2014); Dube et al. (2012), the GMM problem is highly non-linear and thus it is difficult to find a global solution. To address this issue, I solve equation 10 using 20 different random initial conditions and keep the estimates that generate the smallest value for the objective function.

Second, consider the pricing equation and the estimation of the marginal cost parameters. With the demand estimates, I obtain the markup term in equation 7. The markup estimates together with prices imply an estimate for the marginal cost of each product. With the marginal cost for each

[14] As proposed by Dube et al. (2012) I use a tight tolerance of 1e-14 to define the convergence of the fixed point algorithm.

[15] To eliminate the car model fixed effects ϕ_m I use a within transformation of the data.

product, I estimate the parameters in equation 8 using standard linear regression methods.

To obtain bounds on fixed costs, I rely on a revealed preference argument. The assumption that the outcomes observed in the data are a Nash Equilibrium implies that given competitors' product portfolio, no firm is able to increase its expected profits by unilaterally changing the assortment of products it offers. Two particular types of deviations are helpful to obtain bounds on fixed costs: removing a product that is observed in the data and adding a product that firms could have offered but did not.

Consider the empirical content of removing a product j offered in the data. Intuitively, Nash Equilibrium and the revealed preference argument indicate that for products that were offered, the expected profit gains obtained by offering it must have exceeded the fixed cost of offering the product. Hence, the change in expected variable profits that follows the removal of a product j provides an upper bound on its fixed cost:

$$\mathbf{E}_{(\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t)}\left[\pi^*_f\big(J_{ft},J_{-ft},\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t\big)-\pi^*_f\big(J_{ft}\backslash\{j\},J_{-ft},\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t\big)\right]\geq FC_j\ \forall j\in J_{ft} \tag{11}$$

where $\pi^*_f\big(J_{ft},J_{-ft},\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t\big)$ is the 2nd stage profit obtained by f when its product assortment is J_{ft}, $\pi^*_f\big(J_{ft}\backslash\{j\},J_{-ft},\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t\big)$ is the 2nd stage profit obtained by f when j is not offered, FC_j is the fixed cost of offering product j and $\mathbf{E}_{(\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t)}[.]$ is the expectation operator with respect to demand and marginal cost shocks.

Now, consider the empirical content of adding a product k that firms could have offered but decided not to. Nash Equilibrium and the revealed preference argument indicate that the fixed cost of adding product k exceeded the gain in expected profit generated by doing so. Thus, the change in expected variable profits following the addition of a product k provides a lower bound for the fixed cost of offering k:

$$FC_k\geq\mathbf{E}_{(\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t)}\left[\pi^*_f\big(J_{ft}\cup\{k\},J_{-ft},\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t\big)-\pi^*_f\big(J_{ft},J_{-ft},\boldsymbol{\omega}'_t,\boldsymbol{\xi}'_t\big)\right]\ \forall k\in\mathcal{J}_{ft} \tag{12}$$

I use the demand and marginal cost estimates to obtain the fixed cost upper and lower bounds implied by inequalities 11 and 12. To compute expected profits, I simulate draws from the empirical distribution of $(\boldsymbol{\omega}'_t, \boldsymbol{\xi}'_t)$. For each simulated draw, I compute equilibrium prices and the implied variable profits. Then, I average variable profits across all draws.

4.2 Identification

The GMM problem given by equation 10 requires a set of instruments Z with rank greater or equal to the dimensionality of the demand parameter vector $\theta_d = \big(\beta, \ \alpha, \ \Sigma\big)$. To construct such instruments, I rely on the assumption of econometric exogeneity of the observed product space and on the exogeneity of the tax structure faced by Brazilian automobiles. The econometric exogeneity assumption can be stated as:

$$\mathbf{E}[\xi_{jt} | X_t, \ \forall t] = 0 \tag{13}$$

With the conditional moment restriction (CMR) in equation 13 we have that the unobserved demand component of each car is uncorrelated with observed attributes of every car, in every year, after we condition on car model fixed effects. Intuitively, the CMR states that firms do not change the observed characteristics as a response to the unobserved shocks or as a response to forecasts on those shocks. Formally, the CMR follows the timing of the game played by firms.[16] While the CMR is a strong assumption, as long as the model fixed effects and year fixed effects capture what firms can forecast about demand and cost shocks when choosing the products they will offer, it is still a reasonable approximation.

The first implication of the CMR is that we can use variation within model and over time in $Trunk$, HPW, Km/\$, At, Air and $Safety$ to identify the coefficients that enter the mean utility. Second, it allows me to follow Gandhi and Houde (2016) and construct instruments that measure the amount of local competition faced by a product in the $Trunk$, HPW and Km/\$ dimensions of the product space. These instruments provide the exogenous variation required to identify the variance in tastes for $Trunk$, HPW, Km/\$. In particular, for any product j they are constructed as:

[16] A formal discussion of the role of timing assumptions in structural models can be found in Ackerberg and Hahn (2015)

$$Z_j = \left(\sum_{i \neq j} \mathbf{1}(d_{ij}^x < sdx), \ \sum_{i \neq j} \mathbf{1}(d_{ij}^x < sdx) x_i \right)$$

where $x \in \{Km/\$, \ HPW, \ Trunk\}$ and $d_{ij}^x = |x_j - x_i|$.

The next set of instruments provide exogenous variation in prices. They are constructed based on cost exclusion restrictions and on the discontinuities generated by the Brazilian tax structure. The weight of the car interacted with price of materials (steel) enters marginal cost but does not affect consumer preferences. As such, I can use the interaction of weight and price of materials as an excluded instrument for prices.

Furthermore, the discontinuities in tax liability generated by the tax schedule induce price discontinuities around the displacement thresholds defined by the tax code and as a result, they provide exogenous price variation. Moreover, the tax rate in each threshold changed over time during the period in the sample. This change was a result of counter-cyclical macroeconomic policy implemented by the Brazilian government in the face of the global financial crises. Therefore, it is presumed to be exogenous to the product space.

The identification of the marginal cost parameters follows a similar argument as the identification of the mean utility parameters. The (Econometric) exogeneity of the product space implies that the supply-side structural errors ω_{jt} are mean independent of the car attributes that affect marginal cost after we control for car model fixed effects, i.e $\mathbf{E}[\omega_{jt}|W_t, \ \forall t] = 0$. With this assumption, the cost parameters are identified by within model and over time variation in W.

