Transportation Research Part D 89 (2020) 102643

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Fuel price elasticities of market shares of alternative fuel vehicles in Brazil

Thiago Luis Felipe Brito [a,*], Towhidul Islam [b], Dominique Mouette [a], Nigel Meade [c], Edmilson Moutinho dos Santos [d]

[a] School of Arts, Science, and Humanities (EACH), Universidade de São Paulo, Rua Arlindo Béttio, 1000 - Vila Guaraciaba, São Paulo, SP 03828-000, Brazil
[b] Department of Marketing and Consumer Studies, University of Guelph, 50 Stone Road East, Guelph, ON N1G 2W1, Canada
[c] Business School, Imperial College London, Exhibition Road, London SW7 2AZ, UK
[d] Institute of Energy and Environment (IEE), Universidade de São Paulo, Av. Prof. Luciano Gualberto, 1289 - Cidade Universitaria, São Paulo, SP 05508-900, Brazil

ARTICLE INFO

Keywords:
Ethanol
Flex vehicles
Market-share
Fuel price elasticity
AFV

ABSTRACT

The Brazilian Alcohol Program promotes ethanol as an alternative fuel to gasoline. Policymakers want to know the effect of relative fuel prices on demand for gasoline-fuelled and alternative fuel vehicles (AFVs). Considering vehicle engines dedicated to gasoline, ethanol or flex in the Brazilian market, we use market share models to estimate fuel price market share elasticities, both own and cross effects for each technology. In the first phase, when gasoline and ethanol are the only competing technologies, we find that variations in price profoundly impact the market share of new vehicles. The second phase shows how the efficiency of flex engines, reflected by the car cost per kilometre, significantly contributes to the widespread acceptance of this technology. The near-zero elasticities indicate that the market share of flex vehicles is hedged against price fluctuation. The study provides useful suggestions to help policymakers accelerate the socio-technological transition towards renewable and cleaner energy.

1. Introduction

Currently, the Intergovernmental Panel on Climate Change (IPCC) scenarios (IPCC, 2018) indicates the need for a drastic reduction in net CO_2 anthropogenic emissions to limit global warming to 1.5 °C. The goal is a 45% worldwide reduction in emissions by 2030 (compared to 2010 levels) and to achieve net-zero emissions by 2050. To reach this goal, a set of policies and market actions to promote the necessary technologies and social change is required. In addition, concerns about air quality have focused attention on motorised transportation in developing countries. Fouquet (2016) found that, at low economic levels, energy consumption is highly elastic, but becomes less responsive as a country develops.

For this reason, it is important to ensure that the economies of developing countries do not become reliant on inefficient energy models. Besides, developed countries have a responsibility to promote the replacement of their fossil fuel-based fleets with alternative fuel vehicles (AFV), such as biofuels, hybrid and electric vehicles. In Europe, 96% of the passenger cars use gasoline or diesel oil (ACEA, 2018); in the United States, the comparable figure is 84% (EIA, 2019).

* Corresponding author.
E-mail address: thiagobrito@usp.br (T.L.F. Brito).

https://doi.org/10.1016/j.trd.2020.102643

Available online 23 November 2020

Due to the higher price of AFVs, market forces are insufficient to drive their diffusion sufficiently rapidly. Thus, governments have used a range of incentives to encourage the adoption of cleaner fuel technologies. Overall, studies have shown that policy instruments ranging from fuel tax, vehicle subsidy and penalties, have a positive impact on increasing AFV sales (El Hachem and De Giovanni, 2019). For example, in Canada, taxes and rebates based on fuel economy and carbon price are applied to the consumption of fossil fuel (Rivers and Schaufele, 2017). In 2005, using an alternative approach, the US Federal Government offered a $2000 tax reduction for all qualifying hybrids (Diamond, 2009).

The notable example we focus on here is the Brazilian Alcohol Program, which promotes ethanol as an alternative liquid fuel to gasoline. Although not created to address environmental issues, the program eventually became part of the country's strategy to reduce fossil fuel use in transport. At different stages of the program, ethanol and flex[1] cars have benefited from several incentives to compete against gasoline vehicles.

The success of these incentives largely depends on how the prices of gasoline and other fuels respond to their introduction. Löfgren and Hammar (2000) shows that in many countries, due to a lack of incentives and information, the use of unleaded gasoline was inelastic with respect to the adoption of cars equipped with catalytic converters. Rising energy prices and the implementation of mandatory emission standards encourage the development of energy saving technologies, see Matas et al. (2017). Policymakers need reliable fuel price elasticities to estimate the effect of their incentives on consumer choice between fuel-efficient cars and gasoline cars. Havranek et al. (2012) emphasise the importance of knowing the elasticity of prices to a government's energy security policy and, in the presence of gasoline price inelasticity, knowing the effectiveness of taxes in reducing the emission of greenhouse gases.

Policies related to meeting market share targets and tighter emissions standards are more effective if they subsidise vehicle acquisition, see (Melton et al., 2020). Li et al. (2013) concluded that consumers primarily consider energy security, the quality of the environment and the availability of alternative fuels when buying AFV. Choi and Koo (2019) found that Korean consumers tend to postpone the purchase of electric vehicles more than the purchase of conventional vehicles, but this timing is highly sensitive to incentive policies.

The literature findings on the own-price effect of gasoline vary from inelastic (Havranek et al., 2012) to elastic in OECD countries (Graham and Glaister, 2002). Several studies on the impact of the price of gasoline on the market shares of fuel-efficient cars include analyses for electric cars (Noori and Tatari, 2016) and hybrid cars (Diamond, 2009). These studies modelled the market share of a particular brand without accounting for substitution effects. In a study on the market shares of applications, such as space heating in Nordic countries, where multiple renewable technologies are available, Fazeli et al. (2016) concluded that a simultaneous modelling approach was more effective as it captured substitution effects.

Two studies (Burke and Nishitateno, 2013; Klier and Linn, 2013) estimate the cross-effect of gasoline price on demand for fuel-efficient cars; however, the investigations focused on a single technology, either gasoline or fuel-efficiency. In order to address this gap in the literature, we use the advances in market share modelling to simultaneously estimate the fuel price elasticity of the market share of AFVs, both own and cross effects, of each technology while considering substitution effects. We analyse the transitions of fuel price elasticities through the evolution of the Brazilian vehicle market, whereby environmentally friendly ethanol competes with gasoline. Initially, vehicles dedicated to each fuel were necessary; later, the introduction of flex technology allowed one engine to use either fuel.

The paper is structured as follows. Section 2 is a literature review of fuel price elasticities and approaches to modelling the adoption of AFVs; a summary of the development of the Brazilian Alcohol Program is also included. Section 3 describes our data sources and the model used to estimate the market share elasticity of the three technologies to fuel prices. In Section 4, we present and discuss the implications of our results. Section 5 presents our general conclusions.

2. Review of the literature

The market success of AFV, along with the decline of fossil fuel consumption, depends on a balance of technology and design improvements in addition to consumer preferences (Sprei et al., 2008). Moreover, spatial and demographic factors may also affect the likelihood of adopting an AFV (Liu et al., 2019).

We discuss fuel elasticity in the energy and transport literature and give a brief historical summary of ethanol and flex technologies in Brazil – for a complete overview, see (Coelho et al., 2006; Goldemberg et al., 2004; Moreira and Goldemberg, 1999; Moutinho dos Santos and Parente, 2006; Rodríguez-Morales, 2018; Silveira and Johnson, 2016). We then discuss our choice of models to investigate the market share elasticities (own and cross) of gasoline prices and prices of renewable fuels, ethanol and flex.

