Tax exemption policies to encourage the purchase of electric vehicles in Brazil

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Abstract: Since the 1970s, driven by oil shocks and growing global environmental awareness, various efforts have been made to reduce dependence on fossil fuels. The transportation sector, a major consumer of oil and a source of pollution, has seen global initiatives attempting alternatives to internal combustion engines, with electric motors leading these efforts so far. This study, using panel data and generalized least squares estimates, investigates how tax policies promoting the consumption of electric vehicles affect adoption in Brazilian states from 2016 to 2022. The study's hypothesis is that greater tax incentives result in larger fleets of electric vehicles, which is confirmed, with reservations, by this work. This research aims to positively contribute to the United Nations' Sustainable Development Goals (SDGs) seven, eleven, and thirteen.

Keywords: Public Policies; Electric Vehicles; Electro Mobility; Tax Exemption.

JEL Code: O25; O44; L98

Thematic Area: 6.1 Políticas Industriais e Comerciais

Resumo: Desde a década de 1970, estimulados pelos choques petrolíferos e pela crescente consciência ambiental global, diversos esforços foram tentados com o objetivo de reduzir a dependência dos combustíveis fósseis. O setor dos transportes, um grande utilizador de petróleo e fonte de poluição, viu iniciativas globais tentarem paradigmas alternativos aos motores a combustão, tendo os motores elétricos, até o momento, ganho a dianteira nestes esforços. Este estudo, empregando dados em painel e estimativas de mínimos quadrados generalizados, investiga como as políticas tributárias que promovem o consumo de veículos elétricos afetam a adoção nos estados brasileiros de 2016 a 2022. A hipótese do estudo é: maiores incentivos fiscais redundam em maiores frotas de veículos elétricos. O que é confirmado, com ressalvas, por este trabalho. Esta pesquisa visa contribuir positivamente para os Objetivos de Desenvolvimento Sustentável (ODS) sete, onze e treze da Organização das Nações Unidas.

Palavras-chave: Políticas Públicas; Veículos Elétricos; Eletro Mobilidade; Isenção Tarifária

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1. Introduction

The historic episode known as the oil shock in 1973 put the world on alert. The world's largest economies, which used fossil fuels as their main source of energy, found their hands tied when the group of countries that monopolised production tripled their prices overnight. During this unexpected situation, there were the first formal discussions about how carbon dioxide emissions could affect life on earth and, against this backdrop, the governments of the main countries in the world at the time took steps to reduce oil consumption (Baran; legey, 2011).

In the transport sector, which is responsible for both the emission of toxic gases into the environment and the intensive use of oil to move fleets, governments in various countries have sought to find alternatives to reduce the intensive use of fossil fuels (biofuels in some countries, electricity in others) (Cordeiro; Losekann, 2018).

Those countries that made efforts to make the electric vehicle viable, which was reinvented in the 1980s, came up against bottlenecks that were difficult to overcome at the time (mainly durable, safe, light, and cheap batteries). These difficulties meant that the electric vehicle was relegated to the background, as oil prices returned to stable levels in the 1980s. However, the 1990s changed the panorama of the global automotive industry, as, led by the state of California, research centres in various countries, together with companies of the most different nationalities, accelerated developments to make electrified models viable, resulting in the Prius (the first popular hybrid) being placed on the global market (Toffel; Mchelhaney, 2002).

From the Prius' successful foray in 2001 to the present day, the market has changed a lot. Environmental regulations have become stricter, combustion engines have become more efficient, hybrids have gained greater autonomy and new types such as plug-ins, fully electric cars have seen significant improvements in their performance and are now able to perform with the same autonomy as combustion cars, even though there are still problems and weaknesses that mainly refer to the high cost of the battery and the lack of adequate infrastructure to accommodate them in the world's fleets (IEA, 2021).

Furthermore, transitioning to a fleet of electric vehicles necessitates significant infrastructure investments. This includes the implementation of fast-charging stations and strategies to level the pricing between electric cars and internal combustion vehicles. Addressing these needs calls for the focused efforts of governments aiming to catalyse a transformative change in their transportation sectors.

The introduction of this technology on Brazil began with the tariff exemption policy from the *Inovar-auto* industrial policy programme (2012), which in addition to the tax exemption for imports, promoted credit lines and tax exemptions for companies developing technologies to electrify their fleets. From 2012 to 2022, the electrified vehicle fleet exceeded 100,000 units and a lot has been done since then: new regulations, a new industrial policy with specific lines to promote electric vehicles, investments in infrastructure, tax exemptions from the states, parafiscal policies in other Brazilian states and the cheapening of such vehicles on the domestic market, albeit gradually, in line with global trends (IEA, 2024).

In this way, this article seeks to investigate how public policies to encourage the consumption of electric vehicles are impacting the insertion of this technology in different states of Brazil in the period from 2016 to 2022, with emphasis on the tax exemption provided by the states. The hypothesis to be tested is that the greater the volume of tax incentives, the larger the fleet.