5 Estimates

Table 6 displays the estimates of the random coefficient logit model and of the marginal cost parameters. First, consider the variables that enter only the mean utility. With the exception of automatic transmission (AT), all of the covariates that enter only the mean utility have the expected sign and are statistically significant. Moreover, the negative coefficient on AT may be an indication that this is perceived as a horizontal attribute instead of a vertical one.

Consider the attributes that consumers are assumed to have heterogeneous tastes for. With the exception of the mean and variance of the taste distribution for Km/\$, all of the parameters are statistically significant. The distribution of the price sensitivity parameter is modeled using the Brazilian income distribution. Therefore, I do not need to estimate the mean or variance of the distribution but only the scaling parameter α. The estimates are negative and significant and thus provide evidence of heterogeneity in price sensitivity.

The mean of the distribution of marginal utility for HPW is negative and significant and the standard deviation is statistically different than zero. These estimates imply substantial heterogeneity in the taste for car performance, and they also imply that most consumers (approximately 85%) prefer less powerful cars. The mean of the distribution of marginal utility for $Trunk$ is negative and significant and the standard deviation is statistically different than zero. These estimates imply substantial heterogeneity in the taste for cargo space, which we consider to be a proxy for vehicle size, and indicate that most consumers (86%) prefer smaller cars.

Table 6 goes here

The estimates of the marginal cost parameters are all positive and, with the exception of Km/L, significant. Thus, as expected, it is costly to build cars that are more fuel efficient, powerful, have automatic transmission, air-conditioning and safety equipment. Moreover, $\log(PriceSteel \times Weight)$, which captures the cost of materials used to construct the car also has a positive effect on marginal costs.

I now discuss the economic implications of the raw demand coefficients. Table 6 displays descriptive statistics of the own price elasticities implied by the demand model. Reassuringly, all products are priced at the elastic part of the demand curve. The estimated elasticities range from 2.85 to 8.89 with the median elasticity being 4.93.

Based on a sample of products offered in 2005, tables 7 and 8 associate some names with the substitution patterns implied by the model. The general substitution patterns obtained with the demand estimates are well exemplified by table 7. This table displays the own-price and cross-price elasticities for the sample of the two best-sellers in each tax bin. Each entry in the table gives the percentage change in the market share of the column product associated with an infinitesimal change in the price of the row product. Products in the first tax bin (e.g. VW Gol 1L and Fiat Uno Mille) are close competitors to each other and to a smaller extent they also compete with products in the second tax bin.

Products in the second tax bin (e.g. Fiat Palio 1.3L and VW Gol 1.6L) are close competitors to each other but also to products in the first tax bin. For example, an increase in the price of the Fiat Palio 1.3L has a slightly higher impact on the share of the products in the first tax bin than in the share of the VW Gol 1.6L. A similar pattern holds for the cross-price elasticities of the VW Gol 1.6L. Lastly, products in the third tax bin are close competitors to each other and have cross-price elasticities to products in other tax bins that are of a different order of magnitude.

Table 7 goes here

One important feature of the model is how consumers substitute between products and the outside option of not buying a car. To investigate these substitution patterns, I follow Berry et al. (1995) and construct the diversion ratio between each product and the outside option. Specifically, for a small increase in the price of product j, I construct the percentage of consumers that substitute from j to the outside option relative to all consumers that substitute away from j.[17]

Table 8 displays the diversion ratios for the logit model and for the random coefficient logit model (RCL). In the standard logit model, a price increase leads consumers to substitute to goods in proportion to their relative market share (IIA property). In a setting in which the outside option has a large share, most consumers will substitute to it. This is problematic because it generates counter-intuitive predictions. In particular, regardless of price levels, the logit model predicts that most consumers substitute from the inside goods to the outside good.

One important economic implication of my empirical demand model is that it breaks the IIA property with respect to the outside option. The

[17]For the random coefficient logit model it is $100 \times \frac{ds_0/dp_j}{|ds_j/dp_j|}$. For the logit model it is $s_0/(1-s_j)$.

RCL model implies heterogeneous substitution patterns towards the outside option. As expected, it also captures the intuitive notion that there is some vertical differentiation in the market and thus more expensive cars should have a smaller diversion to the outside good.

Table 8 goes here

Table 9 displays the estimated markup over marginal cost for the sample of selected products. The magnitudes of the estimates are plausible. I find that cars in the first tax bin have low markups and cars in the third tax bin have large markups. When I take into account the whole sample, I find that markups in percent (Lerner Index) range from 19% to 41% with a median of 25.8%. These estimates are on par with the ones obtained in Berry et al. (1995); Petrin (2002) for the American automobile industry during the 1980s and early 1990s but higher than the ones obtained by Cosar et al. (2018) for the Brazilian automobile industry in the late 2000s.[18]

Table 9 goes here

Figure 3a displays the distribution of the fixed cost lower bounds. The average lower bound is 62 million Reais. Figure 3b displays the distribution of the fixed cost upper bounds. The average upper bound is 106 million Reais and the two vehicles with upper bounds greater than 600 million Reais are the two best sellers in the sample. External validation for the fixed cost bounds is difficult as firms keep this type of information confidential. But, to have an idea of how the fixed cost bounds compare to the variable profits, let's consider the specific case of Chevrolet. Using the markups implied by the model, I obtain that the average variable profit per vehicle produced by Chevrolet in Brazil is \$7,312. Using the fixed cost bounds,

[18] A possible explanation for the discrepancy between my estimates and Cosar et al. (2018) estimates is that they use the whole income distribution to draw consumers while I truncate the income distribution and use draws from above the median (middle class and above). By doing so, my demand estimates are less elastic and thus the markups are higher. Moreover, as they pointed out, Brazil is the most concentrated market in their sample and the most closed to foreign competition and hence the lower income can be compensated by the lack of competition. In addition, from 2005 to 2010, the nominal (real) interest rate in Brazil oscillated between 8.75% and 18% (5% and 13%) per year. In such an economic environment, one might argue that firms would not be willing to take the risk of producing and selling cars for an average margin of 8%.