2.1. Fuel price elasticities

Studies show that policy interventions designed to affect the final price of fuel to consumers also have an impact on the market share of AFVs. Endo (2007) shows that severe carbon (CO_2) taxes on conventional gasoline-powered cars would be required to increase the market share of hydrogen fuel-cell vehicles in Japan. Klier and Linn (2015) found that CO_2 charges do affect vehicle registration in some European countries to the advantage of cleaner technologies. Shafiei et al. (2014) have shown that a combination of increased fossil fuel prices, carbon taxes and infrastructure investment could halve Iceland's transportation demand by 2050. Diamond (2009)

[1] Flex or flex-fuel vehicles can use gasoline, ethanol or any mixture of both fuels.

studied market share responsiveness of hybrid car demand to gasoline price, income, mileage travelled and government incentives and noted that a 10% increase in gasoline prices would generate a 72–93% increase in the hybrid car market share. More specifically, key findings show strong cross-price elasticity of gasoline prices on hybrid cars (Prius 9.2, Civic 7.2 and Ford Escape 8.9). While modelling the market share of ethanol sales for flex fuel vehicles, Liu and Greene (2014) found short-run own-price elasticity of −3.5 (Minnesota), −2.82 (North Dakota) and −4.5 (Iowa) while long-run own-price elasticities are −6.9 (Minnesota), −5.6 (North Dakota) and −6.6. (Iowa) under the assumption of USD 3.25 per gallon and 5% market share.

The 2008 financial crisis provided an opportunity for researchers to investigate the impact of policy interventions on price responsiveness. In a study of demand for gasoline and diesel in Spain, a more elastic price response was found during the post-crisis period in contrast to an inelastic price response during the pre-crisis period (Bakhat et al., 2017). Also in Spain, Matas et al. (2017) highlighted the important trade-offs made between fuel consumption and other vehicle characteristics and the economy. For example, a 1% increase in GDP increases gasoline and diesel consumption by 0.23% and 0.35%, respectively, despite significant fuel efficiency improvements over the years (30% and 42%, respectively).

All the German transport market segments are found to be highly elastic with respect to circulation taxes and fuel costs (Vance and Mehlin, 2009). In a multi-country study, Burke and Nishitateno (2013) found price inelasticity for gasoline varying between −0.20 to −0.50 and an inelastic cross-price effect for fuel-efficient vehicles. Mabit and Fosgerau (2011) found that, in Denmark, demand for conventional vehicles is quite sensitive when taxes on registration cause price changes (elasticity −2.05), a much higher impact than increased vehicle annual cost and the driving range of electric vehicles (elasticity −0.87 and 0.34, respectively). Irawan et al. (2018) concluded that hybrid cars could reach a 33% market share in Indonesia if their price is competitive with the established technology. They also found that restricting vehicle age and removing the subsidies on fossil fuels would have a small but positive impact on the hybrid cars market share.

2.2. Approaches to modelling AFV market share

Al-Alawi and Bradley (2013) reviewed studies of modelling the adoption of renewable fuel vehicles such as hybrid, plug-in-hybrid and electric. In their review, they mainly reviewed three types of models: agent-based model (ABM), discrete choice models (DCM) and innovation diffusion models for AFVs. ABM was used by Noori and Tatari (2016) for modelling and forecasting regional electric vehicle market shares in USA. Ewing and Sarigöllü (1998) used DCM to study choices between three types of vehicles: electric, fuel-efficient and conventional and ran a choice simulator to generate market shares using stated preference (SP) data. Feng et al. (2013) used an advanced version of DCM to model both choices of vehicles types (e.g. SUV and small cars) and usage (e.g. vehicles miles travelled) using household level revealed preference (RP) data. One of the objectives of their study was to investigate responsiveness of fuel efficiency on car purchases. ABM is used to optimize the utility of different stakeholders and DCM is an experiment-based survey method used to predict vehicle choices at the pre-launch stage or very early stages of vehicle launch. Both ABM and DCM are survey-based methods that use data at individual and household levels, which is outside the scope and objective of this research.

The third modelling approach discussed by Al-Alawi and Bradley (2013) is an innovation diffusion model using time series data, see (Bass, 1969; Islam and Meade, 1996; Meade and Islam, 2006). Norton and Bass (1987) extended the Bass model to model multi-generations of technologies. Lund (2010) used a diffusion model to predict the pace of penetration of new energy technologies (i.e. solar, wind, nuclear etc.), not AFVs, and then converted long-term penetration forecasts into market shares. The focus of the study was long-term predictions whereby a diffusion model is useful. A multi-generation diffusion model is a suitable candidate to model both diffusion and substitution between technologies; for example, see a study on the transitions between technological generations of alternative fuel vehicles (Brito et al., 2019).

Diamond (2009) used market share models for both cross-sectional and time series data to investigate the responsiveness to government incentives and gasoline prices on three hybrid-electric vehicles (i.e. Toyota Prius, Ford Escape and Honda Civic Hybrid) in different states of the US. Using a linear log–log model, in which the logarithm of market shares of hybrid cars are regressed on the logarithm of gasolines prices and other explanatory variables, the coefficients are interpreted as elasticities. The main findings show a strong relationship between gasoline prices and hybrid market shares but a weaker impact of incentive policies. Using Minnesota, USA data from 1997 through 2006, Anderson (2012) estimated a log-linear model to investigate the willingness to pay for the premium of ethanol (E85) relative to gasoline (E10). His findings implied that the own-price elasticity of E85 at an outlet ranged from −4.3 to −5.3 at the price level of USD 3.25 per gallon. Market share models also used in other renewable energy studies, such as penetration of energy-efficient household appliances (Radpour et al., 2017), generation of electricity using renewable sources (Lund, 2010), but fuel price elasticity was not the focus of those studies.

In our methodology section, we will adapt the market share model of Nakanishi and Cooper (1974) and (Cooper and Nakanishi, 1988). This model is based on models of attraction, see (Kotler 1984); it is used for empirical research (Bell et al., 1975) and for assessing strategic implications (Karnani, 1985). These market share attraction models are derived from econometric models of demand, see Naert and Weverbergh (1981). Wedel and Kannan (2016) concluded that these models have better predictive power than a more classic market share specification.

2.3. Ethanol and flex vehicles

The Brazilian Alcohol Program (Pro-Álcool) was created in the late 1970s to protect consumers from oil price shocks by promoting an alternative liquid fuel derived from sugarcane (Moutinho dos Santos and Parente, 2006). The highlight of the program was the launch of a pure ethanol engine in 1979, which was corrosion-resistant and capable of the necessary higher compression ratio (Yu et al., 2010). By the 1980s, the government had begun an incentive policy to both ethanol producers and vehicle manufacturers (Coelho et al., 2006; Moreira and Goldemberg, 1999). Throughout the years, the productivity of sugarcane ethanol has grown substantially, since it became more and more mechanized. From 1979 to 1999, the number of liters per hectare has almost doubled, from 2,300 l/ha to 5,100 l/ha (Moreira and Goldemberg, 1999). Currently, Brazilian sugarcane yields 6,500 L of ethanol per hectare; while its major competitors, USA's corn and Europe's beet yield 4,200 and 5,500 l/ha (Braskem, 2017). Moreover, ethanol fuel was sold tax-free for final consumers, while ethanol vehicles purchase taxes were 5% lower than gasoline vehicles (ANFAVEA, 2018).

However, despite an initial sales success (see market share data in Section 3), ethanol experienced price shocks during the 1990s, due to a production shift away from ethanol to sugar (Puglieri, 2013). At the same time, the government initiated an incentive scheme for cheaper low capacity engine vehicles (popular cars), which could not use ethanol technology. This situation frustrated consumers and led to a decrease in ethanol vehicles sales, followed by an increase in gasoline vehicles sales (ANFAVEA, 2018; Moutinho dos Santos and Parente, 2006).

