

Welfare and Environmental Benefits of Electric Vehicle Tax Policies in Developing Countries

Evidence from Colombia

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Abstract

Developing countries face a major challenge of decarbonizing their light-duty vehicle fleet and transitioning to the broad use of electric vehicles. However, there is little evidence on which policies can most effectively facilitate that transition in these countries, distinguished by relatively low-income consumers and highly concentrated markets that distort vehicle markups. This paper analyzes existing and proposed policies aiming to reduce emissions from new passenger vehicles in Colombia, which has used preferential sales taxes and import tariffs to stimulate hybrid and electric cars sales. Using highly detailed data on vehicle purchases and attributes, the paper estimates an equilibrium model

of Colombia's market that includes a random-coefficients logit demand structure and endogenizes firms' markups. Using the model to simulate policies, the analysis finds that Colombia's sales tax and import tariffs have increased hybrid and electric vehicle market shares by 0.9 to 2.7 percentage points at welfare costs of \$40-\$48 per ton of carbon dioxide reduction. Potentially taxing carbon dioxide emissions rates of new vehicles would have roughly similar welfare costs. The high welfare costs of these policies arise from preexisting distortions caused by market power, which yields large private welfare costs of shifting from gasoline to hybrid and electric vehicles.

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Welfare and Environmental Benefits of Electric Vehicle Tax Policies in Developing Countries: Evidence from Colombia

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1. Introduction

Electric vehicles and a clean electricity sector offer a promising path to reduce greenhouse gas (GHG) and local air pollution from light-duty vehicles. Passenger cars account for 11 percent of global GHG emissions and 45 percent of global GHG emissions from transportation² and are one of the main factors causing poor air quality in major cities (Gwilliam, Kojima, and Johnson 2004; Kojima and Lovei 2001). Although GHG emissions from light-duty vehicles are declining gradually in some developed economies, most countries struggle to dramatically reduce these vehicles' emissions and achieve international climate objectives.

Designing a cost-effective vehicle policy is particularly important in low and middle-income countries, which will account for most if not all growth of energy and transportation demand in the following decades (Wolfram, Shelef, and Gertler 2012). Non-OECD emissions are expected to increase steadily over the coming decades, absent major technological, market, or policy changes (Bazilian et al. 2019). Apart from China, electric vehicle markets in developing countries are nascent, lagging those in Europe and the United States (throughout the paper, electric vehicles refer to all-electric such as the Tesla Model 3 and plug-in hybrids such as the Chevrolet Volt). Developing countries have a variety of policies from which to choose, including fuel and vehicle taxes and subsidies, trade policy instruments, and regulatory policies, such as, e.g., emissions standards. Yet, despite a growing literature on electric vehicle policy in high-income countries (e.g., Springel 2021), there is little research evaluating these policy options for low and middle-income countries.

For several reasons, electric vehicle policies are likely to have different welfare effects in low and middle-income countries than in high-income economies. First, typical new vehicle consumers in low and middle-income countries have lower disposable incomes. As a result, they may be more responsive to price incentives and fuel cost savings of electric vehicles (Bansal et al. 2021) while having a lower willingness to pay for the relatively more expensive electric cars, making incentives less effective. Second, these countries often have limited charging infrastructure, and electricity may be expensive and unreliable, which may reduce the demand for electric vehicles (Aznar et al. 2021). Finally, many new vehicle markets in low and middle-

² Authors' calculations based on <https://www.iea.org/data-and-statistics/charts/transport-sector-co2-emissions-by-mode-in-the-sustainable-development-scenario-2000-2030> [last accessed: April 2022].

income countries have large pre-existing distortions caused by protective regulations, high import tariffs, and market power (Barwick, Cao, and Li 2021). These distortions can influence the welfare effects of environmental policy; for example, a carbon tax could have higher welfare costs than other policies such as vehicle subsidies (Fowlie, Reguant, and Ryan 2016; Konishi and Zhao 2017).

This paper is among the first to assess the efficacy and welfare effects of tax policies that support hybrid and electric vehicles in a middle-income country, using Colombia as a case study. Several studies have examined China, which has achieved unique electric vehicle market shares, charging station networks, and domestic electric vehicle production among low and middle-income countries (Jin et al. 2021; Li et al. 2020; Sheldon and Dua 2020). As we show below, Colombia is a more representative middle-income economy. Its case is particularly interesting given its sizeable new vehicle market, the recent growth in hybrid and electric vehicles, and its use of both vehicle and import tax policy supporting hybrid and electric vehicles.

In 2017, Colombia substantially reduced consumption taxes for all hybrid and electric vehicles. It also nearly eliminated import tariffs on these vehicles; tariff reductions were substantially larger than the purchase tax reductions. Absent market imperfections, a consumer and manufacturer subsidy should have the same welfare costs per ton of emissions reduction. However, this equivalence breaks down in the presence of market imperfections, such as liquidity constraints, price rigidity, or imperfect competition (Auerbach 2019). As noted above, these imperfections are particularly pertinent in the developing country contexts with highly concentrated markets. We find that pre-existing distortions contribute to relatively high welfare costs of actual and proposed electric vehicle policies.

We estimate a new equilibrium model of Colombia's new vehicle market to evaluate the policies by comparing simulated counterfactual equilibriums. As we explain in Section 2, unfortunately, the structure of the tax policies does not yield sufficient variation to econometrically evaluate their effects, which motivates the use of the equilibrium model for policy analysis. Moreover, the model allows us to compare fiscal cost-effectiveness and welfare effects (including carbon benefits) of actual policies with other policies that policy makers may consider.

The equilibrium model builds on the empirical industrial organization literature such as Berry, Levinsohn, and Pakes (1995, 2004). On the demand side of the market, consumers maximize

utility by choosing a vehicle among available options, where utility is linear in product attributes and a random error term. Because the policies we consider either directly or indirectly affect vehicle prices, the baseline specification of the model allows for a random coefficient on vehicle price to generate more plausible consumer responses to the policies. On the supply side, vehicle manufacturers choose vehicle prices to maximize profits given government policies and consumer demand.

Demand and supply parameters are estimated from observed vehicle market shares, prices, and other attributes using a novel and rich data set of new registrations and vehicle attributes, fuel prices, and relevant government policies between 2015 and 2020. This level of detail is comparable to recent studies of automobile markets in high-income economies and typically is not available for developing countries. Marginal costs of each vehicle are estimated from the first-order condition for vehicle prices to firms' profit maximization problems.

Based on estimated parameters, policy simulations evaluate the effects of Colombia's tax policies on hybrid and electric vehicle sales, GHG emissions, and consumer and manufacturer welfare. Simulations focus on outcomes in 2019 (before the COVID-19 pandemic) and 2020 (when hybrid and electric vehicle market shares increased dramatically). Compared with the 2019 and 2020 equilibriums that include both favorable purchase and import taxes, we simulate counterfactual equilibriums that eliminate one or both policies. That is, the counterfactuals hold fixed all market conditions in 2019 or 2020 and return policies to their 2017 levels. In 2019, the two policies jointly caused the market share of electric vehicles to increase from 0.1 to 0.6 percent, with the tariff reduction having a larger incremental effect on sales than the sales tax exemption. In 2020, the policies raised the market share of electric vehicles from 0.5 to 2.6 percent.

Although the policies are effective at increasing sales, their costs are high because much of the subsidy is claimed by hybrid vehicles, which are less environmentally beneficial than electric vehicles, and because of pre-existing distortions due to market power. The average fiscal cost was \$350-\$510 per ton of carbon dioxide, and the average welfare cost was \$40-\$48 per ton of carbon dioxide. This is comparable to recent estimates of the global social value of emissions reductions (van den Bremer and van der Ploeg 2021 and Interagency Working Group 2021; our welfare results do not include the benefits of local air quality improvements).

The positive welfare cost is perhaps surprising, given that the policies reduced distortionary sales taxes and import tariffs. This is because consumers purchasing hybrid and electric vehicles tend to be more sensitive to vehicle prices than other consumers, which causes relatively low equilibrium markups for hybrid and electric vehicles. Consequently, the marginal private welfare loss of reducing gasoline vehicle sales exceeds the marginal private welfare gain of increasing hybrid or electric vehicle sales. Thus, by causing consumers to shift from gasoline to hybrid and electric vehicles, private welfare decreases, and this effect outweighs welfare gains from reducing distortionary taxes. The importance of pre-existing distortions caused by market power is confirmed by comparing our main results, in which we assume Bertrand competition, with an alternative version of the model that assumes perfect competition.

Distortions caused by market power also explain a second surprising result: a carbon dioxide emissions rate tax has higher welfare costs than reducing sales taxes or import tariffs. Such a tax has been proposed recently in Colombia. We refer to the policy as a carbon tax for consistency with public discussion of the policy; it is more accurately described as an emissions rate tax. We expect the carbon tax to be more effective at reducing emissions because it encourages consumer substitution within and across fuel types to lower-emitting vehicles. In contrast, the other policies only encourage substitution across fuel types. The carbon tax is indeed 7.5-25 times more effective at reducing emissions than either of the other policies. However, the carbon tax imposes higher welfare costs than the other policies because of consumer substitution for lower-emitting gasoline vehicles. These vehicles have lower estimated markups than higher-emitting gasoline vehicles. Therefore, causing market shares of lower-emitting gasoline vehicles to increase partially at the expense of higher-emitting vehicles decreases total private welfare. Because gasoline vehicles account for 97-98 percent of the market in 2019 and 2020, these welfare consequences are large and cause the carbon tax to have higher welfare costs per ton of emissions reduction than the other policies.