The data used come from a variety of sources: the fleet from *Denatran* (National Transit Department), tax incentives and investments in infrastructure from the official websites of each state and specialised agencies such as *Plugshare*, state population from *IBGE* (Brazilian Institute of Geography and Statistic), and the price of fossil fuels from *ANP* (National Oil Agency).

As a proxy to generate a counterfactual to the increase in the electric vehicle fleet, this research uses the country's total vehicle licensing to verify that the increase in the fleet is not just an effect of the expansion of the national market.

Methodologically, the data will be in the form of a panel with dummy's responsible for characterising the existence or not, during the period in question, of the incursion of tax exemptions, with the aim of verifying the differences between the treated group (electric vehicle fleet) and the nontreated group (total fleet) and before and after the treatment (tax exemption). The econometric estimation carried out using generalized least squares points to the statistical significance of the tax incentive to promote the electric car fleet in the country.

In addition to this introduction, this article is organised around five other sections, the first of which is responsible for reviewing the theoretical framework, the second to show the methodology used, the third for explaining the variables and the econometric model used, the fourth for showing the results of the estimations and relevant discussions, and the final section for some considerations on the results obtained.[2]

2. Theoretical framework

This section aims to show the main contributions of theories to the theme of industrial and innovation policies aimed at a sustainable economy (green industrial policies) and, secondly, to present what Brazil has been doing in this sector, to provide support for the variables analysed empirically in the following section of this paper.

A theoretical framework that deals with general theories that contextualise environmentally sustainable industrial policies is fundamental to understanding why physical incentives are decisive for expanding the fleet of electric vehicles, because as well as having very high costs compared to combustion models, they require other investments, mainly aimed at improving the charging infrastructure, which will only be popularised as the market becomes viable for private investment.

2.1 Industrial policies in the era of sustainable development

Public policies to promote new energy vehicles are characterised as industrial policies with up-to-date instruments aimed at sustainability. These public policies, whether in developed or developing countries, are underpinned by an appropriate education system, prepared, and equipped infrastructure, responsible institutions, and clear legislation. This means that industrial policies lead to development by being able to disrupt and restructure a country's productive organisation (Rodrik, 2011; Zhao; Zhang, 2022; Kastelli et al. 2023).

Modern industrial policies have a variety of instruments to achieve their goals, be they on the supply side, such as investment in R&D, expanding the volume of credit, creating infrastructure, among others, or actions on the demand side, such as the use of state purchasing power (Mathews, 2020; Tamasiga et al. 2023).

Moving from drafting to implementation is a fundamental step that often represents the first barrier to the full implementation of an industrial policy. In this regard, Oqubay (2020) draws attention to the clarity and flexibility needed for an industrial policy to succeed in a dynamic world.

This dynamism must be accompanied by clear objectives that are concerned with creating a dynamic efficiency ecosystem capable of promoting innovative activities, preferably those with a high technological content and which bring with them the possibility of generating high skill, high wage jobs (Mazzucato; Semieniuk, 2017; Cimoli et al., 2020; Zhao; Zhang, 2022).

The new reality of industrial policies, which must now include environmental concerns, goes beyond reducing uncertainties and creating new markets, incorporating efforts to change the energy paradigm, broadening the horizons of opportunities that new energy sources make it possible to explore, expanding technological sophistication, remodelling old sectors, and boosting new environmentally friendly sectors (Aiginger; Rodrik, 2019; Mathews, 2020; Benito; Meyer, 2024).

Green industrial policies (which have sustainability as an objective) have the goal of achieving a sustainable economy, in which resources are used sparingly and circularly, so that the notion of generational solidarity is present and allows new generations to enjoy the same level of comfort and resources as the present generation (Rodrik, 2015; Capra; Jackobsen, 2017; Kastelli et al. 2023).

In this sense, Aiginger and Rodrik (2019) argues that the formulation of these policies should be

[2] This study aims to positively contribute to the United Nations' Sustainable Development Goals by highlighting and studying clean and accessible energies; sustainable cities and communities; and combating climate change, which correspond, respectively, to goals seven, eleven, and thirteen out of the fourteen proposed by the organization.

easy to monitor, and the ways of measuring results should be defined in advance and be as simple as possible, thus avoiding unnecessary noise that could demobilise the efforts of the formulators and the firms involved.

2.2 The panorama of industrial policies for the Brazilian automotive industry, capturing actions aimed at electric vehicles

It was the country's choice in the 1970s, in the face of the oil shock, to invest in biofuels as a way of getting round the problem of dependence on oil, which at the time was mostly imported. As an industrial policy programme, *Pro-álcool* was able to coordinate the agricultural sector, fuel production industries, engine companies that were able to adapt to the new technology and public opinion, which quickly accepted products that used alcohol fuel (Andrade et al, 2009; Sachs et al. 2024).

And it is the successes achieved with biofuels that permeate industrial policy projects aimed at the automotive sector even today (Cortez et al. 2024). However, the aim of this research is to see what is being done in the form of public policies by the Brazilian government to encourage the market for hybrid and electric vehicles, which are increasingly being seen as the future carriers of the automotive industry.