In the early 2000s, flex technology was introduced and refreshed the ethanol program. This initiative was part of a series of policies including the creation of the National Agency for Petroleum, Natural Gas and Biofuels (ANP). In addition, the liberalisation and commercialisation of electricity produced from sugarcane bagasse (a fibrous by-product of sugar manufacture used as a biofuel) further stimulated sugar cane producers (Puglieri, 2013). Ethanol usage is a crucial component of Brazil's strategy for reducing CO_2 emissions to achieve the Kyoto Protocol target (Moreira et al., 2005). Consequently, three years after its introduction, flex technology dominated the passenger vehicles market, with a market share of over 90%.

When launched, a flex vehicle was less efficient than a vehicle using one of its component fuels. Flex vehicles could run 6.9 km per litre of ethanol and 10.3 km per litre of gasoline, while single fuel vehicles ran 7.5 km and 11.2 km, respectively (CETESB, 2017). Although the efficiency of flex technology has increased by 40%, a litre of ethanol has about 70% of the gasoline energy content, and the final price for consumers must reflect this variation; i.e., consumer will save money only if the ethanol price is least 30% lower than gasoline (Coelho et al., 2006). Since the introduction of flex vehicles in Brazil, ethanol and gasoline prices fluctuate about a long-run equilibrium level (Du and Carriquiry, 2013). However, price dynamics are influenced by supply and demand factors, such as sugar price, ethanol exports and the increasing proportion of flex vehicles in the fleet.

The use of biofuels in the fleet has contributed to achieving the national emission standard program goals over the last decades, which reduced pollutants such as carbon oxides (CO), hydrocarbons (HC) and nitrogen oxides (NO_x) by 50% (Szwarcfiter et al., 2005). Rodríguez-Morales (2018) argues that the transition to liquid bioenergy (ethanol and biodiesel) in Brazil is a consequence of the historical evolution of the relationship between the agro-industry and the Brazilian government, involving both convergence and conflict. Silveira and Johnson (2016) identify important lessons from the Brazilian transition to biomass including coordination among private and public stakeholders, the definition of goals and policies to attract investments, the creation of the market and the required infrastructure, and efforts to balance supply and demand. They concluded that technological innovation would be insufficient, without the alignment of the dominant interest groups.

3. Data and methodology

First, we describe the data and secondly, the model we use to estimate own and cross price effects.

3.1. Data description

Our analysis is divided into two phases —Phase 1 covers 1980 to 2002, when only gasoline and ethanol were available, while Phase 2 covers 2003 to 2017 when the flex-fuel technology started competing for market share. We exclude sales of diesel and electric cars from our study. Diesel vehicles are prohibited in most cities and tend to be used off-road. Electric, including hybrid, cars have a negligible market share, accounting for 0.067% of passenger car sales in 2017.

To calculate the annual market share for each technology, we use vehicle sales data from the Brazilian Automotive Industry Association Yearbook (ANFAVEA, 2018). Registrations are recorded by vehicle type (passenger, light commercial, trucks and buses) and by fuel type. Firstly, we summarize the time series data using two plots. Fig. 1 shows the market shares of passenger vehicles using gasoline, ethanol and flex-fuel technology since 1980.

The annual average price to final consumers for gasoline and ethanol is drawn from the Energy Research Office (EPE, 2018) and converted into 2018 USD (USBLS, 2018). Each technology efficiency values is provided by the State of São Paulo Environmental Company (CETESB, 2017). We estimate the cost of kilometre driven (in USD/km) by Eq. (1).

$$C_{ge} = P_{ge} \times F_{gef} \tag{1}$$

where:

C_{ge} is the estimated cost (in USD) per kilometre for either gasoline or ethanol;

P_{ge} is the gasoline or ethanol price per litre (in current USD);

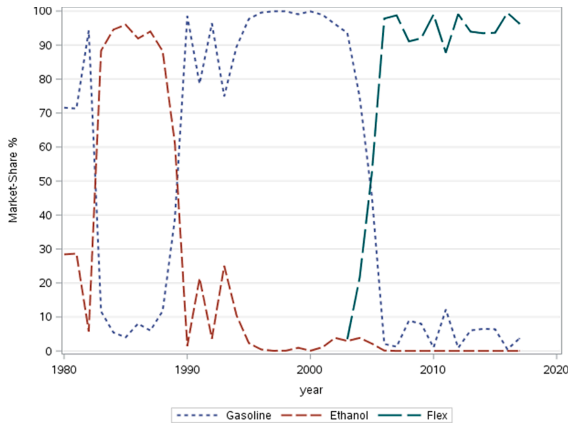

Fig. 1. Yearly market share for vehicle technologies.

F_{gef} is the gasoline, ethanol and flex vehicle fuel efficiency (in km/litre)

The estimated cost per kilometre[2] for either dedicated gasoline and ethanol vehicles and flex vehicles is shown in Fig. 2. Since the cost per km for flex vehicles depends on the fuel used, we take the lower cost. The ethanol price shocks during the 1990s, mentioned in Section 0, are evident; during that decade, ethanol car owners spent more per kilometre than gasoline car owners. Flex has been cheaper than gasoline since 2004, due to its flexibility in using the cheaper fuel.

Secondly, we summarize the distribution of the market share and price data in Phase 1 and Phase 2 using box plots in Fig. 3. The box plot for market shares shows both gasoline and ethanol cars have dominated Phase 1 at different times as the boxes overlap. In Phase 2, we see the withdrawal of ethanol cars from the market and the eventual dominance of flex cars. In Phase 1, the cost per km driven has a similar distribution for both gasoline and ethanol, apart from three years of high gasoline prices. In Phase 2, the cost is lower for flex than gasoline.

3.2. Model description

To investigate the price responsiveness of multiple AFV market shares (e.g. gasoline, ethanol and flex-fuel), we need a model that can estimate all market shares simultaneously to get own and cross-elasticities. We adapt the market share model of Nakanishi and Cooper (1974) and (Cooper and Nakanishi, 1988). The market share of a firm, brand or technology is assumed to be proportional to its marketing/attraction effort (Cantamessa and Montagna, 2016; Karnani, 1985), for example, how much do price, and other related marketing mix and policy variables contribute to a technology attractiveness (Kotler, 1984). The attraction model for technology is shown in (2).

$$A_i = exp(\alpha_i + \varepsilon_i)\prod\nolimits_{k=1}^{K} f_k(X_{kit})^{\beta_{ki}} \tag{2}$$

and the market share is shown in (3)

$$s_{it} = \frac{A_{it}}{\sum_{j=1}^{m} A_{jt}} \tag{3}$$

where:

s_{it} is the market share of technology i at time t

$A_{it}$is the attractiveness of technology i at time t

m is the number of technologies

X_{kit} is the value of the k^{th} explanatory variable X_k for technology i at time t

K is the number of explanatory variables

f_k is the log-normal transformation of X

α_i is the parameter for the constant influence of technology i

β_{ki} is the parameter for variable k effectiveness on technology i

$\varepsilon_i$is the error term

Competing technologies are differentiated by their capacity to influence their own sales, and by the other technology sales. Our

[2] In Brazil there are two kinds of gasoline:Gasoline A: pure gasoline, which is not available in public stations.Gasoline C: gasoline with 20~25% blend of ethanol.The fuel efficiency and price parameters we used to estimate USD/km is for Gasoline C, thus already accounting for the ethanol content.