This paper contributes to several strands of literature. First, as noted above, the paper is the first to evaluate electric vehicle policies in a middle-income country other than China. A growing literature examines electric vehicle demand and policy in high-income countries and China, such as Li et al. (2017), Li (2019), Li et al. (2020), Sheldon and Dua (2020), Xing, Leard, and Li (2021), and Springel (2021). Colombia is unusual among these countries in using import tariffs

to promote hybrid and electric vehicles. Our estimated fiscal and welfare costs appear to be broadly similar to estimates in this literature.

Second, the paper contributes to the literature on vehicle environmental taxation. Many countries, particularly in Europe, tax vehicle purchase or ownership in accordance with the vehicle's emissions rate. D'Haultfœuille, Givord, and Boutin (2014) and Klier and Linn (2015) find that such taxation schemes effectively reduced average emissions rates of new vehicles in France, Germany, and Sweden. Alberini et al. (2018) conclude that Switzerland's vehicle taxation scheme, which links a vehicle's annual registration fee to its emissions rate, reduced emissions by increasing retirements of high-emissions vehicles. Several papers, such as Grigolon, Reynaert, and Verboven (2018), show that taxing fuels rather than vehicles is more efficient at reducing emissions, particularly when consumer purchase and driving decisions respond strongly to fuel prices. Our paper shows that sales and import tariffs can increase hybrid and electric vehicles sales. Most of the literature on environmental taxation is reduced form, whereas we estimate welfare costs of the policies.

Third, the paper builds on recent work evaluating environmental policy in the presence of pre-existing distortions caused by market power. Fowlie, Reguant, and Ryan (2016) show that an emissions rate standard may have lower welfare costs than a carbon tax when producers restrict output because of market power, particularly after accounting for dynamic entry decisions. Whereas they analyze a homogeneous product, we consider a differentiated product for which markups vary both across firms and within the vehicles sold by a firm. Though other studies that model imperfectly competitive markets also include these distortions (e.g., Xing, Leard, and Li (2021)), they have not been emphasized in the literature on environmental policy for passenger vehicles.

Finally, this paper adds to the literature on trade policy, vehicle demand, and consumer welfare. Fershtman and Gandal (1998) and Clerides (2008) find sizeable consumer gains (\$2,000-\$2,500 per consumer) resulting from the removal of non-tariff restrictions in automobile markets in Israel and Cyprus, respectively. Brambilla (2005) and Tovar (2012) assess the effects of a reduction in import tariffs and non-tariff barriers stemming from the establishment of the Mercosur customs union in Argentina and Brazil and government economic liberalization reforms in Colombia. Like ours, both papers find limited consumer gains due to import tariff

reduction. Brambilla's (2005) policy simulations suggest that after equalizing tariffs between the two countries, Argentine consumers gained 393 dollars per vehicle sold, whereas their Brazilian peers lost 204 per vehicle. Tovar (2012) finds sizeable welfare gains of \$3,000 per vehicle from trade liberalization but concludes that 95 percent of these welfare gains for consumers came from expanded product variety, not from price changes. Unlike our study, none of these papers accounts for the environmental costs and benefits of a trade policy.

2. Data and Policy Context

This section describes the data sources, provides key characteristics of Colombia's new vehicle market, and outlines the major policy changes affecting hybrid and electric vehicles during the data period.

2.1 Data

The primary data set used to estimate the model parameters and conduct counterfactual simulations consists of quarterly observations of new vehicles in Colombia between 2015 and 2020. For each vehicle, we observe new registrations, prices, and attributes. This subsection describes the construction of the data set.

Data on vehicle registrations and attributes from IHSMarkit are the primary data source. A vehicle is defined by a unique model name, trim, engine size, and fuel type. Each quarter, there are typically about 30,000 vehicles with positive registrations. The definition of a vehicle is highly specific and distinguishes between vehicles sold under the same model's name, but which have different fuel types (such as gasoline or hybrid), engine size (such as 4-cylinder or 6-cylinder), or trim level (such as the "standard" or "sport" trim). For example, a gasoline-powered Mazda 3 Standard trim with a 1.6-liter engine is a unique vehicle. This level of detail is comparable to some recent papers on Europe (Grigolon, Reynaert, and Verboven, 2018) or the United States (e.g., Leard, Linn, and Zhou 2021), and it is unusual for papers on low- or middle-income countries. As Section 4 explains in more detail, disaggregation helps identify preference parameters.

Although the IHS data provide extensive detail about the vehicles, unfortunately, the data are incomplete for vehicle prices and certain other attributes. We use El Motor Magazine³ to impute vehicle prices. We use Carfolio.com to impute fuel economy, GHG emissions rates, and other attributes.

To assess the quality of the imputation, we compare imputed values with non-missing data. For vehicle attributes with continuous values, such as horsepower and price, the absolute mean difference between the observed and the imputed data was 5%, with a standard deviation of 0.8%. We obtain gasoline and electricity prices from Colombia's Ministry of Energy.

Data for charging stations come from different sources, including OpenChargeMap,⁴ Electromaps,⁵ and PlugShare.⁶ Because our registration data are at the national level, we compute the total number of public charging stations by quarter.

2.2 Characteristics of Colombia's New Vehicle Market

Colombia is Latin America's fourth largest market for both automobiles sales and production (after Brazil, Mexico, and Argentina).⁷ There are two large light-duty vehicle manufacturers in Colombia (Colmotores/GM and Sofasa/Renault).⁸ These two firms assemble cars from imported materials that represent around 70 percent of a fully assembled car.⁹ These imported materials are subject to import tariffs of a similar magnitude (currently 35 percent) as imported cars. Since Colombia liberalized trade in light-duty vehicles in 1991, the incumbent advantage of the domestic assembly plants has gradually dissipated, and previously nonexistent imports of other cars have grown significantly (Tovar 2012). Currently, two-thirds of new vehicle sales are imports.¹⁰

³ <https://www.motor.com.co/precios> [last accessed: April 2022].

⁴ <https://openchargemap.org/site> [last accessed: April 2022].

⁵ <https://www.electromaps.com/en> [last accessed: April 2022].

⁶ <https://www.plugshare.com/> [last accessed: April 2022].

⁷ See <https://www.globalfleet.com/en/manufacturers/latin-america/analysis/latam-vehicle-sales-down-2020-commercial-fleet-solid> and <https://investincolombia.com.co/en/sectors/manufacturing-industries/automotive> [last accessed: April 2022].

⁸ The third large manufacturer, Compañía Colombiana Automotriz, closed its operations in Colombia in 2014.

⁹ To our knowledge, none of the cars assembled at these plants are electric or hybrid vehicles.

¹⁰ See <https://www.industryweek.com/the-economy/competitiveness/article/22018055/growing-opportunities-in-colombias-automotive-market> [last accessed: April 2022].

Table 1 shows key characteristics of Colombia’s new vehicle market based on the data set used for demand estimation and policy simulations.

Table 1: Summary statistics for vehicle characteristics

Variable	Mean	Standard deviation	10th percentile	90th percentile	Within model standard deviation	Across model standard deviation
Retail price (including taxes, \$)	36,341.5	28,275.7	12,312.1	73,699.6	2,887.2	23,542.9
Fuel cost (\$/100 miles)	10.5	4.8	6.6	14.1	1.1	4.8
Engine power (kilowatts)	131.9	67.6	66.0	230.0	1.4	9.7
Fuel consumption rate (miles/gallon)	28.3	9.5	19.7	40.0	1.9	66.8
Engine displacement (cubic centimeters)	1,822.0	846.5	1,197.0	2,488.0	107.1	845.4
Weight (kilograms)	1,683.9	346.2	1,301.0	2,150.0	72.8	347.3
Battery capacity (kWh)	28.9	19.9	7.6	61.0	0.1	21.5
Range (miles)	138.7	100.5	25.5	251.7	0.5	98.6
Number of chargers	18.8	31.4	0	82.0	NA	NA

Variable	Market share
Automatic transmission	15.7%
Electric	0.23%
Hybrid	0.38%

Note: The table reports summary statistics for the data set used for estimation and policy simulations, which includes 9,999 observations. Electric vehicles include plug-in hybrid electric vehicles and all-electric vehicles.