In this way, the two nationwide industrial policy programmes for the automotive sector that have been directed, albeit timidly, towards the promotion of hybrid and electric vehicles, namely *Inovar Auto* and *Rota 2030*, are explored below.

The industrial policy programme in the automotive sector (*Inovar Auto*), as part of an even larger project (*Programa Brasil Maior*), helps to explain the government's move, which at the time saw industry and industrial policies as drivers of growth that would occur through incremental gains in production and productivity. This government vision, which thus articulated more ambitious plans in various sectors and with greater spill over effects, helps to explain some of the programme's positive results (Marx, 2013; Messa, 2016; Palmeri et al. 2017).

Inovar Auto was promoted in a period characterised by the flood of various imported products, both in the form of finished cars and auto parts, mainly from the productive Chinese industry. The aim of the programme was to densify the production chain in the Brazilian automotive sector, and to this end it instituted a scope of tariffs that affected firms that did not fit into the programme (importers) (Cunha, 2016; Palmeri et al. 2017).

To escape this tariff barrier, firms that produced domestically had to carry out at least eight stages of local car manufacturing on at least 80 per cent of the vehicles sold in the country (BRASIL, 2012).

Even though *Inovar Auto* does not deal with mechanisms that encourage the industry to move towards the production of new energy vehicles, be they electric, fuel cells or hydrogen, and shows a preference for strengthening competences already acquired, such as encouraging improvements in the efficiency of flex engines that use biofuel in their platform, it does propose a tariff proposal that encourages the introduction of imported new energy vehicles into the national fleet, reducing tariffs that were previously 35 per cent to zero (BRASIL, 2012; Wolffenbuttel, 2022).

Despite this ambiguous measure, which does not encourage the formation of domestic production skills but does enable the innovative product to reach Brazilian consumers, this action proved to be important because the market and the consumers who settled here were responsible for putting pressure on the government to take more concrete measures to encourage electric cars in the subsequent programme, *Rota 2030* (Messa, 2016; Cunha, 2016).

The economic crisis that began in 2016 reduced the prospects once held out for the automobile sector, and production, which had been on the rise year after year, reversed to a situation considered disastrous for the industry (Daudt; Willcox, 2018). Even so, given the importance of the sector, policymakers were quick to introduce another state incentive programme for the sector (Pelegrina et al. 2023).

The long-term programme set up by law 13.755/18, known as "*Rota-2030 Mobilidade e Logística*", aims to:

> "To support technological development, competitiveness, innovation, vehicle safety, environmental protection, energy efficiency and the quality of cars, lorries, buses, chassis and auto parts" (BRASIL, 2018,

p.1).

This programme sets targets to be achieved by 2030, with five-yearly reviews.
It is worth noting that the programme makes clear the country's concern with low-carbon mobility and mentions several times the importance of introducing new technological paradigms into its fleet, but without forgetting the broad leadership it has in biofuel technologies, made explicit in the very first section of the law, in paragraph four.

> "Hybrid vehicles equipped with an engine that uses, alternatively or simultaneously, petrol and alcohol (flexible fuel engine) must have a reduction of at least three percentage points in the IPI rate in relation to conventional vehicles, of a similar class or category, equipped with this same type of engine." (BRASIL, 2018, p.4).

And that they also have:

> "Investment project related to the installation, in the country, of a production line for vehicles with alternative propulsion technologies to combustion" (BRASIL, 2018, p.4).

The preference for a hybrid engine that uses the Brazilian biofuel platform and the tax incentive that keeps the import tax for new energy vehicles at zero show the programme's attention to sustainability and the new paradigms of the industry, and for the first time it is targeting the electrification of national production chains, even if initially only using the hybrid platform (Pelegrina et al. 2023).

In addition, the change of government in 2023 helped to put the automotive sector and sustainable mobility more firmly on the agenda within government circles, which began to see industrial and innovation policies as the key to what the Ministry of Industry and Foreign Trade calls "*Neo*industrialization" (Moura; Guedes, 2023).

This new perception, coupled with the completion of the first five-year term of *Rota-2030* and the decision by the Chinese company Build Your Dreams (a global leader in the production of electric vehicles) to acquire the Ford Motor Company factory in the country, has led the government to change its stance on tax exemptions for imports, which have been in place since *Inovar Auto* in 2012. The end of import exemptions will be gradual and should take place in stages until 2026, which should not hinder the increase in the electric vehicle fleet that has been taking place, since production tends to be internalised, driven by the start of operations by China's Build Your Dreams on Bahia state (Caram, 2023; Pedroso, 2023).

In addition to the industrial policy projects carried out by the federal government, many initiatives are taking place at state and municipal level to promote and encourage low-carbon mobility, especially electric and hybrid vehicles.