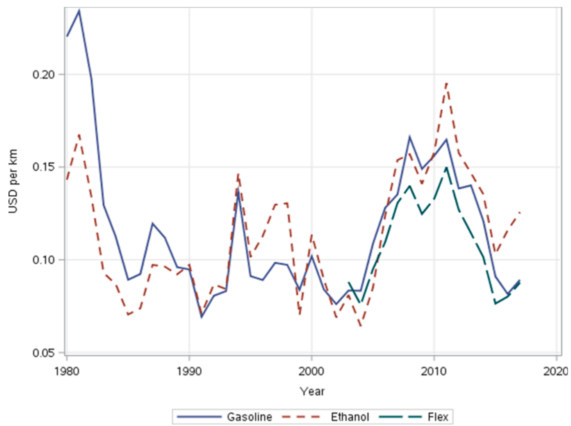

Fig. 2. Fuel cost per kilometre driven (estimated based on CETESB, 2017; EPE, 2018).

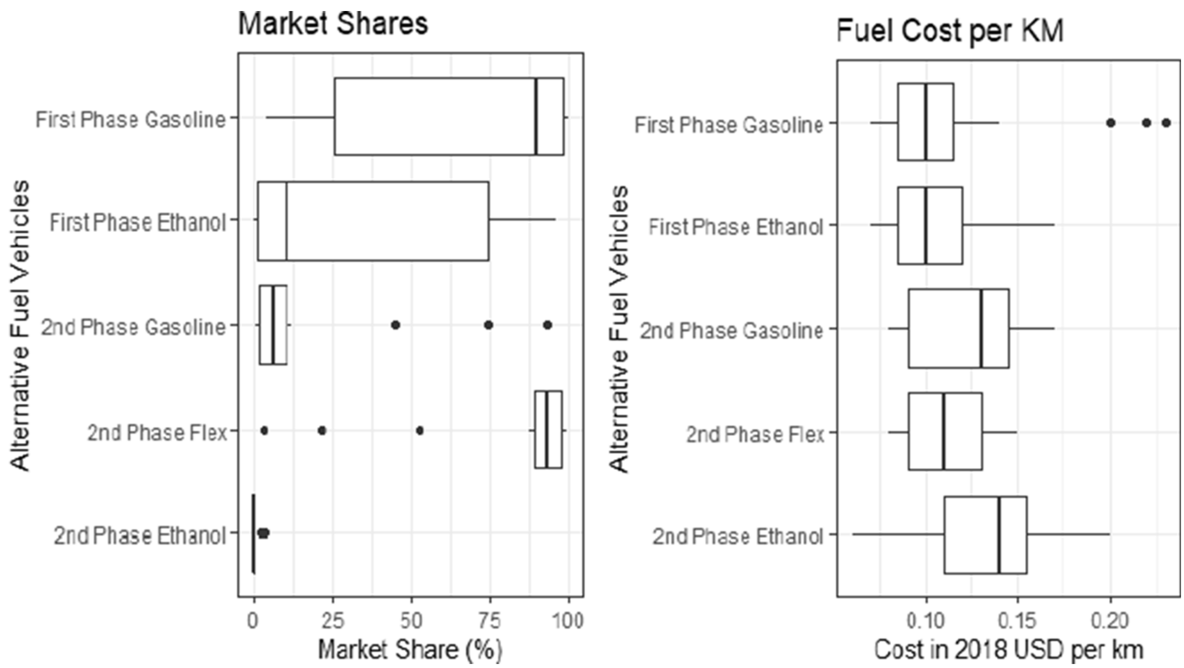

Fig. 3. Box plots of market shares and cost per KM driven at two phases (Phase 1: 1980–2002; Phase 2: 2003–2017).

model considers the impact of these cross-effects – e.g. how does a change in gasoline price affect the market shares of ethanol and flex vehicles? Multiplicative Competitive Interaction (MCI) and Multinomial Logit (MNL) are two widely used market share models (Cooper and Nakanishi, 1989) used to capture these effects. Given the similarity of their findings, we focus on the MCI model and results and omit the MNL formulation for parsimony. In the MCI model, the predicted market share of a technology is defined by the product of its marketing variables, weighted by their respective effectiveness, as shown in (4).

$$\log\left(\frac{s_{it}}{s_t}\right) = (\alpha_i - \overline{\alpha}) + \sum_{k=1}^{K} \beta_{kij} \log\left(\frac{x_{kit}}{x_{kt}}\right) + \epsilon_i \tag{4}$$

where:

s_t is the geometric mean of s_{it} at in period t

$\overline{\alpha}$ is the arithmetic mean of α_i

$\beta_{kij}$is the parameter for variable k effectiveness of technology i on technology j

x_{k_t} is the geometric mean of the kth explanatory variable at time t

Log-centred transformations of market-share data and fuel prices are used to allow the use of linear-regression techniques to estimate the coefficients of the non-linear model (Cooper and Nakanishi, 2010). From these estimated coefficients, we can calculate the product market share elasticity for a given variable, as shown in (5).

$$e_{s_i} = \beta_{kij} \times (1 - s_{it}) \quad (5)$$

Here, the dependent variables are the yearly market share for gasoline, ethanol and flex passenger cars normalized by the geometric mean of the shares of all technologies at time *t*. The explanatory variables (X_{kit}), normalized by the geometric mean all prices at time *t* reflect the technology cost per kilometre driven of each fuel, as shown in Fig. 2. We used SAS studio regression tool (SAS Institute Inc, 2018) to estimate the coefficients of the models.

4. Results and discussion

We here give details of the MCI model estimates for the data from Phase 1 and from Phase 2. We then compare and discuss the results.

4.1. Fuel price elasticity: gasoline and ethanol cars (1980–2002)

The coefficient estimates from the MCI cross effects model, see (Eq. (4)), for Phase 1 of our study are summarised in Table 1. The parameters are symmetrical because we have only two competing technologies. The R^2 of model fit is 0.68, i.e. the price explains about 68% of the variability of the market share in this period. All the coefficients are highly significant ($p < 0.001$) and their estimates have the expected sign: own-price effects are negative, and cross-price effects are positive.

We calculated own and cross-price elasticities using Eq. (5) and parameter estimates from Table 1. In Fig. 4, we see that the gasoline vehicle market share was sensitive to price from 1983 to 1989, when own-price and cross-ethanol price elasticities reached −5.29 and 7.08, respectively. There were variations in elasticity when the ethanol vehicle market share recovered to 21% and 25% in 1991 and 1993, respectively. After 1995, the gasoline vehicle market-share became highly inelastic for the rest of Phase 1. These results reinforce the idea that the higher the market share of the vehicle, the less sensitive the share is to fuel prices. This inelasticity is partly due to the higher market share that brings motorists greater accessibility and convenience (i.e. refuelling stations) and signals the perception of quality by creating positive network externalities (Hellofs and Jacobson, 1999).

Alves and Bueno (2003) observed that from 1984 to 1999, gasoline price elasticity was inelastic with regard to demand and that cross-elasticity between alcohol and gasoline was positive, as expected, thus making ethanol an incomplete substitute of gasoline. As shown in Fig. 5, the analysis shows that the ethanol vehicle market-share is highly sensitive to price immediately after its launch in the early 1980s. However, once the technology becomes dominant between 1983 and 1988, its elasticity dropped to near zero. As soon as the price of ethanol, relative to gasoline, starts to rise in the early 1990s, the period referred to as the 'Ethanol Shock', elasticity returns to a high level (–7.27), the greater expense of owning an ethanol vehicle results in decline in sales. The own-price elasticity of gasoline, −5.51, is high as compared to the price elasticity of – 1.35 for OECD countries found in (Graham and Glaister, 2002). The range of cross-price elasticities is comparable to other findings for fuel-efficient hybrid cars (Diamond, 2009).