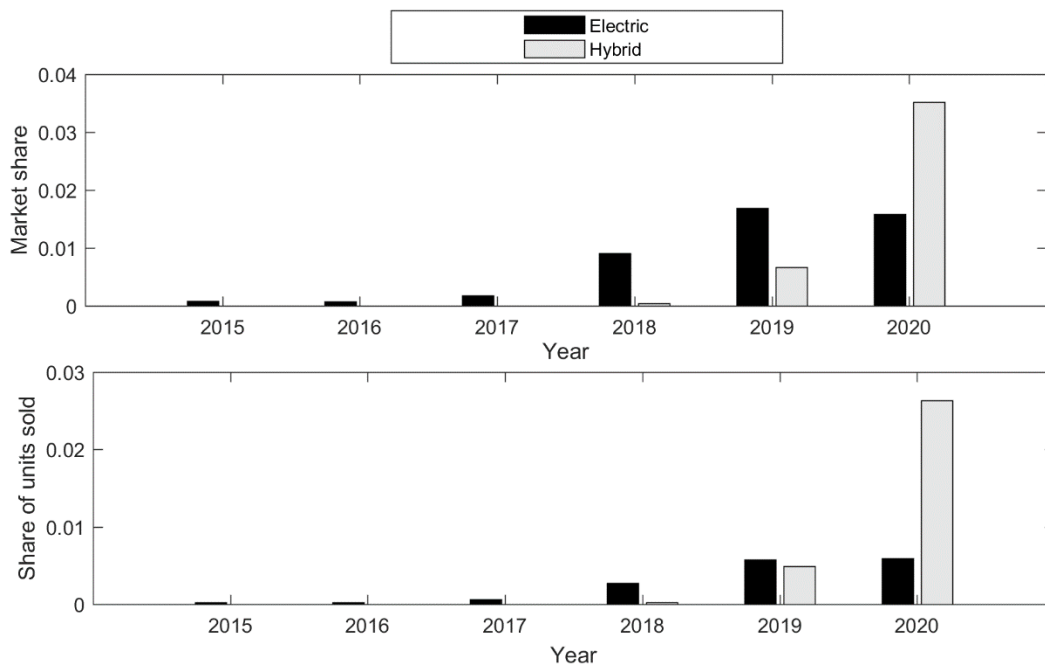
Prices and fuel costs are in current dollars, and the table indicates a substantial variation of the attributes across vehicles. For gasoline and hybrid vehicles, fuel costs are the price of gasoline

(dollars per liter) multiplied by the fuel consumption rate (liters per 100 miles). For electric vehicles, fuel costs are the price of electricity (dollars per kilowatt-hour, kWh) multiplied by electricity consumption (kWh) per 100 miles.

The table includes two measures of engine performance: power (measured in kilowatts), which is directly proportional to horsepower, and displacement (in cubic centimeters), which is the volume of the engine cylinders. Like most of the recent vehicle demand literature (e.g., Xing et al. 2021), we use power as a proxy for performance because it is highly correlated with other potential performance measures such as acceleration and towing capacity, which are not observed.

The table also reports the battery capacity and electric range of electric vehicles. The range is the number of miles that can be driven in all-electric mode, and the electric range is typically substantially lower for plug-in hybrids than for electrics. However, because plug-in hybrids have a gasoline engine, their total range is usually higher than all-electric vehicles.

Figure 1. Market Shares of Electric and Hybrid Vehicles and Shares of Available Electric and Hybrid Vehicles in Total Vehicles

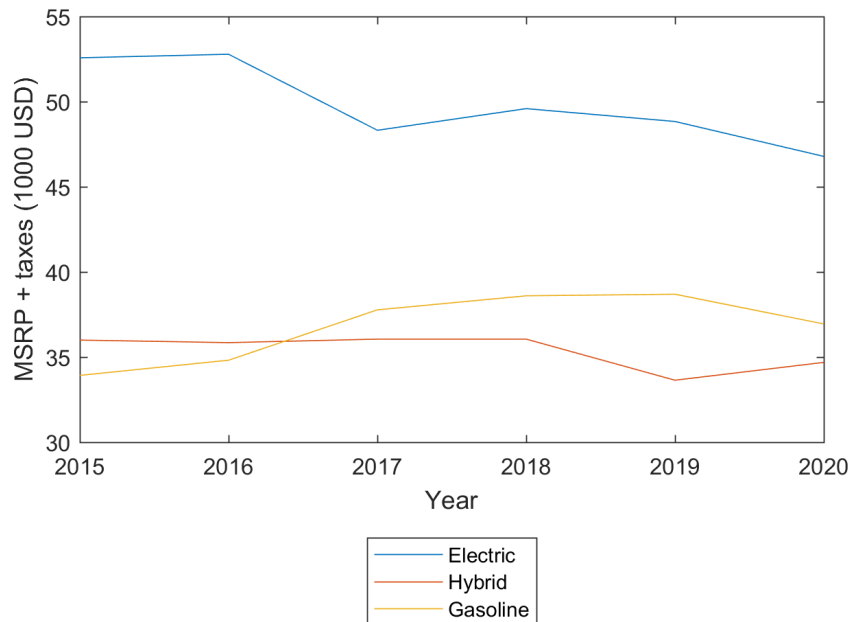


The bottom of Table 1 shows that about 84 percent of the vehicles have a manual transmission. The market shares of electric and hybrid vehicles are small, with each less than 1 percent over

the entire sample. However, these vehicles have gained in importance over time (Figure 1). The market shares of hybrid and electric vehicles have increased rapidly, particularly after 2017 (Figure 1, upper panel). By 2020, the combined market share of these vehicles was about 5 percent. The sales growth coincides with an increase in the number of hybrid and electric vehicle options; by 2020, these vehicles accounted for about 3 percent of the unique vehicles offered in the market (Figure 1, lower panel).

Moreover, Figure 2 shows that the average price of electric vehicles declined somewhat, but the average remains substantially higher than prices of gasoline and hybrid vehicles, which were relatively stable over the same period.

Figure 2: Average Vehicle Prices by Fuel Type



Note: MSRP is the manufacturer’s suggested retail price. The vertical axis plots the combined MSRP and tax in thousands of dollars.

For additional context about Colombia’s market, Table 2 reports the five top-selling models by fuel type. BMW and Renault sell the top-five most popular electric vehicle models (Mini is a brand sold by BMW). The most popular electric models tend to be in the small or mini segments, whereas the most popular hybrid models tend to be only slightly larger. The most popular gasoline models have market shares two orders of magnitude larger than the most popular

electric and hybrid vehicles. Moreover, the top-five gasoline models account for almost half of all sales. These gasoline vehicles have multiple trims and engine configurations, whereas electric vehicles typically have just a few available trims. These statistics indicate that the market is highly concentrated, more than typical in high-income countries.

Table 2: 5 top-selling models by fuel type

Model	Fuel Type	Market share (USD)	Market share (Q)	Mean MSRP	Market Segment
BMW I3	Electric	0.09%	0.09%	48,129	Small
RENAULT TWIZY	Electric	0.04%	0.04%	31,602	Mini
RENAULT ZOE	Electric	0.04%	0.04%	31,954	Small
BMW 3-SERIES	Electric	0.04%	0.04%	52,465	Medium
MINI COUNTRYMAN	Electric	0.03%	0.03%	44,849	Off-Road
TOYOTA COROLLA	Hybrid	0.33%	0.33%	20,836	Lower Medium
HYUNDAI IONIQ	Hybrid	0.03%	0.03%	24,682	Lower Medium
FORD FUSION	Hybrid	0.01%	0.01%	30,603	Medium
AUDI A6	Hybrid	0.00%	0.00%	51,043	Upper Medium
BYD QIN	Hybrid	0.00%	0.00%	17,586	Lower Medium
RENAULT SANDERO	Gasoline	14.25%	15.16%	12,493	Lower Medium
CHEVROLET SPARK	Gasoline	8.66%	10.90%	8,555	Mini
CHEVROLET SAI	Gasoline	5.91%	8.27%	10,534	Small
KIA PICANTO	Gasoline	5.95%	8.06%	9,805	Mini
MAZDA 3	Gasoline	6.19%	5.19%	16,509	Lower Medium

2.3 Country and Policy Context

Colombia is the third most populous country in Latin America and the fourth largest economy. Table 3 provides background information about Colombia's economy, electricity sector, and CO₂ emissions for 2019. It also compares these indicators with other middle-income countries to

motivate our choice of Colombia as a representative case study. Compared to other middle-income economies, Colombia is a richer country that grows at a slower rate. However, these differences are not substantial, and we can consider Colombia a representative middle-income economy.

Colombia’s emissions are half as large as the average middle-income country (on a per-capita basis), which is partly explained by the extensive use of hydroelectricity in Colombia. Electricity access is also high and comes close to 100 percent. Low carbon intensity and good availability of electricity make a strong case for electric vehicles to help decarbonize the economy.

The Colombian government has set an ambitious goal to reduce its greenhouse gas emissions by 20% by 2030 under the Paris Agreement commitments (Law 1844, 2017). To help achieve this commitment, the government intends to have 600,000 electric vehicles on the road by 2030.¹¹

Table 3: Summary statistics of Colombia’s economy in 2019

Variable	Colombia	Middle Income Countries
GDP per capita (current US\$)	6425.0	5480.3
GDP growth (annual %)	3.3	4.6
CO ₂ emissions (metric tons per capita)	1.6*	3.7*
Access to electricity (% of population)	99.8	93.5
Renewable energy consumption (% of total final energy consumption)	30.7*	20.4**

Note: Calculations are based on the World Bank Open Data. Middle-income countries are defined based on the World Bank country classification for 2021. * Latest data available for 2018. ** Latest data available for 2015.

The government has recently adopted and proposed several tax policies to promote the uptake of hybrid and electric vehicles. First, starting in 2017, the sales tax on new vehicles was reduced from 19 percent to 5 percent for hybrid and electric vehicles; the sales tax for gasoline vehicles remains at 19 percent. In 2017, Colombia also reduced import tariffs from 35 percent to 0 for electrics and 5 percent for hybrids; tariffs for gasoline vehicles remain at 35 percent. Initially, the

¹¹ See <https://www.worldenergy.org/news-views/entry/electric-mobility-is-a-reality-in-colombia> [last accessed: February 2022].

tariff reduction applied only to the first 1,500 units each year, but starting in December 2019, the caps were eliminated.¹²

Both tax policies affect vehicles according to their fuel type (gasoline, hybrid, or electric), but there is no policy variation within a fuel type. Moreover, as Figure 1 shows, the increase in market share coincided with the entry of new vehicle options. Since entry is a long-term decision that probably did not respond immediately to the policy changes, it is difficult to disentangle the effects of the policies and vehicle entry on market shares. The limited tax variation and coinciding entry prevent an econometric policy evaluation. This motivates our strategy of specifying an equilibrium model of the new vehicle market, estimating parameters, and simulating policies to evaluate these policy interventions.