At state level, some initiatives are worth highlighting, the main one being the exemption or reduction of tariffs for alternative propulsion vehicles. The states that offer total exemption from Tax on Motor Vehicle Ownership (IPVA) are Rio Grande do Sul, Rio Grande do Norte, Pernambuco, Piauí, Maranhão, Sergipe, Ceará and São Paulo.
Rio de Janeiro and Mato Grosso do Sul offer a 50% tax exemption, and the state energy companies of Minas Gerais and São Paulo have lines of research studying the impacts of electrification on the energy infrastructure of their transmission lines (Risso, 2018; PROMOB-E, 2019).

Although tax incentives in the country have the characteristic of reducing transaction and ownership costs, such as tax reductions for both purchase and annual legalisation, they have a much more complex characteristic worldwide, often being an equaliser that guarantees the competitiveness of electric vehicles compared to combustion vehicles, as can be seen with Chinese, South Korean and US tax incentives and subsidies (Feng; Li, 2019; IEA, 2022; Pereira Neto, 2023).

At state and municipal level, in countries such as Chile and South Korea, it is common for new energy vehicles to receive a variety of urban benefits, the most common of which are exclusive parking spaces, not being on the road, the use of exclusive lanes and other non-fiscal benefits that are gradually being incorporated into Brazilian urban centres, such as São Paulo, Curitiba, among others (PROMOB, 2018; IEA, 2021; PLUGSHARE, 2022).

It is on state tax exemption initiatives, which are added to the federal government's efforts in the same direction, that this research seeks to focus, verifying whether this tax increase is effective in expanding the fleet of new energy vehicles in the country.

3. Theoretical and empirical methodology

The theoretical and bibliographical reference will follow the methodology proposed by Bowen (2009), who uses the method of document analysis. The author defines his method as a systematic procedure for reviewing and evaluating documents.

The documentary analysis proposed by the author involves searching for, selecting, and evaluating documents beforehand. The evidence must come from different sources, varying in databases and search methods, so that there is a kind of triangulation/absence of data bias and, consequently, greater credibility is achieved.

In practice, the method is realised through three principles: skimming, reading and interpretation. These mean, respectively, a superficial documentary review in which the researcher separates what is important from what is not important, moving on to an analysis of patterns within the texts that are in line with the research objectives, and finally, after categorising the subjects of interest, proceeding to interpret the selected material.

The empirical part of this research will use panel data to be analysed using the generalised least squares method. Panel data has the characteristic of simultaneously containing cross-sections and time series in the same database, so that the dynamics of the cut can be assessed over time. There are advantages to using such a model, such as the ease with which it captures heterogeneity, the dynamics in the behaviour of the variables and greater completeness in the analyses, as it can capture greater variability and better control multicollinearity (Bueno, 2018; Bai et al. 2020).

Estimation using the above-mentioned generalised least squares method was carried out because the database chosen, after treatment, had the characteristics of a random effect panel. This effect considers the intercept, which varies between individuals, but does not vary over time. Heterogeneity is an integral part of the estimation in the part of the model's errors ($vit = ai + uit$) In this case, the intercepts have random characteristics (Wooldridge, 2021; Rocha; Miranda, 2022).

There are also estimations that capture fixed effects. In this case, the intercept varies over time but is constant between individuals. This characteristic assumes the existence of heterogeneity between individuals and the estimation is done using the ordinary least squares model, not considering the existence of correlation in the model's error term, which are also normally distributed and homoscedastic (Bueno, 2018).

The choice of a Generalised Least Squares estimation, which therefore captures random effects, is not by chance. The Hausman test (1978), whose null hypothesis is that the coefficients for fixed and random effects are equal, indicates that rejection of this null hypothesis points to consistent fixed effects, while non-rejection points to the opposite, with the random effects model being the most appropriate (Greene, 2012; Baltagi, 2021).

4. Variable description

This article seeks to investigate how public policies to incentivise the consumption of electric vehicles are impacting the introduction of this technology in different Brazilian states between 2016 and 2022. The hypothesis to be tested is that the greater the volume of tax incentives, the larger the fleet.

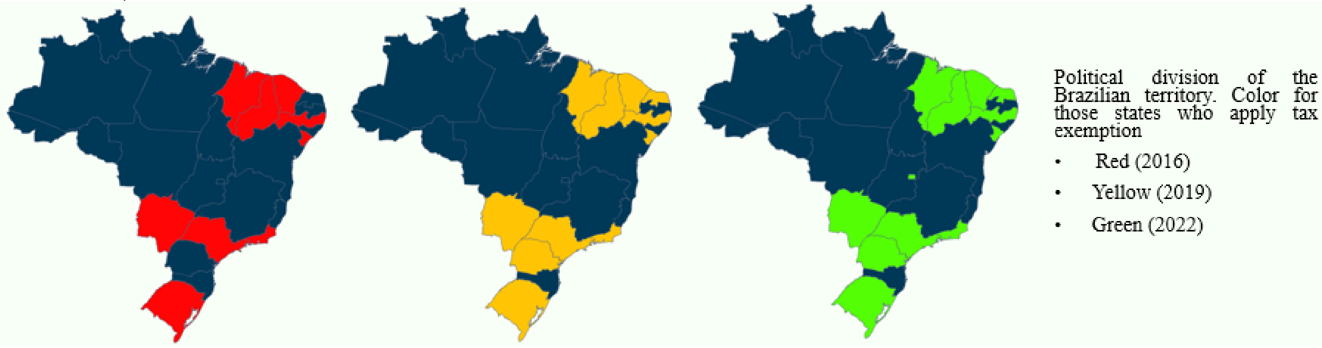
The variables used in this research have a logarithmic transformation, and this is because different states have different fleets and different distributions, which could lead to inaccurate estimations due to peaks and outliers, thus containing possible biases (Winter; Lobo, 2022).