Despite the shortcomings of the Brazilian Alcohol Program, the final price of ethanol to consumers (at refuelling stations) was becoming more competitive due to reduced production costs (Goldemberg et al., 2004; Witcover and Williams, 2020). This favourable situation led to the introduction of flex-fuel vehicles, as discussed below.

4.2. Fuel price elasticity: gasoline, ethanol and flex cars (2003–2017)

The introduction of flex-fuel technology marks the beginning of Phase 2 of the study. The own and cross-price effects for the three technologies are presented in Table 2. In Phase 2, the share of gasoline was not responsive to the prices of the three fuels. This finding is consistent with (Havranek et al., 2012), in which a zero short-run price elasticity for gasoline in a meta-analysis from 41 studies falls within a confidence interval of price elasticities (−0.96 to 0.08). The own-price effects on market shares are highly significant for both ethanol and flex vehicles. Of 6 cross effects, 4 have the correct positive sign, but only two are significant at 5% (ethanol on flex and flex on ethanol).

Table 1
Parameter estimation for gasoline and ethanol from 1980 to 2002.

Parameters		Parameter estimate	Standard error	t value	p-value
$\alpha_{gasoline}$	Alternative specific constant	0.959	0.241	3.98	<0.001
$\alpha_{ethanol}$	Alternative specific constant	−0.959	0.241	−3.98	<0.001
	Own effects				
β_{gg}	Gasoline	−5.513	1.166	−4.73	<0.001
β_{ee}	Ethanol	−7.383	1.463	−5.05	<0.001
	Cross-effect				
β_{eg}	Ethanol on gasoline	7.383	1.463	5.05	<0.001
β_{ge}	Gasoline on ethanol	5.513	1.166	4.73	<0.001

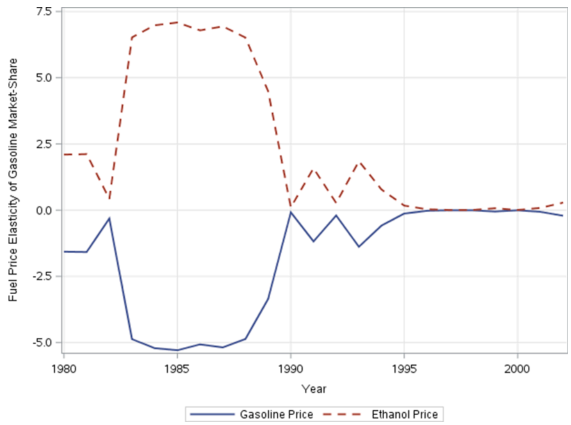

Fig. 4. Fuel price elasticity of gasoline market share (1980–2002).

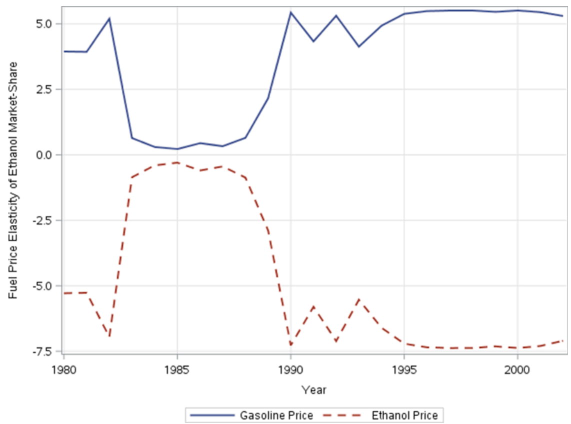

Fig. 5. Fuel price elasticity of the ethanol market share (1980–2002).

Table 2
Parameter estimation for gasoline, ethanol and flex from 2003 to 2017.

Parameter		Parameter estimate	Standard error	t value	p-value
$\alpha_{gasoline}$	Alternative specific constant	1.364	0.208	6.57	<0.001
$\alpha_{ethanol}$	Alternative specific constant	−5.160	0.208	−24.83	<0.001
α_{flex}	Alternative specific constant	3.796	0.208	18.27	<0.001
	Own effect				
β_{gg}	Gasoline	1.982	2.985	0.66	0.511
β_{ee}	Ethanol	−10.514	1.315	−8.00	<0.001
β_{ff}	Flex	−14.074	3.619	−3.89	0.005
	Cross effect				
β_{eg}	Ethanol on gasoline	0.196	1.315	0.15	0.882
β_{fg}	Flex on gasoline	−2.624	3.619	−0.73	0.474
β_{ge}	Gasoline on ethanol	−7.563	2.985	−2.53	0.016
β_{fe}	Flex on ethanol	16.700	3.619	4.61	<0.001
β_{gf}	Gasoline on flex	5.581	2.985	1.87	0.070
β_{ef}	Ethanol on flex	10.317	1.315	7.85	<0.001

In Phase 2, fuel price variables explain 97% (i.e. R^2) of the market-share variability compared to 68% in Phase 1. Fig. 6 shows the extreme and constant elasticities expected for products with low market share; a 1% increase in ethanol price would cause a 10% decrease in the technology market share (calculated using Eq. (5) and parameter estimates from Table 2). As demand for new ethanol vehicles falls, improvements in technological efficiency cease, increasing the cost per kilometre of ethanol car use. By observing the

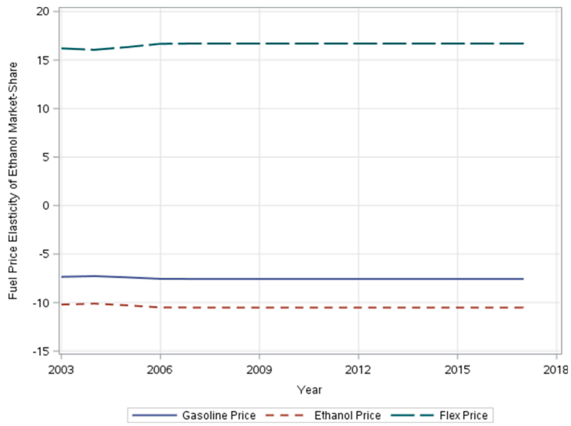

Fig. 6. Fuel price elasticity of the ethanol market share (2003–2017).

flex price cross-elasticity (Fig. 6), the model suggests that if owning a flex car becomes one percent more expensive, the ethanol market share might increase at a higher rate (roughly 16) than its linear elasticity.

Fig. 7 reflects the reduced cost per kilometre of the first flex vehicles models when compared to single fuel ones. Despite being more expensive to refuel in the three years that followed its launch, sales snowballed due to decreases in flex cars fuel costs from 2003 to 2005, as well as increases in gasoline and ethanol fuel cost. This period also marks the moment when flex-vehicle efficiency was improving (by roughly 13% for both fuels) to similar levels their single fuel equivalents. Flex vehicles become inelastic to price as soon as the technology improves and the market share increases.

4.3. Discussion of results

Our results have shown fuel price changes have caused significant variation in the vehicle market share elasticity during Phase 1 (1980–2002). Own-price and cross-price elasticity for both gasoline and ethanol cars behaved as expected in terms of sign. Phase 2 (2003–2017) shows that the cost per kilometre driven of flex-fuel engines significantly contributed to the widespread acceptance of this technology. The near-zero elasticities estimated in our analysis indicate that the market share of flex vehicles is hedged against price fluctuation.