I obtain that the average fixed cost per vehicle produced by Chevrolet in Brazil ranges from \$3,505 to \$5,404.[19] These estimates indicate that fixed costs of production take a considerable share of profits, but firms are still able to obtain a sizeable return.

Figure 3 goes here

6 The equilibrium effects of the Engine Tax

Using the Brazilian market in 2005 as a laboratory, I perform a series of counterfactual exercises to investigate how market power affects the ability of the engine tax to address its distributive and environmental goals. The first counterfactual holds the set of products fixed and obtain equilibrium outcomes under different pricing behavior and with or without the engine tax. By doing so, I am able to disentangle the effect of the engine tax and market power on prices, pass-through and sales. The second counterfactual investigates how firms are able to reposition their products to avoid the tax, and quantify the impact of this repositioning on equilibrium outcomes.

6.1 Counterfactual outcomes with fixed product assortment

I use the demand and marginal cost estimates implied by the model to obtain equilibrium outcomes for three different scenarios: (1) firms use marginal cost pricing and the engine tax is set to zero; (2) firms use marginal cost pricing and the engine tax is in place; and (3) firms use marginal cost pricing, the engine tax is in place but the tax pass-through is the one implied by the Bertrand-Nash model.

Table 10 presents the counterfactual equilibrium outcomes (columns 1, 2 and 3) and the outcomes in the data (column 4). The comparison between the outcomes in (1) and (2) provides a measure of the distortions caused by the engine tax. The comparison between the outcomes in (2) with the

[19] For each firm, I sum over the implied fixed cost upper/lower bounds and divide the resulting number by total sales. Notice that by computing the average over products that were offered (upper bound) and products that were not offered (lower bound) I am not accounting for potential selection issues.

data, which is rationalized by the model previously described, provides a measure of the total distortions caused by market power. Consider the case of prices and sales. Notice that market power is the most relevant factor increasing prices. With marginal cost pricing the engine tax raises average prices by approximately $1,600. In contrast, market power raises average prices by approximately $9,200. As a consequence, market power is the main factor in reducing sales. While the engine tax reduces total sales in 123,000 cars, market power reduces sales in 438,000 cars.

The markup over marginal costs impacts not only price levels but also tax pass-through. Intuitively, firms' price at the elastic part of the demand curve, thus the engine tax should be followed by a reduction in markups.[20] The results displayed in column 4 show that the engine tax is not fully passed-on to consumers and is heterogeneous across tax bins. In contrast, constant marginal cost together with marginal cost pricing imply a tax pass-through of 100%.

Table 10 goes here

Next, I investigate how the change in price levels, tax pass-through and total sales implied by market power affects the ability of the engine tax to address its distributive and environmental goals.

6.2 Market power and progressivity of the engine tax

For both marginal cost pricing and Bertrand-Nash pricing, I construct a Gini coefficient that measures the cumulative share of the expected tax paid by consumers given their income level (Suits, 1977). The Gini coefficient is defined as the area between the 45° line and the Lorenz curve. It ranges from -1 to 1, with negative values indicating a regressive tax, positive values indicating a progressive tax and 0 indicating a proportional tax.

The Lorenz curve is given by,

[20] To obtain tax pass-through under multi-product Bertrand-Nash, I use the first order conditions characterizing the equilibrium in the pricing game to obtain equilibrium prices in a setting without the engine tax. The difference between these prices and the prices in the data divided by the difference in the amount of taxes is my measure of tax pass-through.

$$t(y_k) = \sum_{j=1}^{J} s_{kj} t_j, \quad L_i = \frac{\sum_{k \leq i} f(y_k) t(y_k)}{\sum_{k \leq N} f(y_k) t(y_k)}, \quad F_i = \sum_{k \leq i} f(y_k) \tag{14}$$

where, k index consumer and j index product. Furthermore, $t_j = p_j^d - p_j^s$ is the amount of tax paid when purchasing product j, $s_{kj}(y_k)$ is the probability that consumer with income y_k purchases product j, and $f(.)$ is the *pmf* of the discretized income distribution.

Figure 4 displays two Lorenz curves for the engine tax, one for each competitive conduct. The dashed line is used for perfect competition and the solid line for Bertrand-Nash pricing. Market power generates a more convex Lorenz curve. It then follows that market power increases the share of the tax paid by high income consumers and thus it increases the progressivity of the engine tax. This result is confirmed when I calculate the Gini coefficient for both cases: (i) the Gini coefficient is 0.71 with marginal cost pricing; and (ii) the Gini coefficient is 0.76 with Bertrand-Nash pricing.

Figure 4 goes here

As equation 14 indicates, market power affects the Gini coefficient through two channels. First, market power affects the amount of tax levied on each product, t_j. Second, market power affects choice probabilities. Specifically, it affects t_j because of changes in the price levels and tax pass-through. In turn, these changes in prices affect the individual probability choices. To capture each of these effects, I compute two alternative Gini coefficients:

- G' is constructed based on price levels and quantities from marginal cost pricing model but uses the tax pass-through implied by the Bertrand-Nash model to adjust t_j.
- G'' is constructed using the same t_j as in G' but uses the quantities implied by Bertrand-Nash pricing.

The comparison of the Gini coefficient obtained under marginal cost pricing (0.71) with G' (0.72) captures the effect of the heterogeneous tax pass-through implied by Bertrand-Nash Pricing. The increase in Gini coefficient indicates that the heterogeneous pass-through increases the progressivity of the engine tax. This result is consistent with the fact that under Bertrand-Nash pricing, the average pass-through in the first tax bin is smaller than average pass-through in the second and third tax bins.

The comparison of G' (0.72) with G'' (0.77) captures how the impact of market power on sales affects the progressivity of the engine tax. The increase in the Gini coefficient indicates that the reduction in sales increases the progressivity of the engine tax. This result is consistent with the higher prices implied by market power leading to a reduction in overall market participation of consumers with lower incomes. Lastly, the comparison of G'' (0.77) with the Gini coefficient obtained under Bertrand-Nash (0.76) captures the effect of price levels on the progressivity of the engine tax. This result indicates that the overall price levels under Bertrand-Nash pricing are regressive and is consistent with the relative higher markups faced by automobiles in the first tax bin.