The second policy development is that the Colombian government has proposed a carbon tax as part of its climate change agenda (draft law 439 of 2021 presented by the executive branch but later withdrawn). This carbon tax for new vehicles was calculated based on their sales price and estimated carbon emissions rates. Electric cars and hybrids were exempted from the sales price component of the tax. All other vehicles were grouped into three price bands with an increasing marginal tax rate for higher price bands.¹³ The emissions component of the proposed carbon tax allocated all vehicles into 50 bins (or "contamination factors") based on their estimated emission rate levels. The value of the emissions component is determined by multiplying the value of the contamination factor (e.g., 1 for the first bin and 50 for the last bin) by \$14.55. The total proposed tax is the sum of these two components.

Finally, in 2018 Colombia reduced taxes for charging station investment. It also implemented several non-tax policies to improve the uptake of electric vehicles.¹⁴ Unfortunately, we cannot assess the effects of these policies because of limited data on charging stations and sub-national vehicle registrations.

¹² This import tax exemption quota was not binding and thus had no effect on our study's findings. The highest number of an electric vehicle brand sold in the market in 2019 was 827 units, or 55 percent of the quota.

¹³ Specifically, vehicles with a price below \$13,221 would have been subject to a 1.5% tariff. Vehicles with a price range of \$13,221 to \$29,740 would have been subject to a 2.5% tariff. Vehicles with a price above \$29,740 would have been subject to a 3.5% tariff.

¹⁴ For example, the government gave plug-in vehicle owners some exemptions from the Pico y Placa — a national measure to mitigate the traffic congestion and pollution problems by restricting the presence of cars on the roads based on their plate numbers on each day of the week.

3. Equilibrium Model

This section describes the equilibrium model of the new vehicle market. Each consumer chooses the vehicle that maximizes subjective utility, and each vehicle manufacturer maximizes profits.

3.1 Demand

The demand side of the model is similar to other random coefficients logit models of the market, such as Berry, Levinsohn, and Pakes (1995, 2004) and Li (2019). Markets are indexed by t , which corresponds to a year-quarter. Each market includes a fixed number of households that consider buying a used vehicle or one among the J available new vehicle types.

The subjective utility u_{ijt} that consumer i receives from purchasing vehicle j in market t is:

$$u_{ijt} = \alpha_i(p_{jt} + \tau_{jt}^s) + \sum_k x_{jkt}\beta_k + \xi_{jt} + \varepsilon_{ijt}, \quad (1)$$

where p_{jt} is the vehicle's purchase price excluding the sales tax, τ_{jt}^s is the sales tax, α_i is the individual's sensitivity of utility to price (that is, the marginal utility of income), x_{jkt} is the value of observed vehicle attribute k with coefficient β_k , ξ_{jt} is the mean combined utility of all unobserved vehicle attributes, and ε_{ijt} is the individual's idiosyncratic utility from purchasing the vehicle net of the utility from price, observed attributes, and unobserved attributes. Observed attributes include engine power (measured in kilowatts), per-mile fuel costs, a dummy variable for an automatic transmission, a dummy variable for an electric vehicle, the interaction of the electric vehicle dummy with the number of charging stations, battery size, and a dummy variable for a turbocharger.¹⁵ The set of attributes contains variables that consumers use to distinguish vehicles from one another, including traits related to fuel consumption, engine performance, and fuel type. Battery size is a proxy for (unobserved) range in all-electric mode, and preferences for battery size may reflect range anxiety.

In the benchmark specification of demand in equation (1), consumer heterogeneity enters the price sensitivity and error term. The coefficient on the tax-exclusive purchase price is the same as the coefficient on the sales tax, meaning that consumers care only about the tax-inclusive sales

¹⁵ It is more common in the literature to use horsepower than engine power. We use engine power because of data availability, but this likely has little effect on the results because the two variables are highly correlated with one another.

price. In principle, the utility could depend differently on the tax-exclusive price and sales tax, but the policy variation discussed in Section 2 prevents us from estimating a different sensitivity parameter for tax-exclusive prices and taxes.

Equation (1) makes the standard distinction between vehicle attributes that are observed in the data and those that are unobserved; below, we discuss the implications of the unobserved attributes for parameter estimation. We assume that α_i has a normal distribution with mean α and standard deviation σ . We use F to denote the joint distribution of the preference parameters α , σ , and β_k .

If ε_{ijt} has a Type 1 extreme value distribution and the utility of the outside option is normalized to zero, the market share of vehicle j in market t , s_{jt} , is:

$$s_{jt} = \int \frac{\exp(\alpha_i(p_{jt} + \tau_{jt}^s) + \sum_k x_{jkt} \beta_k + \xi_{jt})}{1 + \exp(\alpha_i(p_{jt} + \tau_{jt}^s) + \sum_k x_{jkt} \beta_k + \xi_{jt})} dF. \quad (2)$$

Equation (2) links the vehicle's market share to its price and attributes and the preference parameters.

3.2 Supply

The supply side is static and similar to Berry et al. (1995), among others. Each firm f maximizes the profits of selling its $j \in J_f$ vehicles, taking tax policies and consumer preferences as exogenous:

$$\max_{\{p_{jt}\}_{j \in J_f}} (p_{jt} - c_{jt} - \tau_{jt}^m) q_{jt},$$

where c_{jt} is the vehicle's marginal cost of production, τ_{jt}^m is the import tariff, and q_{jt} is the vehicle's sales, which depend implicitly on the vehicle's price according to equation (2). Thus, the costs contain two components: the marginal cost of producing the physical vehicle and the import tariff. Marginal costs are a linear function of engine power, fuel consumption rate, transmission type, and battery size.

The first-order condition for the price p_{jt} is:

$$\sum_{k \in J_f} \frac{\partial q_{kt}}{\partial p_{jt}} (p_{jt} - c_{jt} - \tau_{jt}^m) + q_{jt} = 0. \quad (3)$$

The profit-maximizing price depends on the own- and cross-price elasticities of demand, marginal costs, and the import tariffs.

3.3 Estimation

3.3.1 Identification

For each market t , equations (2) and (3) characterize the equilibrium prices and market shares. To calculate counterfactual prices and market shares, we need to estimate the preference parameters α , σ , and β_k , the unobserved vehicle utilities, ξ_{jt} , and marginal costs, c_{jt} .

The highly disaggregated vehicle definition aids identification of the parameters α , σ , and β_k . For many models in the data, we observe multiple versions with different engine sizes or transmission types but are otherwise similar to one another. In contrast, as we see from Table 1, if the data were aggregated to the model level, there would be less variation to identify the coefficients.

Recall that equation (2) includes the unobserved utility of the vehicle. We decompose this utility into three components plus a random error term: $\xi_{jt} = \eta_m + \gamma_t + \lambda_s + v_{jt}$, which includes the make fixed effects (η_m), year-quarter fixed effects (γ_t), and market segment fixed effects (λ_s). The make fixed effects distinguish the luxury and base brands that some firms offer, such as Nissan and Infiniti, which are both sold by Nissan.¹⁶ The year-month fixed effects control for any unobserved demand shocks that affect the utility of all vehicles proportionately. The segment fixed effects control for preferences for vehicle size since the segment variable is based largely on the vehicle's size.

Complicating the estimation is that the equilibrium price of each vehicle is correlated with the random error term, v_{jt} , via equation (3). Following standard practice since Berry et al. (1995), we use instruments based on attributes of other vehicles in the market. The rationale is that the vehicle's price depends implicitly on attributes of other vehicles according to equation (3). The exclusion restriction is that attributes of other vehicles are exogenous to v_{jt} . Since vehicle manufacturers typically adjust vehicle attributes every several years rather than annually, this

¹⁶ It would be feasible to include model rather than make fixed effects. Unfortunately, there is insufficient variation in attributes and prices to identify the preference coefficients if we include model fixed effects.

may be a valid assumption in the short run. Unfortunately, data are not available to partially relax this assumption, as in Klier and Linn (2012).

We use three sets of instruments. The first set includes the sums and deviation from averages of competing firms' engine displacement, power, emissions rate, weight, and the number of transmission speeds. The second set includes similar attributes and is based on deviations from the firm's averages. The third set the number of vehicles within the same segment that has the same drive type, turbocharger, and transmission type. Taken together, the instruments approximate the degree of competition from similar vehicles sold by other firms or sold by the same firm, which affects equilibrium prices according to equation (3).

3.3.2 Estimation Results

Table 4 shows the estimated preference parameters. Column 1 shows estimates of a nested logit model compared to the random coefficients logit in column 2. In the random coefficients specification, the price coefficients are statistically significant at the 1 percent level, and they imply mean own-price elasticities of about -5. This magnitude appears reasonable given the disaggregate level of the data (Li 2019). The magnitude is also substantially larger than the nested logit coefficient, which implies an implausibly small degree of price responsiveness.