A high crude oil price generates ethanol demand (Debnath et al., 2017). However, in Brazil, the demand for ethanol is more price elastic than gasoline, and both fuels are highly competitive against each other (Rodrigues et al., 2018). A recent study (Rodrigues and Bacchi, 2017) indicates that the demand for gasoline and ethanol in Brazil is inelastic to income and price in the short term, due to the inertia inherent in vehicle ownership. In the longer term, fuel demand is more sensitive to income and less sensitive to price changes. These findings suggest the light fuels market is already consolidated in the country due to the dominance of the flex-fuel technology. Our results complement fuel demand studies, demonstrating that the long-term dominant market share of the flex vehicle technology will maintain the competition between gasoline and ethanol prices.

Our findings might raise some concerns about the refuelling choice of flex car owners. Huse (2018) showed that gasoline is preferred by flex-fuel vehicle drivers in Sweden when in price parity with ethanol. He also found that the ethanol price elasticity is high, while the gasoline price is quite inelastic. Thus, ethanol would need to have a premium price over gasoline to be the preferred fuel. In the United States, ethanol used to be a substitute to gasoline between 1982 and 2005, but since 2006, its consumption has been complementary to the latter because US flex cars cannot use blends higher than E85 (Tenkorang et al., 2015). These studies show that, despite the specific characteristics of the development of the Brazilian ethanol market, different markets might yield similar results to ours.

Moreover, a study by Salvo (2018) found that Brazilian consumers often purchase fuel yielding fewer miles per dollars despite having a flex car. The study demonstrates that consumers need to understand how price differences affect their miles per USD so they can make full use of the vehicle flexibility. This knowledge is essential to ensure that policies promoting alternative technologies and reducing fossil fuel consumptions have the desired impact.

5. Conclusions and policy recommendations

We conducted a market-share analysis of alternative fuel vehicle technologies in Brazil. MCI models were used to estimate own and cross-price elasticities of vehicle market share with respect to fuel price. Our results show small elasticities for the technologies with a large market share. The study of cross-elasticities sheds further light on the effect of the prices of different fuels. When gasoline and ethanol are the only competing technologies, price variations lead to changes in the market share of different vehicle technologies. Aside from the effect of fuel price on market share, there are other relevant aspects of the environment to consider. During the 1980s, there was government support for, and national pride in, ethanol technology. Subsequently, a marked increase in the price of ethanol led to a growing distrust in it, and eventual discontinuation of the technology.

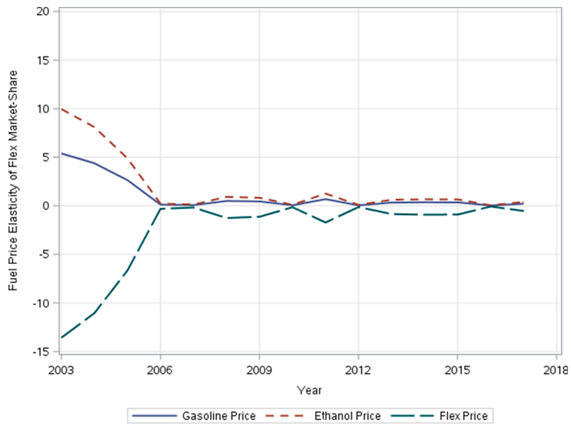

Fig. 7. Fuel price elasticity of flex market share (2003–2017).

For Phase 2 of our study, we show that the reduced cost per kilometre of flex-fuel vehicle technology significantly contributed to the rapid spread and eventual dominant market share of this technology. We further demonstrate that the market share of flex vehicles is hedged against price fluctuation, as shown by the near-zero elasticities obtained by the model.

The policy implications of this study are useful for decision makers seeking to increase the market share of alternative clean fuel technologies at municipal, state or national level. Since the key explanatory variable for our model was price, we recognize that our policy recommendations are limited to this approach and there might be further monetary and non-monetary incentives. The priority is to assure competitive prices for alternative fuel technologies through programs that incentivise the relevant agents. These programs may include the provision of support for producers, credit lines for consumers, non-monetary incentives, such as reductions in, or exemption from, parking and traffic fees.

We also raise a concern about the Brazilian experience with the National Alcohol Program; despite enabling the significant participation of biofuels in the country's transport sector, it now acts as a barrier to the entry of other environmentally beneficial technologies, such as hydrogen or natural gas-fueled vehicles and pure electric or hybrid cars. Future research areas can focus on the recent debates on the limits of Brazilian ethanol expansion (Jaiswal et al., 2019, 2017). Köberle et al. (2019) are not convinced about the ability of ethanol energy to replace heavy duty transportation need such as diesel and noted that the ethanol market could be challenged by the expansion of the electric car market. In turn, Goldemberg (2018) is doubtful about the suitability of electric cars in the Brazilian context and disapproves of a push for electric cars as it might encourage nuclear energy. Further research areas should include investigations on: the competitive dynamics among different renewable energy technologies since experience curve and learning rates drive costs down and increase availability; the potential impact of vehicle fuel policies on the electricity generation mix in the future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We gratefully acknowledge the support of the RCGI – Research Centre for Gas Innovation, hosted by the Universidade de São Paulo (USP) and sponsored by FAPESP – the State of São Paulo Research Foundation (2014/50279-4) and Shell Brasil. We also thank the support from the National Agency for Petroleum, Natural Gas and Biofuels Human Resources Program (PRH-ANP), funded by resources from the investment of oil companies qualified in the R,D&I clauses from ANP Resolution number n° 50/2015 (PRH 33.1 – Related to Call N° 1/2018/PRH-ANP; Grant FINEP/FUSP/USP Ref. 0443/19). This research was conducted in part when Thiago was a visiting doctoral student at the Department of Marketing and Consumer Studies, University of Guelph, Canada. We gratefully acknowledge the research support from the Social Sciences and Humanities Research Council (SSHRC) of Canada, Grant No. 430199.

References

ACEA, 2018. ACEA Report Vehicles in use Europe 2018. European Automobile Manufacturers Association.

Al-Alawi, B.M., Bradley, T.H., 2013. Review of hybrid, plug-in hybrid, and electric vehicle market modeling Studies. Renew. Sustain. Energy Rev. 21, 190–203. https://doi.org/10.1016/j.rser.2012.12.048.

Alves, D.C.O., Bueno, R. de L. da S., 2003. Short-run, long-run and cross elasticities of gasoline demand in Brazil. Energy Econ. 25, 191–199. https://doi.org/10.1016/S0140-9883(02)00108-1.

Anderson, S.T., 2012. The demand for ethanol as a gasoline substitute. J. Environ. Econ. Manage. 63, 151–168. https://doi.org/10.1016/j.jeem.2011.08.002.

ANFAVEA, 2018. Brazilian Automotive Industry Yearbook. Brazilian Automotive Industry Association, São Paulo and Brasilia.

Bakhat, M., Labandeira, X., Labeaga, J.M., López-Otero, X., 2017. Elasticities of transport fuels at times of economic crisis: An empirical analysis for Spain. Energy Econ. 68, 66–80. https://doi.org/10.1016/j.eneco.2017.10.019.

Bass, F., 1969. A new product growth for model consumer durables. Manage. Sci. 15, 215–227. https://doi.org/10.1287/mnsc.15.5.215.

Bell, D.E., Keeney, R.L., Little, J.D.C., 1975. A market share theorem. J. Mark. Res. 12, 136–141.

Braskem, 2017. The Ethanol [WWW Document]. URL http://www.braskem.com/site.aspx/Etanol (accessed 8.4.17).

Brito, T.L.F., Islam, T., Stettler, M., Mouette, D., Meade, N., Moutinho dos Santos, E., 2019. Transitions between technological generations of alternative fuel vehicles in Brazil. Energy Policy 134, 110915. https://doi.org/10.1016/j.enpol.2019.110915.

Burke, P.J., Nishitateno, S., 2013. Gasoline prices, gasoline consumption, and new-vehicle fuel economy: Evidence for a large sample of countries. Energy Econ. 36, 363–370. https://doi.org/10.1016/j.eneco.2012.09.008.