The dependent variable fleet (*lfleet*) represents the number of annual licences for new energy vehicles (hybrids, electrics, and fuel cells) between 2016 and 2022 in the 27 states of the federation. The data was collected from the licensing database by fuel and type on Denatran (National transit department) digital platform.

The dummy for the presence of a tax exemption shows when, between 2016 and 2022, a given state introduced a package of tax exemptions that benefited electric vehicles to the detriment of vehicles powered by other fuels. This variable is the main variable of interest in this article, and it is expected to be not only significant but also positive. This variable was captured by searching the websites of each state government for the desired information, so that from the year the law comes into force onwards, the dummy takes on the value 1, and before the introduction of a tax incentive package it takes on the value zero.

The annual data from 2016 to 2022 are used by the database; however, to enhance the reader's understanding of the distribution of these rates, the maps in Figure 1 show the evolution of this exemption for the years 2016, 2019, and 2022. The states shown in distinct colours offer benefits, while those in blue do not.

Figure 1: Political map of Brazil highlighting in colour the states that offer tax benefits (2016; 2019 and 2022)



Source: IBGE, 2023. Edited in Figma.com.

This database does not consider tax incentives from national industrial policy programmes since they apply simultaneously to all states. This is therefore implicit data, but it is no less significant as it covers all 27 units of the federation.

The fuel price variable (*lfuel*) was taken from the ANP (National Petroleum Agency's) website and the values in the database refer to the annual average price of petrol, as this is the price of ethanol biofuel. In line with the specialised literature, this variable is expected to have positive and significant effects, indicating that the higher the fuel price, the larger the fleet of new energy vehicles tends to be.

The total fleet (*lfleetall*) was added as a control, because omitting it could cause the omission of a relevant variable, since the expansion of the fleet as a whole indicates a time of economic expansion, which also affects the fleet of electric vehicles, and a positive value would indicate that the tax incentives put in place by the federal government would have a positive impact on the purchase of electric vehicles to the detriment of conventional vehicles, even in scenarios of economic expansion in which the fleet would naturally have to expand. The expected sign is positive and significant for this variable. As with the electric vehicle fleet, this variable was also found in Denatran's annual licensing database.

Finally, the population variable (*lpop*) was added because it is expected that, in larger urban concentrations, the impulse to purchase new energy vehicles will be boosted, since along with the tax incentive package, it is common for new energy vehicles to have urban benefits that help the owner in the traffic of large cities, using exclusive lanes, reserved car parks, free chargers, among others. In this sense, a positive and significant sign is expected for this variable. The data tabulated here is taken from the Brazilian Institute of Geography and Statistics (IBGE).

All this data can be seen in Table 1 for the period from 2016 to 2022 and is divided among the 27 units of the Brazilian federation. To facilitate visualization, the same standard for the maps will be used, with data available for 2016; 2019 and 2022 due to space constraints in the text. Note that the logarithmic application has not yet been applied here.

Table 1: Summary of data used (2016; 2019; 2022).