6.3 Market power and the environmental impact of the engine tax

The results displayed in table 10 show the extent which market power increases price levels, decrease tax pass-through and as a consequence reduce sales and impact CO_2 emissions. Next, I first evaluate the role of each of these channels in affecting the ability of the engine tax in reducing CO_2 emissions. Then, I investigate the product assortment responses to the engine tax and quantify how these responses impact equilibrium outcomes.

To predict the CO_2 emissions of the cohort of cars sold in 2005 and the emissions in the different counterfactual scenarios, I use the parameters considered by the Brazilian Environmental Agency (MMA, 2014). These parameters include automobile survival probabilities for 50 years, the average intensity of car usage per year for 50 years, and engineering measures of the amount of CO_2 (kg) per liter of fuel. Specifically, with the fuel efficiency (Km/L) of each car (model/engine) offered by firms and the average intensity of car usage per year (Km/year), I obtain the average annual fuel consumption for each car (L/year). Using engineering measures of CO_2 per liter of fuel, I obtain the amount of CO_2 emitted by each car in a given year (Kg). For each year I adjust car emissions by its survival probability and scale up by sales in 2005. By adding over every car offered in 2005, I obtain the expected total amount of CO_2 emitted by the cohort of cars sold 2005.

Pass-through and price levels

Column 3 of table 10 displays the outcomes in a counterfactual where firms use marginal cost pricing, the engine tax is in place and the tax pass-through is equal to the pass-through implied by the Bertrand-Nash model. The comparison of the outcomes in column 3 with the outcomes in column 2 highlights the role of the incomplete pass-through generated by Bertrand-Nash in affecting relative prices and thus shifting demand away from large engine cars. The comparison of the outcomes in column 3 with the outcomes in column 4 highlights the role of price levels in reducing sales.

Overall, I find that relative to the perfect competitive benchmark, the increase in price levels is the main factor reducing sales and thus predicted CO_2 emissions. The incomplete pass-through attenuates the price signal generated by the engine tax. Since prices do not increase as much as in the case with complete pass-through, total sales do not fall as much either. Therefore, incomplete tax pass-through reduces the ability of the engine tax in reducing CO_2 emissions. At the same time, market power raises price levels substantially. This increase leads to a sizeable reduction in sales and as a consequence, in the total expected CO_2 emissions. The fact that the two channels work in opposite directions highlight the relevance of empirically accounting for the degree of market power in the industry when designing a corrective tax (Buchanan, 1969).

Product assortment

Next, I investigate the impact of the engine tax on equilibrium product assortment and its implications to expected CO_2 emissions. To this end, I compare the outcomes in the data, which are assumed to be an equilibrium of a game in which firms choose product assortment and prices under the engine tax, with the equilibrium outcomes of a game in which firms choose product assortment and prices when the engine tax is not in place.

To use the two-stage game to run the counterfactual analysis, I need to obtain the fixed cost for each product that firms can offer. However, my empirical model only allows me to obtain an upper bound on the fixed cost of products that were offered and a lower bound on the fixed cost of products that firms could have offered. To circumvent this issue, the literature has followed two main approaches. The first consists of estimating average fixed costs and then using this single estimate to simulate the counterfactuals. In my setting, following this approach would require additional assumptions on the support of the distribution of fixed costs (Eizenberg, 2014; Pakes et al., 2015). The second approach consists of drawing fixed costs for each product from an interval consistent with the bounds implied by the model. Doing so requires an assumption on the missing bound and on the distribution of fixed costs within the interval (Fan and Yang, 2020). Since both approaches require some restriction on the support of the fixed cost distribution, I proceed according to the second approach. I do so to allow for fixed cost heterogeneity in my counterfactual simulations.

To proceed, I fill missing bound for each product. Then, I uniformly draw 10 fixed cost shocks within the implied fixed cost range for each product. Specifically, for a product j that I observe being offered in the data I use 0 to fill in for the missing lower bound and draw F_j from the interval $\left[0, \bar{F}_j\right]$. For the potential products that could have been offered, I fix the range of the interval to be equal to the difference between the average upper bound and average lower bound in the sample ($\bar{F} - \underline{\mathrm{F}} =$ R\$ 44 millions). As such, I draw F_j from the interval $\left[\underline{\mathrm{F}}_j, \underline{\mathrm{F}}_j + (\bar{F} - \underline{\mathrm{F}})\right]$. The results reported in this subsection are the averages across the 10 simulations. Appendix A investigates the robustness of my results to the assumption on the fixed cost support.

Obtaining the equilibrium counterfactual set of products without the engine tax is challenging because it requires computing expected profits for a substantial number of alternatives. To overcome this computational problem, I employ the algorithm developed in Fan and Yang (2020). The algorithm begins with firms offering the products observed in the data. Firms move sequentially based on their market share. When called to play, a firm consider all possible one car additions and removals.[21] If the firm playing does not find profitable to deviate, then the observed set of products is that firms' best response and the algorithm moves to the next firm. Otherwise, I consider all analogous one car additions/removals from the set of products that generated the highest payoff, continuing until the firm playing does not find it profitable to deviate. The algorithm continues until no firm can benefit from any one product additions/removals given what the rivals are offering.

Table 11 displays market outcomes under three different scenarios. The first column displays the equilibrium outcomes when the engine tax is set to zero and firms are only able to choose prices. The second column displays the equilibrium outcomes obtained when the engine tax is set to zero and firms choose product assortment and prices. The third column displays outcomes associated with the engine tax and the products offered in the data, i.e, the factual data. To quantify the impact of the engine tax on equilibrium outcomes, I treat the the setting without the engine tax as the benchmark and compare the outcomes in the third column with the outcomes in the first and second column.

The results indicate that the engine tax decreases the total number of cars offered. On average across simulations, firms offer 105 cars. With the engine tax firms offer 91 cars. This reduction in the number of cars offered is across all engine sizes. However, the largest percentage of cars that are dropped are the ones with 1.1L to 1.4L engines. Not surprisingly, with the engine tax there is an increase in the number of 1L engine cars. Despite the increase of cars offered with 1L engines, the total net effect of the engine tax on the number of cars offered is still negative.