Cantamessa, M., Montagna, F., 2016. Management of Innovation and Product Development: Integrating Business and Technological Perspectives. Springer, Torino, Italy.

CETESB, 2017. Vehicle Emissions in São Paulo State 2016. São Paulo State Environmental Company, São Paulo.

Choi, H., Koo, Y., 2019. Do i have to buy it now? A vehicle replacement model considering strategic consumer behavior. Transp. Res. Part D Transp. Environ. 73, 318–337. https://doi.org/10.1016/j.trd.2019.07.009.

Coelho, S.T., Goldemberg, J., Lucon, O., Guardabassi, P., 2006. Brazilian sugarcane ethanol: lessons learned. Energy Sustain. Dev. 10, 26–39. https://doi.org/10.1016/S0973-0826(08)60529-3.

Cooper, L.G., Nakanishi, M., 2010. Market-share analysis: evaluating competitive marketing effectiveness. Kluwer Academic Publishers, Philadelphia, PA.

Cooper, L.G., Nakanishi, M., 1988. Market-share analysis: evaluating competitive marketing effectiveness. Kluwer Academic Publishers, Philadelphia, PA.

Debnath, D., Whistance, J., Thompson, W., Binfield, J., 2017. Complement or substitute: Ethanol's uncertain relationship with gasoline under alternative petroleum price and policy scenarios. Appl. Energy 191, 385–397. https://doi.org/10.1016/j.apenergy.2017.01.028.

Diamond, D., 2009. The impact of government incentives for hybrid-electric vehicles: Evidence from US states. Energy Policy 37, 972–983. https://doi.org/10.1016/j.enpol.2008.09.094.

Du, X., Carriquiry, M.a., 2013. Flex-fuel vehicle adoption and dynamics of ethanol prices: Lessons from Brazil. Energy Policy 59, 507–512. https://doi.org/10.1016/j.enpol.2013.04.008.

EIA, 2019. Annual Energy Outlook 2019 with projections to 2050. U. S. Energy Information Administration, Washington, D. C. https://doi.org/DOE/EIA-0383(2012) U.S.

El Hachem, W., De Giovanni, P., 2019. Accelerating the transition to alternative fuel vehicles through a Distributive Justice perspective. Transp. Res. Part D Transp. Environ. 75, 72–86. https://doi.org/10.1016/j.trd.2019.08.020.

Endo, E., 2007. Market penetration analysis of fuel cell vehicles in Japan by using the energy system model MARKAL. Int. J. Hydrogen Energy 32, 1347–1354. https://doi.org/10.1016/j.ijhydene.2006.10.015.

EPE, 2018. Brazilian National Energy Balance - Historical Series. Energy Research Office, Rio de Janeiro and Brasilia.

Ewing, G.O., Sarigöllü, E., 1998. Car fuel-type choice under travel demand management and economic incentives. Transp. Res. Part D Transp. Environ. 3, 429–444. https://doi.org/10.1016/S1361-9209(98)00019-4.

Fazeli, R., Davidsdottir, B., Hlynur, J., 2016. Residential energy demand for space heating in the Nordic countries: Accounting for interfuel substitution. Renew. Sustain. Energy Rev. 57, 1210–1226.

Feng, Y., Fullerton, D., Gan, L., 2013. Vehicle choices, miles driven, and pollution policies. J. Regul. Econ. 44, 4–29. https://doi.org/10.1007/s11149-013-9221-z.

Fouquet, R., 2016. Lessons from energy history for climate policy: Technological change, demand and economic development. Energy Res. Soc. Sci. 22, 79–93. https://doi.org/10.1016/j.erss.2016.09.001.

Goldemberg, J., 2018. Electric Cars or Ethanol? by José Goldemberg [WWW Document]. Fecomercio SP. https://www.fecomercio.com.br/noticia/carros-eletricos-ou-etanol-por-jose-goldemberg (accessed 7.7.20).

Goldemberg, J., Coelho, S.T., Nastari, P.M., Lucon, O., 2004. Ethanol learning curve - The Brazilian experience. Biomass Bioenergy 26, 301–304. https://doi.org/10.1016/S0961-9534(03)00125-9.

Graham, D.J., Glaister, S., 2002. The demand for automobile fuel: A survey of elasticities. J. Transp. Econ. Policy 36, 1–26.

Havranek, T., Irsova, Z., Janda, K., 2012. Demand for gasoline is more price-inelastic than commonly thought. Energy Econ. 34, 201–207. https://doi.org/10.1016/j.eneco.2011.09.003.

Hellofs, L.L., Jacobson, R., 1999. Market share and customers' perceptions of quality: when can firms grow their way to higher versus lower quality? J. Mark. 63, 16. https://doi.org/10.2307/1251998.

Huse, C., 2018. Fuel choice and fuel demand elasticities in markets with flex-fuel vehicles. Nat. Energy 3, 582–588. https://doi.org/10.1038/s41560-018-0175-3.

Irawan, M.Z., Belgiawan, P.F., Widyaparaga, A., Deendarlianto, Budiman, A., Muthohar, I., Sopha, B.M., 2018. A market share analysis for hybrid cars in Indonesia. Case Stud. Transp. Policy 6, 336–341. https://doi.org/10.1016/j.cstp.2017.09.003.

Islam, T., Meade, N., 1996. Forecasting the development of the market for business telephones in the UK. J. Oper. Res. Soc. 47, 906–918. https://doi.org/10.1057/jors.1996.116.

Jaiswal, D., De Souza, A.P., Larsen, S., Lebauer, D.S., Miguez, F.E., Sparovek, G., Bollero, G., Buckeridge, M.S., Long, S.P., 2017. Brazilian sugarcane ethanol as an expandable green alternative to crude oil use. Nat. Clim. Chang. 7, 788–792. https://doi.org/10.1038/nclimate3410.

Jaiswal, D., De Souza, A.P., Larsen, S., LeBauer, D.S., Miguez, F.E., Sparovek, G., Bollero, G., Buckeridge, M.S., Long, S.P., 2019. Reply to: Brazilian ethanol expansion subject to limitations. Nat. Clim. Chang. 9, 211–212. https://doi.org/10.1038/s41558-019-0423-y.

Karnani, A., 1985. Strategic implications of market share attraction models. Manage. Sci. 31, 536–547. https://doi.org/10.1287/mnsc.31.5.536.

Klier, T., Linn, J., 2015. Using taxes to reduce carbon dioxide emissions rates of new passenger vehicles: evidence from France, Germany, and Sweden. Am. Econ. J. Econ. Policy 7, 212–242. https://doi.org/10.1257/pol.20120256.

Klier, T., Linn, J., 2013. Fuel prices and new vehicle fuel economy-Comparing the United States and Western Europe. J. Environ. Econ. Manage. 66, 280–300. https://doi.org/10.1016/j.jeem.2013.03.003.

Köberle, A.C., Portugal-Pereira, J., Cunha, B., Garaffa, R., F. P. Lucena, A., Szklo, A., Schaeffer, R., 2019. Brazilian ethanol expansion subject to limitations. Nat. Clim. Chang. 9, 209–210. https://doi.org/10.1038/s41558-019-0422-z.

Kotler, P., 1984. Marketing Management: Analysis, Planning, and Control, Fifth. ed. Prentice-Hall Inc., Englewood Cliffs.

Li, X., Clark, C.D., Jensen, K.L., Yen, S.T., English, B.C., 2013. Consumer purchase intentions for flexible-fuel and hybrid-electric vehicles. Transp. Res. Part D Transp. Environ. 18, 9–15. https://doi.org/10.1016/j.trd.2012.08.001.