Federal unit	Year	Fleet	Population	All Fleet	Fuel price (R$/L)	Federal unit	Year	Fleet	Population	All Fleet	Fuel price (R$/L)
Acre	2016	19	828096	251556	4,14	Para	2019	309	8559656	2120020	4,61
Acre	2019	60	875364	292659	4,92	Para	2022	1809	8885858	2478988	7,27
Acre	2022	237	922632	334337	7,41	Paraíba	2016	11	3926552	1184259	3,72
Alagoas	2016	3	3254052	753825	3,84	Paraíba	2019	182	4006564	1353093	4,24
Alagoas	2019	93	3320832	889900	4,58	Paraíba	2022	1438	4086576	1523167	6,90
Alagoas	2022	1062	3387611	1034187	7,09	Paraná	2016	522	11073412	7140437	3,70
Amapá	2016	11	783028	179665	3,63	Paraná	2019	1935	11387855	7845576	4,25
Amapá	2019	37	839779	205459	3,97	Paraná	2022	10865	11702298	8575904	6,93
Amapá	2022	209	896530	232691	6,22	Pernambuco	2016	127	9275545	2816115	3,78
Amazonas	2016	75	3912718	819382	3,93	Pernambuco	2019	669	9515094	3129195	4,36
Amazonas	2019	214	4127084	928423	4,30	Pernambuco	2022	4531	9754643	3439164	7,01
Amazonas	2022	1187	4341450	1069794	7,22	Piauí	2016	43	3211595	1085009	3,76
Bahia	2016	182	14545112	3801090	3,80	Piauí	2019	202	3258212	1250493	4,57
Bahia	2019	996	14809215	4332564	4,57	Piauí	2022	1079	3304829	1385426	7,61
Bahia	2022	6235	15073318	4887673	7,43	Rio de Janeiro	2016	363	16793613	6377484	3,94
Ceara	2016	55	8882299	2909172	3,93	Rio de Janeiro	2019	1674	17195454	6950940	4,87
Ceara	2019	491	9097267	3283529	4,54	Rio de Janeiro	2022	9850	17597296	7475503	7,62
Ceara	2022	2675	9312236	3625994	7,23	Rio Grande do Norte	2016	13	3382323	1183363	3,85
Distrito Federal	2016	214	2856068	1699681	3,83	Rio Grande do Norte	2019	184	3489471	1346696	4,40
Distrito Federal	2019	1212	2999022	1884919	4,28	Rio Grande do Norte	2022	1342	3596619	1495094	7,39
Distrito Federal	2022	6513	3141976	2021626	7,22	Rio Grande do Sul	2016	376	11115402	6650259	3,94
Espírito Santo	2016	99	3838710	1811993	3,71	Rio Grande do Sul	2019	1630	11326139	7309131	4,57
Espírito Santo	2019	679	4000589	2011184	4,47	Rio Grande do Sul	2022	7487	11536876	7869630	6,77
Espírito Santo	2022	3377	4162468	2248960	7,18	Rondônia	2016	35	1700338	905487	3,95
Goiás	2016	132	6659861	3657751	3,83	Rondônia	2019	128	1769302	1030614	4,56
Goiás	2019	613	6987898	4054788	4,50	Rondônia	2022	583	1838266	1154287	7,21
Goiás	2022	5736	7315935	4542236	7,29	Roraima	2016	21	560788	201081	3,90
Maranhão	2016	98	6890320	1541845	3,66	Roraima	2019	40	615943	228983	4,09
Maranhão	2019	259	7048085	1777081	4,36	Roraima	2022	163	671098	263345	6,84
Maranhão	2022	1531	7205850	2031236	7,06	Santa Catarina	2019	1624	7140284	5384378	4,12
Mato Grosso	2016	234	3325365	1881794	3,73	Santa Catarina	2022	9285	7437567	5974106	6,88
Mato Grosso	2019	556	3470486	2209898	4,48	São Paulo	2016	2788	44200526	27332101	3,55
Mato Grosso	2022	2845	3615608	2568240	6,79	São Paulo	2019	9863	45669690	30058975	4,16
Mato Grosso do Sul	2016	67	2662159	1459464	3,64	São Paulo	2022	48208	47138853	32293190	6,68
Mato Grosso do Sul	2019	327	2768376	1649789	4,20	Sergipe	2016	29	2215539	709682	3,71
Mato Grosso do Sul	2022	2007	2874594	1824708	7,00	Sergipe	2019	131	2289300	806366	4,39
Minas Gerais	2016	331	20586764	1E+07	3,79	Sergipe	2022	847	2363061	907388	7,04
Minas Gerais	2019	1718	21081482	1,2E+07	4,72	Tocantins	2016	26	1505582	637236	3,89
Minas Gerais	2022	10646	21576199	1,3E+07	7,35	Tocantins	2019	95	1566651	721803	4,55
Para	2016	90	8233454	1827134	4,08	Tocantins	2022	476	1627719	830733	7,26

Source: ANP; DENATRAN; Setran (27 states), IBGE.

To contain non-stationary processes that could put in denger the principles of constant mean and variance, unit root tests were carried out to determine whether the variables had processes that could make the estimation spurious (Granger; Newbold, 1974). These tests indicate that it is necessary to lag the variables *lfleet; lfuel* and *lfleetall* by 1, 2 and 1 periods respectively, so that they start to show stationary characteristics. It is worth noting that the population variable has stationary characteristics without any lags.

The equation to be estimated is as follows:

$$Y(lfleet(-1))it = \beta 0 + \beta 1(dummy)it + \beta 2(lfuel(-2)) + \beta 3(lfleetall(-1)) + \beta 4(lpop) + \alpha t + \mu it$$
(1)

The description of the variables used and their respective justification in the specialised literature are shown in Table 2.

Table 2: Description of the model variables

Variable	Description	Theoretical background	Source	Expected Signal
Electric fleet (*lfleet*)	Total fleet of electric vehicles		DENATRAN	
dummy	Incursion of a tax incentive package in the state	Leh, Mah (2020); PROMOB-E (2019); Pereira Neto (2023) Pereira (2013)	Setrans 27 states	+
Price of fossil fuel (*lfuel*)	Average annual value of fuel by state	Feng; Figliozzi, 2012; IEA, 2022; Trost et al, 2017.	ANP	+
Total fleet (*lfleetall*)	Annual licensing of light vehicles	Tan et al (2018); Vaz et al (2015); EV outlook (2022); Cordeiro; Losekann (2018)	DENATRAN	+
State Population (*lpop*)	Evolution of the state population	Borray et al (2020); Wu et al (2017)	IBGE	+

Source: own elaboration.