The change in the sizes of the engines offered has direct implications to the average fuel efficiency of the cars supplied in equilibrium. With the engine tax the average fuel efficiency of the cars offered decreases from 9.22 Km/L to 9.10 Km/L. Specifically, the discontinuities in the tax schedule give firms incentives to move away from the tax thresholds. Firms do so by disproportionately dropping products with engine displacement between

[21] At every deviation, equilibrium prices for all products are obtained by solving the first order conditions of the pricing game. Moreover, I use the empirical distribution of marginal cost and demand shocks to compute the expected profit of any given set of products.

1.1L and 1.4L. Since these automobiles are on average more fuel efficient, the net impact on the average fuel efficiency of the cars offered is negative. Not accounting for the change in product assortment overstates the impact of the engine tax on the fuel efficiency of the products demanded. Holding the set of products fixed, the engine tax increases the sales weighted average fuel-efficiency from 9.76 Km/L to 9.86 Km/L. When the product assortment is allowed to change, the engine tax has no meaningful impact on the sales weighted average fuel-efficiency.

Product assortment responses decrease the variety of engines available to consumers and hence reduce the total sales of automobiles. Not accounting for this mechanism understates the impact of the engine tax on the total number of cars sold. Holding the set of products fixed, the engine tax decreases total sales by 113,000 cars. In contrast, when firms adjust product assortment, the engine tax reduces total sales by 190,000 cars. This result points out the empirical relevance of considering assortment responses and the business-stealing and market expansion effects that follows when evaluating a corrective tax in a setting with differentiated goods.

To quantify how the impact of the engine tax on fuel efficiency and total sales translates into the emissions of CO_2, I compute total expected emissions of CO_2 when firms adjust only prices and when firms adjust both prices and product assortment. The results indicate that the reduction in product variety caused by the engine tax and the further decrease in total sales accounts for 30% of the abatement in expected CO_2 emissions by the cohort of cars sold in 2005.

Table 11 goes here

Table 12 displays the impact of the engine tax schedule on measures of surplus. The first column considers the case in which firms respond to the tax by only changing their prices. The second column considers the case in which firms respond to the tax by changing prices and product assortment. Independently of how firms respond to the engine tax, consumers bear most of the burden of the tax. However, not considering the effect of the tax on product assortment understates the loss in consumer surplus by approximately $4,5 billion Reais. The additional surplus loss comes mainly from the reduction in the variety of engines faced by consumers.

Furthermore, ignoring that firms can also respond by changing the products understates the profits losses caused by the tax schedule.

Tax revenues are also affected by firms' response. When firms are assumed to respond to the tax by only re-optimizing prices, the tax generates a revenue of almost \$3.9 billion Reais. When we consider that firms respond to the discontinuities in the tax schedule by changing prices and product assortment, the tax generates revenues of \$3.1 billion Reais. Miravete et al. (2018) show empirically that strategic price responses reduce the government ability to raise tax revenues in the market for spirits in Pennsylvania. Taken together, my results indicate another dimension in which firms' response can mitigate the government effort to raise tax revenues - changes in product assortment. This dimension is particularly relevant in settings with differentiated goods where the introduction of products may lead not only to business stealing but also to market expansion.

Table 12 goes here

The qualitative results regarding product assortment responses are robust to a host of assumptions on how I fill the missing bounds of the intervals used to draw the fixed cost of each product. The results of the robustness check are reported in appendix A. In particular, I consider four alternative ways to construct the range used to uniformly draw fixed costs. I also consider an alternative setting in which the models offered and the number of engines per model are fixed and firms are only able to change the size of the engines offered. This setting is relevant to address the potential concern that the logit shocks of the products introduced in the counterfactual are the main reason behind the impact of the increased assortment on sales.

7 Conclusion

I use the Brazilian automobile industry to study the impact of a notched tax schedule on markups, prices and firms' product assortment decisions. To this end, I estimate a model of demand and supply for automobiles in Brazil. Demand builds on the random coefficient logit model proposed by Berry et al. (1995). Supply builds on a two-stage game. In the first stage firms simultaneously choose the set of products they offer. In the second stage, conditional on the set of products chosen in the first stage, firms simultaneously choose prices.

The first finding is that strategic pricing responses imply heterogeneous and incomplete tax pass-through. The heterogeneous and incomplete pass-through together with the increase in price levels caused by market power impact the ability of the notched tax schedule to address its environmental and distributive goals. With the quantity distortion implied by the markup over marginal costs, it is likely that market power distorts equilibrium quantities past the first best. Also, the main mechanism through which market power increases the progressivity of the tax schedule is by driving consumers with low/middle income out of the market.

The second finding is that the discontinuities of the engine tax lead firms to choose engine sizes away from the thresholds defined by the tax schedule. This movement reduces the variety of engines offered and in turn it provides a further reduction in total sales. Not accounting for the assortment effect of the notched engine tax would understate its ability to reduce sales and expected CO_2 emissions.

The notched structure of the engine tax has the advantage of highlighting what the policy objectives are. Regardless of the policy objectives, my analysis points out the importance of accounting for market power and the strategic pricing and product assortment responses when studying taxation in differentiated goods markets. Similar to Fowlie et al. (2016) and Preonas (2019), my results provide empirical support for Buchanan (1969) insights that market power and the associated allocative inefficiencies limit the ability of a corrective tax to achieve the first best allocation. However, I depart from these papers by empirically pointing out a novel and important dimension in which firms' response can impact the ability of the government to achieve its desired policy goals - changes in product assortment. Assortment responses are particularly relevant in differentiated goods markets where the introduction/removal of products can expand/contract quantity demanded.

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Tables

Table 1: Sample of firms in 2012.

Firm	Market Share (%)
Chevrolet (GM)	19.7
Fiat	25.3
Volkswagen	24.1
Ford	9.6
Renault	6.7
Honda	4.4
Toyota	2.3
Others	7.9

Table 2: Evolution number of products offered.

Year	#Products	#Models	Mean #engine-displacement	Mean # domestic models per firm	# of Models more than 1 tax bin	M. Share of Models more than 1 tax bin (%)
2005	91	47	1.94	4.1	15	59
2006	99	52	1.9	4.3	15	59
2007	98	54	1.81	4.5	13	48
2008	106	59	1.8	4.6	13	46
2009	115	65	1.77	4.9	12	48
2010	134	67	2	5	12	50
2011	140	72	1.94	5	13	50
2012	145	73	1.99	5.2	14	52

Table 3: Sales and share of products by tax bin.