Liu, C., Greene, D.L., 2014. Consumer choice of E85 denatured ethanol fuel blend: Price sensitivity and cost of limited fuel availability. Transp. Res. Rec. 2454, 20–27. https://doi.org/10.3141/2454-03.

Liu, J., Khattak, A.J., Li, X., Fu, X., 2019. A spatial analysis of the ownership of alternative fuel and hybrid vehicles. Transp. Res. Part D Transp. Environ. 77, 106–119. https://doi.org/10.1016/j.trd.2019.10.018.

Löfgren, Å., Hammar, H., 2000. The phase-out of leaded gasoline in the EU: A successful failure? Transp. Res. Part D Transp. Environ. 5, 419–431. https://doi.org/10.1016/S1361-9209(00)00009-2.

Lund, P.D., 2010. Exploring past energy changes and their implications for the pace of penetration of new energy technologies. Energy 35, 647–656. https://doi.org/10.1016/j.energy.2009.10.037.

Mabit, S.L., Fosgerau, M., 2011. Demand for alternative-fuel vehicles when registration taxes are high. Transp. Res. Part D Transp. Environ. 16, 225–231. https://doi.org/10.1016/j.trd.2010.11.001.

Matas, A., Raymond, J.L., Dominguez, A., 2017. Changes in fuel economy: An analysis of the Spanish car market. Transp. Res. Part D Transp. Environ. 55, 175–201. https://doi.org/10.1016/j.trd.2017.06.025.

Meade, N., Islam, T., 2006. Modelling and forecasting the diffusion of innovation – A 25-year review. Int. J. Fore 22, 519–545. https://doi.org/10.1016/j.ijforecast.2006.01.005.
Melton, N., Axsen, J., Moawad, B., Bentall, B., Vxa, V.B.C., 2020. Energy Research & Social Science Which plug-in electric vehicle policies are best ? A multi-criteria evaluation framework applied to Canada. Energy Res. Soc. Sci. 64, 101411 https://doi.org/10.1016/j.erss.2019.101411.
Moreira, J.R., Goldemberg, J., 1999. The alcohol program. Energy Policy 27, 229–245. https://doi.org/10.1016/S0301-4215(99)00005-1.
Moreira, J.R., Nogueira, L.A.H., Parente, V., 2005. Biofuels for transport, development, and climate change: lessons from Brazil. In: Bradley, R., Baumert, K.A. (Eds.), Growing in the Greenhouse: Protecting the Climate by Putting Development First. World Resources Institute, p. 132.
Moutinho dos Santos, E., Parente, V., 2006. The second alcohol shock in brazil - looking for more flexibility. International Association of Energy Economics, Potsdam.
Naert, P., Weverbergh, M., 1981. On the prediction power of market share attraction models. J. Mark. Res. 18, 146–153. https://doi.org/10.1177/002224378101800202.
Nakanishi, M., Cooper, L.G., 1974. Parameter estimation for a multiplicative competitive interaction model—least squares approach. J. Mark. Res. 11, 303–311. https://doi.org/10.1177/002224377401100309.
Noori, M., Tatari, O., 2016. Development of an agent-based model for regional market penetration projections of electric vehicles in the United States. Energy 96, 215–230. https://doi.org/10.1016/j.energy.2015.12.018.
Norton, J.A., Bass, F.M., 1987. A diffusion theory model of adoption and substitution for successive generations of high-technology products. Manage. Sci. 33, 1069–1086.
Puglieri, R., 2013. Analysis of the Sugar-Alcohol Industry Under the Optics of the Competition Defence: How to Define Relevant Markets. Universidade de São Paulo.
Radpour, S., Hossain, A., Kumar, A., 2017. Market penetration modeling of high energy efficiency appliances in the residential sector. Energy 134, 951–961. https://doi.org/10.1016/j.energy.2017.06.039.
Rivers, N., Schaufele, B., 2017. Gasoline price and new vehicle fuel efficiency: Evidence from Canada. Energy Econ. 68, 454–465. https://doi.org/10.1016/j.eneco.2017.10.026.
Rodrigues, L., Bacchi, M.R.P., 2017. Analyzing light fuel demand elasticities in Brazil using cointegration techniques. Energy Econ. 63, 322–331. https://doi.org/10.1016/j.eneco.2017.02.012.
Rodrigues, N., Losekann, L., Silveira Filho, G., 2018. Demand of automotive fuels in Brazil: Underlying energy demand trend and asymmetric price response. Energy Econ. 74, 644–655. https://doi.org/10.1016/j.eneco.2018.07.005.
Rodríguez-Morales, J.E., 2018. Convergence, conflict and the historical transition of bioenergy for transport in Brazil: The political economy of governance and institutional change. Energy Res. Soc. Sci. 44, 324–335. https://doi.org/10.1016/j.erss.2018.05.031.
Salvo, A., 2018. Flexible fuel vehicles, less flexible minded consumers: Price information experiments at the pump. J. Environ. Econ. Manage. https://doi.org/10.1016/j.jeem.2018.08.016.
SAS Institute Inc, 2018. SAS OnDemand for Academics 3.7 (Enterprise Edition).
Shafiei, E., Davidsdottir, B., Leaver, J., Stefansson, H., Asgeirsson, E.I., 2014. Potential impact of transition to a low-carbon transport system in Iceland. Energy Policy 69, 127–142. https://doi.org/10.1016/j.enpol.2014.03.013.
Silveira, S., Johnson, F.X., 2016. Navigating the transition to sustainable bioenergy in Sweden and Brazil: Lessons learned in a European and International context. Energy Res. Soc. Sci. 13, 180–193. https://doi.org/10.1016/j.erss.2015.12.021.
Sprei, F., Karlsson, S., Holmberg, J., 2008. Better performance or lower fuel consumption: Technological development in the Swedish new car fleet 1975–2002. Transp. Res. Part D Transp. Environ. 13, 75–85. https://doi.org/10.1016/j.trd.2007.11.003.
Szwarcfiter, L., Mendes, F.E., La Rovere, E.L., 2005. Enhancing the effects of the Brazilian program to reduce atmospheric pollutant emissions from vehicles. Transp. Res. Part D Transp. Environ. 10, 153–160. https://doi.org/10.1016/j.trd.2004.12.002.
Tenkorang, F., Dority, B.L., Bridges, D., Lam, E., 2015. Relationship between ethanol and gasoline: AIDS approach. Energy Econ. 50, 63–69. https://doi.org/10.1016/j.eneco.2015.04.019.
USBLS, 2018. Consumer Price Index. United States Bureau of Labor Statistics, Washington.
Vance, C., Mehlin, M., 2009. Tax Policy and CO2 Emissions - An Econometric Analysis of the German Automobile Market. Ruhr University Economic Papers, Bochum. https://doi.org/10.2139/ssrn.1374818.
Wedel, M., Kannan, P.K., 2016. Marketing Analytics for Data-Rich Environments. J. Mark. 80, 97–121. https://doi.org/10.1509/jm.15.0413.
Witcover, J., Williams, R.B., 2020. Comparison of "Advanced" biofuel cost estimates: Trends during rollout of low carbon fuel policies. Transp. Res. Part D Transp. Environ. 79, 102211 https://doi.org/10.1016/j.trd.2019.102211.
Yu, A.S.O., Nascimento, P.T.D.S., Nigro, F.E.B., Frederick, B.W.B., Varandas, J.A., Vieira, S.F.A., Rocha, R.L., 2010. The evolution of flex-fuel technology in Brazil: The Bosch case. Technol. Manag. Glob. Econ. Growth (PICMET), 2010 Proc. PICMET '10 1250–1260.