The next step is to check the results of the generalised least squares model estimation. Along with these results, other robustness tests will be reproduced to give greater credibility to the results. Statistics such as Durbin Watson (1951), which indicates autocorrelation in the model, the adjusted explanation index (adjusted R^2) and the f-statistic for whether the set of variables is significant in explaining the explanatory variable will be set out in the next section. For greater robustness, the estimation will have standard errors corrected by the White method (1980) to contain heteroscedasticity bias (Greene, 2012; Bueno, 2018; Rocha; Miranda, 2022). In addition, other data fundamental to the robustness of the research are presented in the appendix of this work.

5. Analysing the results

The model's dependent variable (*lfleet*) estimated in this equation with a lag makes analysing the coefficients a little more difficult, since we are now dealing with variations applied to variations in different periods.

It is true that the degree of lags applied to the model indicates latency effects in the transmission of each of the explanatory variables to the explained variable, which is to be expected in a model of fleet growth, which occurs annually, since consumers, given the added value of the product, do not make decisions immediately.

The existence of a package of tax incentives, as discussed in Pereira Neto (2023) and Leh and Mah (2020), presents positive and significant benefits for the expansion of the electric vehicle fleet, because, due to their still higher cost than the same combustion model, the tax benefit, which appears as an equaliser, puts the electric vehicle on an equal footing with its combustion competitor. The fact that the fleet is lagging by a period indicates that there is a latency between the introduction of the benefit and the licensing of the product, explained by the consumer's delay in making a decision that involves high costs, be they opportunity costs or transaction costs.

Even so, it should be noted that, in line with the specialised literature, the sign found and the significance level for the tax benefit dummy are as expected. The price of fuel, which only reaches a steady state after two lags, is the variable that has the greatest impact on the increase in the fleet of electric vehicles, and the explanation is based on conventional economic microeconomics, as we are dealing with substitute goods.

And the fact that it has two lags shows that the consumer decides to wait to see if the increase in conventional fuels will persist before making the decision to change paradigm, because a new technology, still little explored and unknown to most, creates costs and uncertainties that are difficult to measure immediately.

According to Feng; Figliozzi (2012); Trost et al (2017) and IEA (2022) the positive and significant sign found by the estimation is supported by reality and other research in the area.

The volume of total annual licences (*lfleetall*) was added to the model as a control, since a negative result would indicate that the growth of the overall fleet is greater than that of the electric vehicle fleet, an indicator that this technology is not, in fact, gaining market share. By showing a positive value and statistical significance, the variable indicates that the expansion of the total fleet, as an indicator of expansion in the consumption of such products, expands the electric vehicle fleet to a greater extent. This correlates with specialised texts in the area that demonstrate this relationship in other countries, such as Tan et al (2018) and Vaz et al (2015).

Finally, the population variable was the only one to show counterintuitive results and somewhat contrary to the specialised literature for electric vehicles, since in larger urban centres, the larger and more suitable infrastructure for receiving such vehicles should be an enabler for the adoption of such technology, which shows that there is no adherence to the Brazilian case, which may be correlated with traffic congestion that makes people look for ways to avoid cars, regardless of the fuel used.

The presentation of a negative and statistically significant value shows that the larger the population of a region, the greater the disincentive to opt for an electric vehicle in Brazilian states tends to be. It should be noted that all the variables are statistically significant, and it is not possible to determine the autocorrelation between the variables. The results of the estimation via generalised least squares (GLS) can be seen in table 2[3] .

Table 3: MQG estimation results (27 states 2016-2022)

Variable	Coefficient	Standard Error	T Statistics	Prob.
C	Δ -1,688	1.714	-9.848	0.0000
Dummy	Δ 0.312	0.120	2.598	0.0104
lfuel (-2)	Δ 7.816	1.404	5.563	0.0000
lfleetall (-1)	Δ 2.614	0.441	5.916	0.0000
lpop	Δ -1.703	0.491	-3.467	0.0007
Prob (F-Statistics)			0.000	
Hausmann test (prob)			1.000	
Durbin-Watson			1.696	
R-squared			0.722	
Adjusted R-squared			0.713	

Source: Own elaboration via reproduction of Eviews10 software.

The evidence shows that in addition to the national tax incentive, the existence of benefits for annual licensing in some states is an important boost to the expansion of the electric vehicle fleet beyond the normal expansion of the fleet. Nonetheless, what significantly influences consumer adoption of the electric paradigm is the enduring burden of high daily expenses, particularly evident in fuel prices.

[3] The existence of unit roots was analysed using the KPSS, PP and ADF methods. The results found and the respective lags to overcome this problem are explained in table 5 of the Appendix. In addition, the results of the estimation that captures fixed effects are shown in table 6 of the same section.

6. Conclude remarks

Migrating from a paradigm established more than a hundred years ago to one full of uncertainties and advances that occur as the technology is adopted, makes consumers around the world resistant to the mass adoption of such technology. Central governments, understanding the need for rapid migration to environmentally friendly technologies, have been trying to boost their industries in any way they can, using various mechanisms to try to popularise and lower the costs of such technology so that it becomes competitive as soon as possible.