The coefficient on power is positive and statistically significant at the one percent level. The magnitude implies that consumers are willing to pay on average 6.1 dollars for a 1 percent power increase, which indicates that consumers in Colombia have a smaller willingness to pay for power than in high-income countries (Grigolon et al. 2018 and Xing et al. 2021). As expected, the fuel cost coefficient is negative, but it is statistically significant at only the 10 percent level. The magnitude suggests that consumers undervalue fuel cost savings. If we compare two identical vehicles except that one vehicle has lower fuel costs, consumers are willing to pay less than the present discounted value of the fuel cost savings.¹⁷

¹⁷ More specifically, we estimate a valuation ratio of 0.1. The valuation ratio is the ratio of the willingness to pay for a 1 percent reduction in the fuel cost variable, divided by the present discounted value of the fuel costs. The latter depends on miles traveled and fuel prices over the life of the vehicle, as well as vehicle lifetime and discount rate. We assume annual miles traveled of 12,400 (average miles according to El Motor). Expected future fuel prices equal current prices, which is a common assumption in the literature (e.g., Grigolon et al. 2018). We assume vehicle lifetime of 10 years and a discount rate of 3.38 percent, which is the average passive rate in Colombia for 2020.

Table 4: Demand estimation results

Variable	Nested Logit	Random Coeff. Logit
Non - linear		
Price mean	-0.016*** (0.004)	-0.342*** (0.015)
Price random coeff.		0.112*** (0.006)
Linear		
Intercept	0.726*** (0.389)	-0.713** (0.280)
Power (Engine Kw)	0.004*** (0.001)	0.012*** (0.001)
Consumption (USD/ 100 miles)	-0.084*** (0.006)	-0.005* (0.003)
Transmission (Automatic =1)	-0.096* (0.040)	0.072** (0.031)
Electric dummy	7.650*** (0.642)	-2.937*** (0.434)
Electric X charging stations	0.029*** (0.003)	0.018*** (0.002)
Battery size (kWh)	-0.066 (0.004)	0.012*** (0.002)
Turbo	-0.192 (0.042)	0.032 (0.037)
Sigma lower nest (Standard seg)	0.856*** (0.040)	
Sigma upper nest (fuel type)	0.920*** (0.043)	
Maker fixed effects	Yes	Yes
Year - month fixed effects	Yes	Yes
Standard segment fixed effects	Yes	Yes

Note: Standard deviation in parenthesis, ***p < 0.01, **p < 0.05, *p < 0.1

The coefficient on the interaction of electric vehicles with the number of charging stations is positive—which we would expect since public charging stations can reduce range anxiety. However, because the number of charging stations increases steadily through the sample and the variable does not vary across electric vehicles, the positive coefficient may (at least partially) reflect an omitted time trend of electric vehicle demand. That is, we cannot identify the charging station interaction if we include market fixed effects interacted with the electric vehicle dummy variable.

The turbocharger coefficient is positive, but it is not precisely estimated. Turbochargers affect fuel costs and performance, but we control separately for fuel costs and performance, which may explain the lack of statistical significance. In other words, consumers may value the additional performance that a turbocharger enables rather than the turbocharger per se.

Table 5: Supply estimation results (random coefficients logit model)

Variable	Random Coeff. Logit
Intercept	3.440*** (0.195)
Power (log (HP)/ weight)	0.295*** (0.042)
Consumption (USD/ 100 miles)	-0.002 (0.003)
Transmission (Automatic =1)	0.092*** (0.029)
Battery size (kWh)	0.011*** (0.002)
Maker fixed effects	Yes
Year - month fixed effects	Yes
Standard segment fixed effects	Yes

Note: Standard deviation in parenthesis, ***p < 0.01, **p < 0.05, *p < 0.1

Table 5 shows the estimates of the supply-side parameters. Increasing a vehicle’s horsepower, replacing a manual with an automatic transmission, and increasing the battery size have the expected signs, and the coefficients are precisely estimated. The automatic transmission coefficient is larger than expected, which may reflect a correlation between transmission type

and unobserved attributes offered in premium vehicles. Note that such a correlation would likely have small effects on the counterfactual analysis in Section 4 since vehicle attributes are exogenous in that analysis. The coefficient on fuel consumption has the expected negative sign, meaning that reducing fuel consumption (that is, increasing fuel economy) while holding fixed other attributes causes the marginal costs to increase.

Table 6 reports mean own-price elasticity of demand, profit margin, and markup by fuel type. The large magnitudes of the own-price elasticities reflect the disaggregated definition of vehicles and that manufacturers often sell multiple versions of a model (such as the Chevrolet Spark); if Chevrolet increases the price of one version of the Spark, consumers may substitute to other versions of the Spark. Consumers are more price-sensitive for electric and hybrid than for gasoline vehicles. This difference is intuitive because it indicates that consumers consider the prices of the alternative technologies more carefully.

Table 6: Own-price elasticity, profit margin, and markup by vehicle’s fuel type

Fuel Type	Mean own-price elasticity	Mean profit margin	Mean markup (USD)
Electric	-5.6	4.7%	2,031
Hybrid	-5.4	7.3%	2,055
Gasoline	-4.7	10.9%	2,304

Note: This table presents mean price elasticities, mean profit margins, and mean markups by vehicle fuel type. Averages are taken over all vehicles belonging to a fuel type. Mean own-price elasticity is the percent change of a vehicle’s market share caused by a one-percent increase in the price of the vehicle.

The profit margin and markup are consistent with the differences in price elasticity of demand; the more price-elastic is demand, the lower the profit margin and markup. The lower markups for electric and hybrid vehicles preview the high welfare costs of the policies that increase the market shares of these vehicles. That is, reducing sales taxes or import tariffs for electric and hybrid vehicles increases their market shares, which on the margin reduces manufacturer profits because of the lower markups.

Table 7 presents own and cross-type elasticities of demand by vehicle’s fuel type. Because the policies (i.e., taxes and tariffs) affect end-use prices by vehicle’s fuel type, this table reports elasticities of demand caused by 1 percent changes of the prices of all vehicles belonging to the

fuel type in the column heading. Consequently, magnitudes of the own-price elasticities of demand are smaller in this table than in the previous table, which uses price changes of individual vehicles to compute elasticities. In Table 7, the cross-price elasticities of demand indicate that hybrid vehicles are closer substitutes for electric vehicles than are gasoline vehicles. Intuitively, consumers regard electric vehicles as closer substitutes for hybrid vehicles than for gasoline vehicles. The reasonableness of the consumer substitution patterns helps validate the demand model.

Table 7: Own- and cross-price elasticity of demand by fuel type

Fuel Type	Electric	Hybrid	Gasoline
Electric	-4.0	0.0	2.6
Hybrid	0.1	-3.9	2.5
Gasoline	0.0	0.0	-2.1

Note: This table shows the own- and cross-price elasticities by fuel type. Elasticities are the percent change in market share of the fuel type caused by a 1 percent increase of the prices of all vehicles belonging to the fuel type in the column heading.

4. Policy Simulations

4.1 Scenarios

We compare a baseline no-policy scenario that removes the preferential sales and import taxes against scenarios that include one or both of the preferential taxes. We use data from 2019 and 2020 for the simulations and report results separately for each year. Simulating outcomes for 2019 allows us to characterize the equilibrium before the COVID-19 pandemic, which likely disrupted Colombia’s new vehicle market as the economy contracted. The market shares of hybrids and electrics increased threefold between 2019 and 2020 (see Figure 1), and it is interesting to consider the effects of the tax policies when market shares reached historical highs. The baseline or ‘no-policy’ scenario includes the pre-reform status quo of 19 percent sales tax and a 30 percent import tariff for all vehicles. In the first policy scenario, we reduce the sales tax to 5 percent for hybrid and electric vehicles. In the second policy scenario, we reduce the import tariff to 5 percent for hybrids and 0 for electrics; we maintain the 30 percent import tariff for gasoline vehicles and the sales tax at 19 percent for all vehicles. The second scenario is the actual

policy, which includes both the lower sales tax and the lower import tariffs for hybrids and electrics. The third scenario considers the effects of the carbon tax proposed by the Colombian government (see Section 3).

The algorithm for finding the equilibrium begins by making a guess on vehicle market shares and prices. For the baseline scenario, the initial guesses include the observed prices and market shares predicted by equation (2). For each firm, we use equation (3) to compute the profit-maximizing vector of prices for its vehicles, conditional on the prices of other firms' vehicles. We iterate through the firms in the market until the price vector converges to within a specified tolerance. The equilibriums for the three policy scenarios are found similarly, using the observed prices and predicted market shares as initial guesses.

4.2 Effects of Existing Policies on Market Shares and Welfare

Table 8 shows the results of simulations of the no-policy scenario, which includes a 19 percent sales tax and 30 percent tariff for all vehicles. The second column shows the current policy, which includes both the lower sales tax and lower import tariffs for hybrids and electrics. The third and fourth columns show the effects of only changing the sales tax or importing tariff. The fifth column shows the effects of the proposed carbon tax. Note that the first column reports levels for the outcomes indicated in the row headings, and all other columns report changes relative to the 'no-policy' baseline.