Year	Sales	% Sales per engine segment			% Cars offered per engine segment		
		<1L	(1L, 2L]	>2L	<1L	(1L, 2L]	>2L
2005	1,343,826	57.1	42.8	.2	16.5	81.3	2.2
2006	1,517,643	58	41	1	15.2	80.8	4
2007	1,867,665	56.7	42.3	1	15.3	81.6	3.1
2008	2,120,857	51.9	47.1	.9	15.1	81.1	3.8
2009	2,383,719	54.1	45.3	.7	13.9	82.6	3.5
2010	2,485,533	53.2	46.2	.6	11.9	85.1	3
2011	2,429,346	50.5	49.1	.5	12.1	85.7	2.1
2012	2,665,036	44.7	55.1	.3	12.4	85.5	2.1

Table 4: Average sales-weighted product characteristics.

Year	Price	HP	HPW	Km/$	Bifuel	At	Air	Safety	Trunk (L)
2005	42,025	83.08	8.26	3.75	.49	.01	.24	.13	333.38
2006	43,276	84.22	8.28	3.66	.9	.01	.25	.15	338
2007	43,313	85.54	8.46	4.28	.95	.02	.27	.15	342.73
2008	43,595	87.25	8.54	4.59	.97	.03	.28	.14	343.33
2009	39,368	88.08	8.62	4.67	.98	.02	.26	.14	350.55
2010	37,859	89.43	8.77	4.32	.99	.04	.26	.13	347.18
2011	36,486	91.43	8.83	4.13	.99	.05	.29	.18	347.68
2012	34,615	93.78	8.92	4.46	.99	.07	.34	.29	351.6

Note: The entry in each cell of the last 7 columns is the sales weighted mean. Prices are in 2010 BRL.

Table 5: Characteristics of products that were not offered in Brazil in 2005.

Maker	#Products	#Models	Min. #Engines	Max. #Engines	Min. Displacement	Max. Displacement	Min. HP	Max. HP
Chevrolet	24	6	3	5	1.2	2.2	75	200
Citroen	3	2	1	2	1.1	1.8	61	115
Fiat	6	3	1	3	1.2	1.6	65	105
Ford	7	2	2	5	1.2	1.6	60	101
Honda	4	2	1	3	1.2	1.6	78	110
Peugeot	5	2	2	3	1.1	2	60	136
Renault	8	3	2	4	1.1	1.8	58	116
Toyota	3	2	1	2	1.4	1.6	97	110
Volkswagen	6	2	2	4	1.2	2.3	54	170

Table 6: Random coefficient logit demand (RCL) and marginal cost estimates.

	RC-Logit			Supply	
	Coefficient	Robust SE		Coefficient	Robust SE
Mean Utility (β)			Cost (γ)		
HPW	-0.295	(0.141)	Km/L	0.004	(0.003)
Km/$	0.051	(0.210)	HP	0.004	(0.0003)
Trunk	-3.054	(1.138)	Displacement	0.05	(0.02)
AT	-0.187	(0.174)	AT	0.07	(0.007)
AIR	0.408	(0.253)	AIR	0.08	(0.008)
Safety	0.418	(0.161)	Safety	0.05	(0.009)
			$\log(PriceSteel \times Weight)$	0.484	(0.098)
Consumer Heterogeneity					
Price/Income	7.042	(2.590)			
HPW	0.284	(0.127)			
Km/$	0.366	(0.261)			
Trunk	2.877	(0.799)			
Elasticities			Markup(%)		
Median	4.93		Median	22.68	
Min.	2.85		Min.	14.35	
Max.	8.89		Max.	40.88	
Estimation Statistics					
# of Observations	928				
J-Statistic(DF)	13.78(6)				

Table 7: A sample from 2005 of Own-Price and Cross-price Elasticities for selected products.

	VW Gol 1L	Fiat Uno Mille	Fiat Palio 1.3L	VW Gol 1.6L	GM Vectra 2.4L	Fiat Marea 2.4L
VW Gol 1L	-4.277	0.596	0.349	0.310	0.045	0.050
Fiat Uno Mille	0.456	-4.254	0.289	0.278	0.023	0.027
Fiat Palio 1.3L	0.105	0.113	-4.690	0.087	0.024	0.028
VW Gol 1.6L	0.094	0.110	0.088	-4.717	0.025	0.040
GM Vectra 2.4L	0.003	0.002	0.005	0.005	-6.315	0.044
Fiat Marea 2.4L	$< 10^{-4}$	$< 10^{-4}$	0.0001	0.0002	0.001	-5.260

Note: The products displayed are the two best-sellers in each tax bin. Each entry in the table displays $\frac{\partial s_j}{\partial p_i}\frac{p_i}{s_j}$, where i index a row and j index a column.

Table 8: Diversion to the outside option

	Logit	RCL
VW Gol 1L	95.09	34.79
Fiat Uno Mille	95	34.60
Fiat Palio 1.3L	94.67	30.77
VW Gol 1.6L	94.66	29.55
GM Vectra 2.4L	94.55	3.01
Fiat Marea 2.4L	94.54	7.09

Note: Given a price increase, the percentage who substitutes to the outside option as a percentage of all that substitute away from the product.

Table 9: A sample from 2005 of estimated price-marginal cost markup for selected products.

	Price	Markup($)
VW Gol 1L	29,412	5,695
Fiat Uno Mille	26,570	5,549
Fiat Palio 1.3L	36,981	6,832
VW Gol 1.6L	39,638	7,223
GM Vectra 2.4L	105,950	13,201
Fiat Marea 2.4L	101,380	13,255
Market	42,025	7,214

Note: The products displayed are the two best-sellers in each tax bin. Market displays the sales weighted average price and markup. Markup is defined as $p_s - mc$.

Table 10: Equilibrium outcomes with and without engine tax.