Environmentally correct (green) industrial and innovation policies have emerged as a global need imposed by the 21st century in the face of human actions that are harmful to the continuity of life on earth, and in the transport sector, which is doubly responsible for such harm, electric motors have emerged as an ideal response to this need (IEA, 2022).

The window of opportunity opened by a new paradigm has led governments in various countries to adopt measures to dominate the production and encourage the consumption of such technologies, and in Brazil, what is being done is to try to popularise this paradigm by reducing import costs and gradually exempting owners of these vehicles from taxes that reduce transaction costs. In other words, a reward for being environmentally responsible.

Even so, in Brazil, the product has unpopular prices that make massification difficult and concentrate this product in luxury vehicle consumption strata, so that, in addition to tax benefits that reduce such costs, it is necessary to create other incentives such as those being adopted in the city of São Paulo by releasing such vehicles from rotation and allocating them to exclusive lanes and car parks.

The impact of state tax incentives, the focus of this research, is an important factor in boosting the adoption of electric vehicles since the differences between states that adopt this measure and those that do not are positive and significant.

There is also an important indicator related to the price of fossil fuels and their derivatives (ethanol, biodiesel), which, if they rise, will expand the electric vehicle fleet with greater vigour than the tax incentive, something explained by the fact that electric fuel is a substitute for liquid fuels.

The general expansion of the fleet was a control variable that proved to be important to the model, since it includes various factors related to income, wages, access to credit and others that are included in the dynamics of increasing a car fleet. The positive value is important for concluding that the new paradigm is being well accepted by the Brazilian population.

Brazil's large urban centres, despite having a better charging infrastructure that should guarantee a better introduction of this type of vehicle, show the opposite: people tend not to adopt an electric car as the population rises in larger urban agglomerations.

In this way, the results of this study indicate that the new paradigm is advancing in Brazil, and that the use of tax breaks is indeed significant in the consumer's decision to adopt the new technology over the old one.

Disaggregating the variables related to income in the total fleet, creating a variable with the average price of the electric vehicle and the combustion equivalent to capture the price difference in the consumer's decision, and disaggregating the population of the states from the population of the capitals are proposals to be tried for a possible evolution of this research, to make the determinants for the adoption of electric vehicles in the Brazilian fleet more precise. Furthermore, given the production internalisation of electric vehicles by Build Your Dreams and the possible cheapening of this product in the coming years, the research agenda tends to remain open to capture these effects soon.

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Appendix

Table 4: Descriptive Variables

	Lfleet	Dummy	Lfleetall	Lfuel	Lpop
Mean	6.009	0.391	1.449	1.530	1.536
Median	5.966	0.000	1.444	1.469	1.521
Maximum	1.078	1.000	1.729	2.030	1.766
Minimum	1.098	0.000	1.209	1.251	1.323
Standard deviation	1.774	0.489	1.156	0.213	1.009
Jarque Bera	1,1569		**Prob**	0,5607	
Observations	189	189	189	189	189

Source: Own elaboration via reproduction of Eviews10 software.

Table 5: Unit root test and lags applied

Unit root test (prob)	ADF	KPSS	PP	LLC	Results	Lags adopted after tests
lfleet	1	1	0,76	0,96	Presence of a unit root	(-1)
Lfleetall	0,82	0,99	0	0	Undetermined	(-1)
lfuel	1	1	1	1	Presence of a unit root	(-2)
lpop	0	0	0	0	There is no unit root	-

Source: Own elaboration via reproduction of Eviews10 software.

Table 6: Hausmann test for random effects

Hausmann test				
Cross-section test for Random Effects				
Test summary		**Chi-Sq. Statistic**	**Chi-Sq. d.f.**	**Prob.**
Randon Cross-section		0.000000	4	1
Variable	**Fixed**	**Random**	**Var (Diff.)**	**Prob.**
DUMMY	0.303605	0.312314	-0.001587	NA
lfuel (-2)	0.888175	7.816.298	-0.886757	NA
lfleetall (-1)	15.770.295	2.614.390	1.871.268	0.0000
lpop	-8.364.908	-1.703.231	0.283788	0.0000
Result for fixed effects				
Variable	**Coefficient**	**Standard Error**	**t-Statistic**	**Prob.**
C	-9.535.994	1.905.473	-5.004.529	0.0000
DUMMY	0.303605	0.113395	2.677.418	0.0086
lfuel (-2)	0.888175	1.042.474	0.851987	0.3962
lfleetall (-1)	1.577.029	1.437.534	1.097.038	0.0000
lpop	-8.364.908	0.724583	-1.154.445	0.0000
Cross-section Fixed effects (with dummy)				
R-squared	0.782809	Durbin-Watson stat		0.965039
F-statistic	1.981.871	Adjusted R-squared		0.827850
Prob(F-statistic)	0.000000			

Source: Own elaboration via reproduction of Eviews10 software.