Panel A reports results for 2019, and the first two columns show that the lower sales taxes and import tariffs increased market shares from 0.06 to 0.57 ($= 0.06 + 0.51$) percent for electric vehicles and 0.08 to 0.5 ($= 0.08 + 0.42$) percent for hybrids. The lower sales tax and import tariff slightly increased consumer surplus and reduced profits. Government revenue declined by about \$6.4 million, which is about 1 percent of the revenue in the baseline scenario. For simplicity, we assume that the tax decrease is financed by a lump-sum tax on all households.¹⁸ Total welfare is reported at the bottom of the panel, and the change in welfare in the second column is the sum of the total consumer surplus change, total profit change, and fiscal cost. The fiscal cost more than

¹⁸ That is, following the literature, we assume that the fiscal cost of a policy can be financed without creating any further distortions. This assumption allows us to highlight the policies' effects on the market for new vehicles, which is the focus of our paper. To the extent that the tax decreases are financed by distortionary tax increases elsewhere in the economy or lump-sum tax revenues are not fully recovered due to mismanagement common in developing countries, the welfare costs reported in this paper would understate the full welfare costs of the policies.

offsets the consumer surplus increase from reducing taxes, and the total welfare change is negative.

Table 8: Welfare comparison of baseline with status quo and alternative scenarios

Variable	No Policy (level)	Current Policy (diff)	Sales tax reduction only (diff)	Tariff reduction only (diff)	Carbon tax (diff)
Panel A: Year 2019					
Electric vehicle market share	0.06%	0.51%	0.06%	0.22%	0.56%
Hybrid vehicle market share	0.08%	0.42%	0.08%	0.19%	0.46%
Average consumer surplus (USD per consumer)	9380.7	30.5	5.2	14.4	-202.9
Average profit (USD per vehicle)	2287.5	-3.7	-0.5	-1.5	-40.3
Total Consumers Surplus (millions USD)	1150.7	5.9	0.6	1.7	-24.0
Total profit (millions USD per market)	343.1	-0.2	-0.1	-0.2	-4.7
Fiscal cost (million USD)	0.0	6.4	0.4	2.2	-58.3
Total Welfare (million USD per market)	1493.8	-0.7	0.1	-0.7	29.7
Panel B: Year 2020					
Electric vehicle market share	0.08%	0.51%	0.07%	0.24%	0.57%
Hybrid vehicle market share	0.45%	2.18%	0.41%	1.01%	2.75%
Average consumer surplus (USD per consumer)	7004.9	48.6	9.6	23.8	-101.4
Average profit (USD per vehicle)	2164.7	-10.3	-2.1	-5.2	-42.4
Total Consumers Surplus (millions USD)	552.4	9.1	0.7	2.0	-7.3
Total profit (millions USD per market)	208.4	-0.6	-0.2	-0.4	-3.1
Fiscal cost (million USD)	0.0	9.3	1.0	4.1	-30.1
Total Welfare (million USD per market)	760.8	-0.9	-0.4	-2.4	19.7

Note: This table shows the results of the counterfactual analysis for market shares for electric and hybrid vehicles and welfare measures for five scenarios. For the "No Policy" scenario, the calculations are presented in levels. For all other scenarios, calculations are the increments from the "No Policy" scenario. "Average consumer surplus" and the "Average profit per vehicle" are the annual averages weighted by the number of vehicle units sold. "Total consumer surplus," "Total producer surplus," and "Fiscal Cost" are calculated annually. "Total Welfare" is the sum of "Total consumers surplus" and "Total producer surplus" minus the "Fiscal cost."

The negative welfare change may at first appear to be surprising. The sales tax and import tariff in the no-policy scenario are distortionary, and one might expect that reducing these taxes should increase private welfare. However, that intuition does not take account of the pre-existing distortion caused by market power. Specifically, because demand curves for hybrid and electric vehicles tend to be flatter than demand curves for gasoline vehicles, equilibrium markups tend to be higher for gasoline vehicles than for hybrid and electric vehicles. In the no-policy scenario, for example, the average markup for gasoline vehicles is about 30 percent higher than for other

vehicles. Consequently, because the status quo policy increases market shares of hybrid and electric vehicles, which have lower markups than gasoline vehicles, manufacturer profits decrease. In other words, the policy exacerbates pre-existing distortions caused by market power and differential average markups across fuel types (note that the policies have small effects on average equilibrium markups of each fuel type).

The next two columns after the status quo show the results for the sales tax and tariff reductions in isolation. The third column uses the same sales tax as the status quo and the same (higher) tariff in the no-policy baseline. Abstracting for the moment from pre-existing market distortions caused by market power, we expect the two policies in isolation to have qualitatively similar results to one another: by reducing distortionary taxes, the policies should increase welfare and reduce emissions. However, although both policies increase consumer welfare, they reduce profits. Profits decrease for the same reason as the status quo scenario discussed above: lower taxes or tariffs encourage consumers to purchase electric and hybrid vehicles, which tend to have lower markups than gasoline vehicles. The total welfare changes are slightly positive for the sales tax reduction and negative for the tariff reduction.

The rightmost column in Table 8 reports results from simulating the proposed carbon tax. This policy increases overall taxes on consumers and manufacturers relative to the no-policy scenario. The higher taxes create deadweight loss, thus reducing consumer and manufacturer welfare before the tax revenues are reimbursed to the consumers. However, as fiscal revenues increase, the total welfare change is positive (a negative fiscal cost indicates that revenue increases).

Table 9 reports the emissions and cost-effectiveness of the policies, with the columns organized in the same order as in Table 8. We define the fiscal cost-effectiveness of a policy as the decrease in government revenue divided by the emissions reduction, compared to the baseline scenario in the first column. Emissions reductions were achieved at a fiscal cost of \$353 per ton of carbon dioxide reduction. This appears to be the same order of magnitude as Sheldon and Dua (2020) estimate for China.

The welfare cost per ton of carbon dioxide abated is the reduction in consumer and producer welfare divided by the emissions change, comparing the policies with lower taxes or tariffs against the baseline. The welfare cost per ton of carbon dioxide of the status quo policies is

\$40.¹⁹ Because this value measures the private cost to consumers and producers in the market, it should be compared to the social benefit of the lower emissions. Intragency Working Group (2021) provides a preliminary estimate of social benefits equal to about \$47 per ton of carbon dioxide. Van den Bremer and Van der Ploeg (2021) report higher estimates after adjusting for climate and economic risk, although their estimate is generally lower than our estimated welfare costs.

Table 9: Emissions and cost-effectiveness

Variable	No Policy (level)	Current Policy (diff)	Sales tax reduction only (diff)	Tariff reduction only (diff)	Carbon tax (diff)
Panel A: Year 2019					
Lifetime CO ₂ emissions (thousand tons)	3416.8	-18.2	-3.0	-9.0	-59.6
Fiscal cost (USD) per ton of CO ₂	0.0	353.3	140.9	247.3	106.7
Welfare cost (USD) per ton of CO ₂	0.0	39.6	-30.8	76.1	-497.9
Panel B: Year 2020					
Lifetime CO ₂ emissions (thousand tons)	2126.0	-18.4	-3.3	-9.1	-40.6
Fiscal cost (USD) per ton of CO ₂	0.0	509.2	307.9	449.3	-740.6
Welfare cost (USD) per ton of CO ₂	0.0	47.8	135.8	265.7	-486.1

Note: This table shows the counterfactual simulations of emissions and cost-effectiveness for the five scenarios in 2019 and 2020. The "No Policy" scenario's calculations are in levels. All other scenarios' calculations are increments from the "No Policy" scenario. The Lifetime CO₂ emissions are computed by multiplying the emissions produced per vehicle times the average mileage driven per year in Colombia times the expected lifetime of a vehicle. We assume that the average mileage driven in Colombia is 12 thousand miles, while a vehicle's lifetime is ten years. The "Fiscal cost per ton of CO₂" is computed by dividing the fiscal cost by the difference in lifetime emissions in each scenario. The "Welfare cost per ton of CO₂" results from dividing the difference in total welfare by the difference in lifetime emissions in each scenario.

Panel B in Tables 8 and 9 report results using the 2020 market for the simulations. Qualitatively, the results are similar to the 2019 results: the status quo has high fiscal costs and welfare costs that are comparable to global climate benefits, the sales tax reduction has lower average fiscal and welfare costs, and the carbon tax proposal has lower welfare costs than the sales tax or tariff policies. An important difference between the 2019 and 2020 results is that the average costs of the policies tend to be larger in 2020. Much of that difference is explained by the fact that

¹⁹ This estimate is based on assumption that carbon emissions from electric cars is zero. If we account for emissions from electricity generation in the cost of the policy, the welfare cost per ton of carbon dioxide increases to \$63 (see Table A.1 in Appendix).

hybrids in 2020 have higher sales-weighted average emissions than in 2019, causing the policies that favor hybrids over gasoline vehicles to be less effective at reducing emissions in 2020 than in 2019. In other words, replacing a gasoline vehicle with a hybrid vehicle causes a smaller emissions reduction in 2020 than in 2019. The upshot is that the fiscal costs per ton of emissions reduction are roughly twice as high in 2020 than in 2019. This result demonstrates the inefficiency of setting tax policy based on fuel type rather than emissions, which we demonstrate more extensively in the next subsection.