	(1)	(2)	(3)	(4)
	Mg.Cost Pricing			Bertrand-Nash Pricing
	No Engine Tax	Engine Tax	Engine Tax (*)	Engine Tax
Sales	1,905,015	1,781,780	1,822,031	1,343,826
$\leq 1L$	916,304	964,042	1,017,813	766,828
$(1L, 2L]$	982,019	813,986	800,298	574,669
$> 2L$	6,690	3,752	3,918	2,329
Price	31,178	32,813	31,878	42,025
$\leq 1L$	21,768	23,276	22,396	31,463
$(1L, 2L]$	39,674	43,860	43,677	55,860
$> 2L$	73,025	86,334	85,161	105,839
Pass-through (%)		100	90.3	90.3
$\leq 1L$		100	85.3	85.3
$(1L, 2L]$		100	97	97
$> 2L$		100	96	96
CO2 (1000 kg)	102,975,540	95,423,061	97,267,226	71,437,813

Note: Counterfactual outcomes are computed holding the set of products fixed. Price and Pass-through are sales weighted averages.

Table 11: Counterfactual market outcomes for 2005

	No Engine Tax		Engine Tax
	Price	Price & Product	
Price	40,725	41,552	42,809
Lerner Index(%)	25.56	25.13	24.99
Avg. Km/L	9.10	9.22	9.10
Sales weighted Avg. Km/L	9.76	9.86	9.86
Sales	1,492,752	1,570,587	1,379,468
$\bar{J}$	91	105.4	91
CO_2 (1000 kg)	80,521,917	83,783,271	73,645,347

Note: Price, and Lerner Index are sales-weighted averages. Column "Price" displays outcome measures when firms respond to the change in the tax rates by changing only markups. Column "Price & Product" displays outcome measures when firms respond to the change in tax rate by changing markups and also repositioning the products offered. To make results comparable, all of the outcomes are averages across equilibrium outcomes obtained under different ξ and ω shocks. Furthermore, the outcomes in "Price & Product" also average across the 10 FC draws.

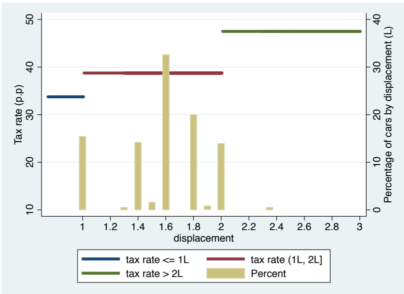
Table 12: Changes in surplus and tax revenue when tax schedule goes from no engine tax to engine tax.

	Price response	Price & Product response
Δ Consumer Surplus ($ mil.)	-5,190	-9,715
Δ Var. Profit ($ mil.)	-1,621	-2,285
Δ Tax Revenue ($ mil.)	3,8779	3,141

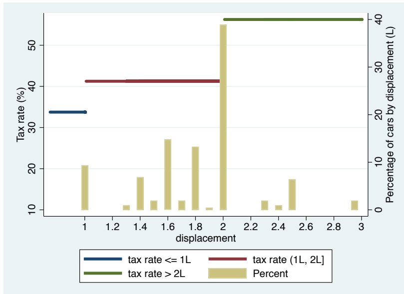
Note: Column "Price response" displays outcome measures when firms respond to the change in the tax rates by changing only markups. Column "Price & Product response" displays outcome measures when firms respond to the change in tax rate by changing markups and also repositioning the products offered. To make results comparable, all of the outcomes are averages across equilibrium outcomes obtained under different ξ and ω shocks. Furthermore, the outcomes in "Price & Product" also average across the 10 FC draws.

Figures

Figure 1: Product offering vs. tax rate by engine displacement

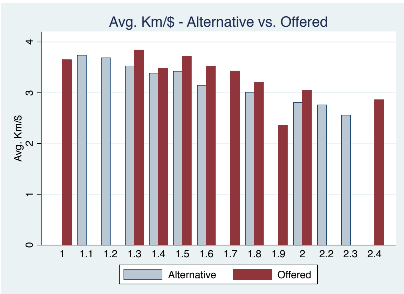


(a) Bifuel

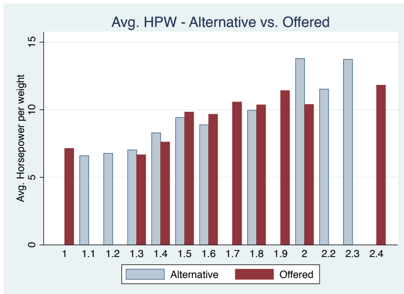


(b) Gasoline

Figure 2: Attributes - Potential Cars vs. Cars offered

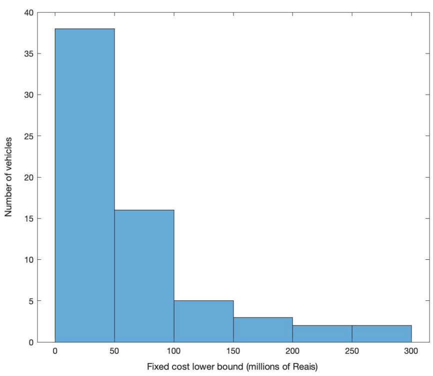


(a) Km/$

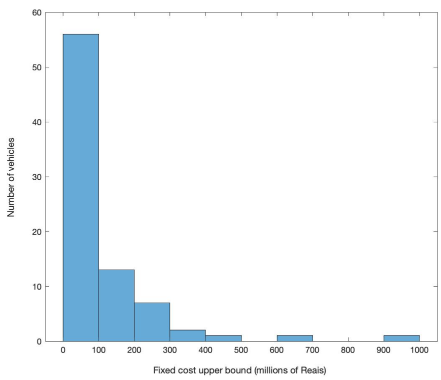


(b) Horsepower per weight

Figure 3: Distribution of fixed cost lower/upper bounds

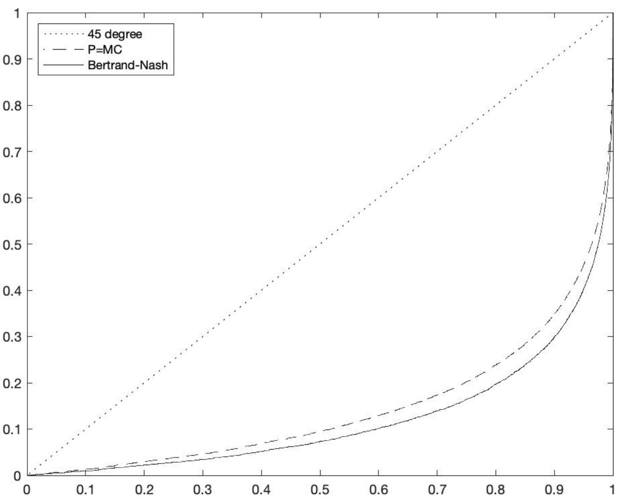


(a) Fixed cost lower bound



(b) Fixed cost upper bound

Figure 4: Tax Lorenz curve



A Alternative assumptions on fixed costs

In this appendix I investigate how the assumptions regarding the limits of the intervals I draw the fixed costs from affect the empirical results. In particular, I consider four different alternatives to fill the missing lower bound for products that are offered in the data, and to fill the missing upper bound for potential products that firms could have offered but decided not to. I also obtain equilibrium outcomes under the assumption that the models offered and the number of engines offered per model is fixed.