Table 10: Consumer surplus changes by vehicle price quintiles

Variable	No Policy (level)	Sale tax and Tariff reduction(diff)	Sale tax reduction only (diff)	Tariff reduction only (diff)	Carbon tax (diff)
Panel A: Year 2019					
Quintile 1	2601	-0.1	0.0	0.0	-13.0
Quintile 2	2573	3.0	0.9	1.7	-13.0
Quintile 3	2569	6.9	1.8	4.2	-1.5
Quintile 4	3284	23.7	5.9	14.2	6.3
Quintile 5	3939	11.1	3.3	6.8	-5.3
Panel B: Year 2020					
Quintile 1	2417	0.0	0.0	0.0	-7.4
Quintile 2	2503	0.1	0.0	0.1	-11.8
Quintile 3	2459	10.3	2.9	6.0	4.2
Quintile 4	2887	18.3	4.9	11.3	9.2
Quintile 5	3354	5.9	1.9	3.9	-4.5

Note: This table shows results from the counterfactual simulations of consumer surplus from different policies sorted by vehicles price quintiles. Column 1 shows consumer surplus in levels for the no policy scenario. Columns 2-5 show the difference in consumer surplus from alternative policies to the no policy scenario.

Finally, we are interested in assessing the distributional effects of the three policy scenarios. We compute quintiles of the retail price distribution in 2019 or 2020 and assign each vehicle to the corresponding quintile as a proxy for the unobserved consumers' disposable income. Table 10 shows how changes in consumer surplus vary by policy and vehicle price. The first column reports the level of consumer surplus by quintile and year, and the remaining columns report changes in consumer surplus relative to the no-policy case. Reducing the sales tax and tariff for hybrid and electric vehicles increases consumer surplus in the upper quintiles more than the

lower quintiles, indicating that the policies are regressive. This is because hybrid and electric vehicles are typically more expensive than gasoline cars, and a large share of these vehicles belong to upper-price quintiles.

Moreover, consumers who purchase gasoline vehicles despite the policy incentives benefit from the resulting lower prices of the gasoline vehicles. The policies reduce demand for gasoline vehicles, causing manufacturers to reduce the prices of those vehicles. Because vehicles belonging to the same quintile are closer substitutes to one another than are vehicles belonging to different quintiles, the policies reduce demand for gasoline vehicles in the upper quintiles more than in the lower quintiles, where competition from hybrid and electric vehicles is almost nonexistent. Consequently, wealthier consumers buying gasoline vehicles in the upper quintiles benefit more than consumers buying gasoline vehicles in the lower quintiles.

The carbon tax raises prices of gasoline vehicles, lowering consumer surplus in the lower quintiles but moderately increasing consumer surplus in the upper quintiles because those consumers benefit more from the decrease in relative prices of hybrid and electric cars.

4.3 Comparison of Policies While Controlling for Fiscal Costs

The baseline and four policy scenarios reported in Tables 8 and 9 are useful for comparing the effects that the sales tax and import tax have had on hybrid and electric vehicle sales and welfare. However, the fiscal costs of the policies differ from one another, making it difficult to compare their efficiency against one another. Such a comparison is important for policy makers considering whether to make further changes to the sales and import taxes.

To facilitate this comparison, we compare sales tax and tariff scenarios that have the same fiscal costs as one another. Column 1 of Tables 11-14 repeats the scenario from Table 8 with the lower sales tax compared with column 2, which shows the scenario with the same fiscal cost as column 1 except that it includes a lower import tariff rather than a lower sales tax. Setting the import tariff to 22 percent yields the same fiscal cost as the sales tax scenario in column 1 (recall that the actual tariff for these vehicles is zero). A comparison of these two scenarios shows that in 2019, the sales tax causes greater increases in electric and hybrid market shares.

Table 11: Welfare results for policies controlling for fiscal costs

Variable	Sales tax reduction only (diff)	Tariff reduction only (diff)	Proposed carbon tax (diff)
Panel A: Year 2019			
Electric vehicle market share	0.06%	0.05%	0.51%
Hybrid vehicle market share	0.08%	0.02%	0.40%
Average consumer surplus (USD per consumer)	5.2	-8.9	0.0
Average profit (USD per vehicle)	-0.5	21.5	-32.2
Total Consumers Surplus (millions USD)	0.6	-1.2	0.7
Total profit (millions USD per market)	-0.1	2.6	-3.7
Fiscal cost (million USD)	0.4	0.4	0.4
Total Welfare (million USD per market)	0.1	1.0	-3.5
Panel B: Year 2020			
Electric vehicle market share	0.07%	0.07%	0.56%
Hybrid vehicle market share	0.41%	0.23%	2.26%
Average consumer surplus (USD per consumer)	9.6	-2.5	-1.2
Average profit (USD per vehicle)	-2.1	23.1	-85.1
Total Consumers Surplus (millions USD)	0.7	-0.1	0.4
Total profit (millions USD per market)	-0.2	1.9	-6.5
Fiscal cost (million USD)	1.0	1.0	1.0
Total Welfare (million USD per market)	-0.4	0.8	-7.2

Note: This table shows the results of the counterfactual simulations of market shares for electric and hybrid vehicles and welfare measures across scenarios, keeping the fiscal cost in all three scenarios at the level of the "Sales tax reduction only" scenario. All calculations are shown as increments from the "No Policy" scenario. "Average consumer surplus" and the "Average profit per vehicle" are the annual averages weighted by the number of vehicle units sold. "Total consumer surplus," "Total producer surplus," and "Fiscal Cost" are calculated annually. "Total Welfare" is the sum of "Total consumers surplus" and "Total producer surplus" minus the "Fiscal cost."

Although the tariff reduction is less effective in achieving higher electric and hybrid vehicles uptake, it reaches higher total welfare than sales tax reduction. This result comes from two opposing effects: the lower import tariffs reduce consumer surplus and increase profits more than the sales tax (see Table 11). Because the second effect is larger, overall, reducing tariffs causes private welfare to increase. The second effect is more significant mainly because the tariff increases the average markup of gasoline vehicles. In other words, the import tariff causes relatively more substitution of consumers away from gasoline vehicles with low markups, which increases the average markup of the remaining gasoline vehicles.

The third column in Tables 11-14 reports results for a carbon tax calibrated to have the same fiscal costs as the first two policies in the tables. To ensure that fiscal costs are constant across three scenarios, in this simulation, we analyze the portion of the carbon tax that depends on the vehicle's emissions rate.²⁰ This scenario includes a reduced sales tax and import tariffs for electric and hybrid vehicles.

Table 12: Welfare results for policies controlling for fiscal costs assuming perfect competition

Variable	Sale tax reduction only (diff)	Tariff reduction only (diff)	carbon tax (diff)
Panel A: Year 2019			
Electric vehicle market share	0.06%	0.06%	0.52%
Hybrid vehicle market share	0.08%	0.07%	0.40%
Average consumer surplus (USD per consumer)	5.3	5.1	-49.1
Average profit (USD per vehicle)	0	0	0
Total Consumers Surplus (millions USD)	0.7	0.6	-1.4
Total profit (millions USD per market)	0	0	0
Fiscal cost (million USD)	0.1	0.1	0.1
Total Welfare (million USD per market)	0.6	0.5	-1.5
Panel B: Year 2020			
Electric vehicle market share	0.07%	0.1%	0.54%
Hybrid vehicle market share	0.41%	0.4%	2.20%
Average consumer surplus (USD per consumer)	10.4	10.1	-70.6
Average profit (USD per vehicle)	0	0	0
Total Consumers Surplus (millions USD)	0.9	0.8	-1.9
Total profit (millions USD per market)	0	0	0
Fiscal cost (million USD)	0.7	0.7	0.7
Total Welfare (million USD per market)	0.2	0.1	-2.6

Note: This table shows the results of the counterfactual simulations of market shares for electric and hybrid vehicles and welfare measures across scenarios, keeping the fiscal cost in all three scenarios at the level of the "Sales tax reduction only" scenario. All calculations are shown as increments from the "No Policy" scenario. "Average consumer surplus" and the "Average profit per vehicle" are the annual averages weighted by the number of vehicle units sold. "Total consumer surplus," "Total producer surplus," and "Fiscal Cost" are calculated annually. "Total Welfare" is the sum of "Total consumers surplus" and "Total producer surplus" minus the "Fiscal cost."

The carbon tax causes much larger increases in market shares of electric vehicles and hybrids than either the sales tax or import tariff reduction. Surprisingly, the carbon tax results in much

²⁰ As we explain in section 2.3, the proposed carbon tax has two components, one related to vehicle purchase price and another one related to vehicle emissions. To avoid multiple solutions, the simulation that holds the fiscal cost constant across the scenarios needs to hold one of these components fixed.

lower welfare than the other policies. As Table 11 shows, the lower profits are the main reason the carbon tax reduces private welfare. The primary explanation for this result is similar to the welfare comparisons in the previous subsection: the carbon tax causes a relatively large amount of substitution away from gasoline vehicles. Because these vehicles have high markups, manufacturer profits decrease.

To illustrate the role of market power more clearly, Table 12 reports results analogous to those in Table 11, except that we assume the market is perfectly competitive. To simulate the perfectly competitive market equilibrium, we re-estimate consumer demand parameters assuming that all vehicles are priced at marginal costs. We simulate the equilibriums under the same policy assumptions and report cost-effectiveness and emissions in Table 11.

Table 13: Consumer surplus changes by vehicle price quintiles

Variable	Sale tax reduction only (diff)	Tariff reduction only (diff)	carbon tax (diff)
Panel A: Year 2019			
Quintile 1	0.0	-1.20	-2.00
Quintile 2	0.9	-0.80	0.50
Quintile 3	1.8	0.90	5.60
Quintile 4	5.9	4.20	22.50
Quintile 5	3.3	3.20	10.00
Panel B: Year 2020			
Quintile 1	0.0	-0.90	-2.50
Quintile 2	0.0	-0.50	-3.80
Quintile 3	2.9	1.10	7.10
Quintile 4	4.9	3.00	16.70
Quintile 5	1.9	1.80	4.10

Note: This table shows results from the counterfactual simulations of consumer surplus from different policies sorted by vehicles price quintiles. Columns 2 to 4 show the difference in consumer surplus from alternative policies to the no policy scenario.

Comparing Tables 11 and 12 demonstrates three results. First, reducing the sales tax and tariff increases welfare in both 2019 and 2020. This is because reducing distortionary tax unambiguously increases consumer surplus in a competitive market by reducing deadweight loss caused by the taxation. Second, reducing the sales tax and tariff has identical welfare effects

(accounting for optimization errors of simulations), illustrating the equivalence of taxing producers or consumers in a competitive market. Third, the welfare loss of the carbon tax is greatly diminished after market power distortions are eliminated.

Table 13 shows consumer surplus changes by vehicle price quintile, similarly to Table 10. The patterns in the two tables are similar to one another. Even when controlling for fiscal costs, policies benefit consumers in the upper quintiles more than consumers in the lower quintiles.

Table 14 reports the emissions and cost-effectiveness of the policies, holding fiscal costs constant. To achieve fiscal cost equivalence, we have to lower the multiplier of the emissions rate of the proposed carbon tax by 50 percent relative to the original proposal: from \$14.55 to \$9.7.

Table 14: Emissions and cost-effectiveness for policies controlling for fiscal costs

Variable	Sale tax reduction only (diff)	Tariff reduction only (diff)	Proposed carbon tax (diff)
Panel A: Year 2019			
Lifetime CO ₂ emissions (thousand tons)	-3.0	-3.9	-29.6
Fiscal cost (USD) per ton of CO ₂	140.9	106.7	14.2
Welfare cost (USD) per ton of CO ₂	-30.8	-265.3	118.5
Average emissions electric vehicle	27.0	28.2	22.6
Average emissions hybrid vehicle	93.2	82.3	91.1
Average emissions gasoline vehicle	139.4	139.3	138.9
Panel B: Year 2020			
Lifetime CO ₂ emissions (thousand tons)	-3.3	-1.6	-40.3
Fiscal cost (USD) per ton of CO ₂	307.9	642.6	25.1
Welfare cost (USD) per ton of CO ₂	135.8	-477.4	177.6
Average emissions electric vehicle (level)	34.6	32.0	28.5
Average emissions hybrid vehicle (level)	101.0	100.0	99.6
Average emissions gasoline vehicle (level)	135.0	135.1	133.6

Note: This table shows the emission and cost-effectiveness calculations, keeping the fiscal cost in all three scenarios at the level of the "Sales tax reduction only" scenario. All calculations are shown as increments from the "No Policy" scenario. The Lifetime CO₂ emissions are computed by multiplying the emissions produced per vehicle times the average mileage driven per year in Colombia times the expected lifetime of a vehicle. We assume that the average mileage driven in Colombia is 12 thousand miles, while a vehicle's lifetime is ten years. The "Fiscal cost per ton of CO₂" is computed by dividing the fiscal cost by the difference in lifetime emissions in each scenario. The "Welfare cost per ton of CO₂" results from dividing the difference in total welfare by the difference in lifetime emissions in each scenario.

The purchase and import tax policies are less efficient than the carbon tax in lowering total emissions. Although they distinguish vehicles according to fuel type, they do not differentiate vehicles within a fuel type according to GHG emissions. For example, a Toyota Corolla and an Audi A6 Hybrid face the same differential sales tax relative to gasoline vehicles, even though the Toyota Corolla has 30 percent lower emissions than the Audi A6. The emissions reduction caused by the carbon tax is 7.5-25 times greater than the emissions reductions caused by the sales tax or import tariff policies.²¹ The carbon tax also has a significantly smaller fiscal cost per ton of CO₂.

5. Conclusions

Passenger vehicle markets in developing countries differ from markets in high-income countries, but there is little evidence on the effects of electric vehicle policies in developing countries. This paper is among the first to estimate welfare effects and emissions reductions of electric vehicle policies in a developing country. To our knowledge, it is the first study to consider a developing country other than China. We focus on Colombia because the country has been using the sales tax and import tariffs to promote hybrid and electric vehicles. Colombia is reasonably representative of other middle-income economies in its levels of economic development, market concentration, and availability of charging infrastructure. We provide the first evidence for a middle-income country (excluding China) using high-quality data and an empirically estimated model of the new vehicle market.

We examine existing policies in Colombia, including sales tax and import tariff reductions for hybrid and electric vehicles, and a recently proposed policy that combines a carbon dioxide emissions rate tax and preferential sales taxes and import tariffs (for convenience, we refer to this policy as a carbon tax). Each of these policies is effective at reducing average carbon emissions rates of new vehicles by encouraging consumer substitution to low-emitting vehicles. Among the

²¹ There are two additional inefficiencies of the sales and import taxes relative to a true carbon emissions tax. First, they affect new but not existing vehicles, which could delay scrappage of older gasoline-powered vehicles, similarly to the Gruenspecht effect (Gruenspecht 1982; Jacobsen and van Benthem 2015). Second, because the policies reduce average per-mile fuel costs of new vehicles by increasing market shares of hybrids and plug-ins, the policies could cause consumers to drive more, increasing fuel consumption and emissions (i.e., the rebound effect, see Gillingham, Rapson, and Wagner 2016). Unfortunately, we lack sufficient data to investigate either of these inefficiencies.

current policies, reducing the import tariff has a larger effect on electric vehicle market shares and emissions than reducing the sales tax, but also higher average fiscal and welfare costs. The private welfare costs of both policies are comparable to the social value of the carbon emissions reductions.

The proposed carbon tax causes a larger emissions reduction than existing policies, but it does so at higher welfare costs. Such costs may dampen political support for this policy.

We conduct simulations that recalibrate the policies to hold their fiscal costs constant, ensuring comparability across the policies. The proposed carbon tax causes larger increases in hybrid and electric vehicle market shares and larger emissions reductions than the other policies. However, the carbon tax also has a higher welfare cost because it causes a greater reduction of oligopolists' profits. Reducing import tariffs is the only policy that does not adversely affect profits and has positive private welfare effects.

All three policies disproportionately benefit arguably wealthier consumers of more expensive cars, where the competition between gasoline and electric vehicles is stronger, and price reductions are steeper.

This paper highlights the role of pre-existing distortions caused by market power in explaining the welfare effects of the policies. For example, the carbon tax would likely be the most efficient policy in the absence of these distortions because it taxes vehicles according to emissions rates rather than fuel type, thus encouraging greater within-fuel type substitution. The market distortions are sufficiently large to outweigh this effect and cause the carbon tax to have higher welfare costs than the other policies. In contrast, if we assume perfect competition rather than Bertrand competition, existing policies increase private welfare by reducing distortionary taxes on imports or vehicle purchases.

An important implication of these results is that policies aimed at increasing electric vehicle market shares should be combined with policies aimed at reducing other market distortions. Barwick et al. (2021) reach a similar conclusion about gasoline cars in China.

We note that this analysis comprises the short run and does not include consumer demand and vehicle supply dynamics. For example, if greater short-run electric vehicle sales increase future demand, long-run welfare costs could be lower. Future research could include consumer

dynamics and other policies not considered in this paper, such as investments in public charging infrastructure.

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Appendix

Table A.1: Emissions and cost-effectiveness accounting for emissions from electricity generation

Variable	No Policy (level)	Current Policy (diff)	Sales tax reduction only (diff)	Tariff reduction only (diff)	Carbon tax (diff)
Panel A: Year 2019					
Lifetime CO ₂ emissions (thousand tons)	3416.8	-11.4	-2.1	-6.1	-52.6
Fiscal cost (USD) per ton of CO ₂	0.0	562.7	188.1	357.9	-1107.8
Welfare cost (USD) per ton of CO ₂	0.0	61.5	-47.0	113.9	-564.3
Panel B: Year 2020					
Lifetime CO ₂ emissions (thousand tons)	2126.0	-13.9	-2.7	-7.1	-36.1
Fiscal cost (USD) per ton of CO ₂	0.0	671.3	374.4	580.6	-833.6
Welfare cost (USD) per ton of CO ₂	0.0	65.0	149.7	339.8	-545.6

Note: This table shows the counterfactual simulations of emissions and cost-effectiveness for the five scenarios in 2019 and 2020, including emissions coming from electricity generation. The "No Policy" scenario's calculations are in levels. All other scenarios' calculations are increments from the "No Policy" scenario. The Lifetime CO₂ emissions are computed by multiplying the emissions produced per vehicle times the average mileage driven per year in Colombia times the expected lifetime of a vehicle. We assume that the average mileage driven in Colombia is 12 thousand miles, while a vehicle's lifetime is ten years. The "Fiscal cost per ton of CO₂" is computed by dividing the fiscal cost by the difference in lifetime emissions in each scenario. The "Welfare cost per ton of CO₂" results from dividing the difference in total welfare by the difference in lifetime emissions in each scenario. Emissions from electricity generation are calculated based on International Energy Agency data for Colombia's electricity generation mix in 2019 as 211.09 t/GWh.