- Alternative 1: draw F_j uniformly from the interval $\left[\max\{0, \bar{F}_j - (\bar{F} - \underline{F})\}, \bar{F}_j\right]$ if j is offered, and draw F_j uniformly from the interval $\left[\underline{F}_j, \underline{F}_j + (\bar{F} - \underline{F})\right]$ if j is not offered.

- Alternative 2: draw F_j uniformly from the interval $\left[0, \bar{F}_j\right]$ if j is offered, and draw F_j uniformly from the interval $\left[\underline{F}_j, \max_{k \in \mathcal{J}}\{\bar{F}_k\}\right]$ if j is not offered.

- Alternative 3: draw F_j uniformly from the interval $\left[0, \bar{F}_j\right]$ if j is offered, and draw F_j uniformly from the interval $\left[\underline{F}_j, 5 \times \underline{F}_j\right]$ if j is not offered.

- Alternative 4: draw F_j uniformly from the interval $\left[0.5 \times \bar{F}_j, \bar{F}_j\right]$ if j is offered, and draw F_j uniformly from the interval $\left[\underline{F}_j, \underline{F}_j + (\bar{F} - \underline{F})\right]$ if j is not offered.

- Alternative 5: compute equilibrium outcomes under the assumptions that (i) fixed costs of production are the same for different engines of the same model but are potentially different across models; and (ii) the models offered and the number of engines offered per model are fixed. This counterfactual exercise does not account for the possibility of dropping models, for the possibility of introducing new models or for the possibility of changing the number of engines offered per model.

Table 13 displays the equilibrium outcomes obtained under different assumptions on fixed costs. To facilitate the comparison, columns 1, 2 and 8 repeat the results displayed in table 11. The equilibrium outcomes obtained with approaches 1 to 4 are reported in columns 3 to 6, respectively. Lastly, column 7 reports the results obtained in alternative 5.

Overall, the results are robust to the different variations in the range used to draw fixed costs (alternatives 1 to 4). In all of these cases we have that not accounting for the impact of the engine tax on product assortment understates its impact on total sales and overstates its impact on the average fuel efficiency of the cars purchased. Furthermore, similar to the main specification, the equilibrium impact of the engine tax on product assortment plays an important role in reducing CO_2 emissions.

The results reported in column 7 (Alt. 5) were computed under the assumptions that the product line of each manufacturer is fixed (models offered and number of engines offered per model) and that the fixed cost is homogeneous within a model. With these two assumptions, I can compute equilibrium assortment by considering only the variable profits of each firm. Despite its restrictions, this is a useful counterfactual as it highlights the incentives faced by firms to differentiate their products by offering different engine sizes.[22] Also, holding the number of products fixed has the advantage of avoiding the introduction of new logit shocks, which may influence the incentives to offering variety.

The restricted counterfactual results indicate that the engine tax leads firms to reposition their cars away from the tax thresholds. This is done by replacing 1.1L to 1.4L engines with 1.6L to 1.8L engines. This movement reduces the variety of engines in the market, and improve the fuel efficiency of the cars offered and demanded. Similar to the specifications in which firms can add/remove products, we find that the impact of the engine tax on product variety and the sales reduction that follows is an important channel to reduce predicted CO_2 emissions.

[22]To fix ideas, consider an example of the possible actions in the counterfactual. In 2005, Renault offered the Clio (model) in Brazil with two different engine displacements: Clio 1L and Clio 1.6L. At the same time, it could have offered the Clio 1.1L and the Clio 1.4L. Thus, when considering what products to offer, Renault chooses between any product combination that contains two versions of the Renault Clio. Specifically, it chooses one alternative of the set {(Clio 1L, Clio 1.1L); (Clio 1L, Clio 1.6L); (Clio 1L, Clio 1.4L); (Clio 1.1L, Clio 1.4L); (Clio 1.4L, Clio 1.6L); (Clio 1.1L, Clio 1.6L)}.

Table 13: Equilibrium outcomes - product assortment counterfactual

	No Engine Tax							Engine Tax
	Fixed Product Space	Main FC Specification	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5	
Price	40,725	41,552	41,572	41,116	41,099	41,558	41,062	42,809
Lerner Index(%)	25.56	25.13	25.1	25.53	25.49	25.12	25.02	24.99
Avg. Km/L	9.10	9.22	9.22	9.11	9.12	9.22	9.33	9.10
Sales weighted Avg. Km/L	9.76	9.86	9.86	9.77	9.77	9.86	9.97	9.86
Sales	1,492,752	1,570,587	1,566,440	1,522,632	1,529,556	1,567,537	1,537,813	1,379,468
CO2 (tons)	80,521,917	83,783,271	83,555,289	82,116,420	82,473,812	83,595,707	81,058,837	73,645,347
$\bar{J}$	91	105.4	104.7	92.1	96.8	103.7	91	91

Note: Price, and Lerner Index are sales-weighted averages. The outcomes reported in columns "Fixed Product Space" and "Engine Tax" were obtained under fixed product assortment. The outcomes reported in "Alt. 5" were obtained holding the number of models and engines per model fixed and considering only changes in the engine sizes. To make results comparable, all of the outcomes are averages across equilibrium outcomes obtained under different ξ and ω shocks. Furthermore, the outcomes in "Main FC Specification" and "Alt.1 to Alt. 4" also average across the 10 FC draws.