Departament d’Economia Aplicada
Universitat Autònoma de Barcelona

WORKING PAPER 25-02

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Policies to reduce cars' emissions between the opposing forces of technological change and demand for characteristics

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February 2025

Abstract

This paper carries out an empirical analysis of the determinants of CO2 emissions of new cars in Spain between 2015 and 2020. Technological change is shown to result in a decrease of emissions by 9%. However, the demand shift towards larger and more powerful vehicles has offset half of these gains. Moreover, the penetration of hybrid technologies has contributed to reducing emissions by a further 8.7%. Additionally, we estimate the determinants of emissions due to car characteristics, and we find that they are sensitive to socioeconomic and geographic variables, such as income, city size or its rural/urban character. We find an emissions elasticity with respect to fuel prices of -0.37. This is shown to be due to the purchase of less emitting cars and a higher share of more technologically efficient vehicles. Finally, scrappage programs, subsidies to the purchase of electric vehicles and the establishment of low emission zones succeed in reducing emissions. However, their effects are small and depend on the design of such measures.

Keywords: CO2 emissions, technological change, car characteristics, hybrid technology, demand determinants, electric vehicles

JEL: Q55, Q58, R48

1. Introduction

Some of the policies that have received more attention in the fight against climate change are the ones aiming at decarbonizing new vehicles, which is justified by their large contributions to CO_2 emissions. Different policies are being developed in Europe in this vein. Among the most drastic, the EU set, in 2009, an upper limit to CO_2 emissions by registered new vehicles. This regulation, binding on all car makers, became increasingly restrictive in the following years. Besides, EU member states have also tried to reduce the emissions of new vehicles by making their taxation dependent on emissions and subsidising the replacement of cars using internal combustion engines by those using hybrid technologies or alternative energy sources, such as gas or electricity. As a more drastic measure, in 2023 the EU decided to ban the sales of new CO_2-emitting cars in 2035 (Regulation (EU) 2023/851). Nevertheless, given the strong opposition to this measure from the European car manufacturers[1], it may well be that combustion-engine vehicles remain on the market for a longer period of time.

Despite the fact that decarbonizing policies have been applied for a relatively long period of time, the rate of reduction of CO_2 emissions has not always been fast enough. In this paper we aim at quantifying the main determinants of CO_2 emissions of new registered cars with the ultimate goal of contributing to the better design of policies oriented at reducing cars' emissions. We analyse the case of the Spanish passenger vehicle market during the years 2015-2020 using administrative data of the complete population of new cars registered during that period. We distinguish between different types of engine: gasoline, diesel, hybrids (HEV), plug-in hybrids (PHEV) and battery electric (BEV).

We approach our goal from two perspectives. In the first one, we decompose the shift over time in CO_2 emissions into changes due to technical change and the changes in the characteristics of the vehicle fleet. In addition to quantifying the role played by technical change, this approach allows estimating the counteracting effects caused by an increase in the engine power and size of vehicles and the positive effects derived from the increasing penetration of hybrid and electric vehicles. We carry out such decomposition distinguishing between gasoline and diesel engines and hybrid technologies. The second approach consists of identifying which are the drivers of consumers' behaviour which explain the demand for

[1] Car manufacturers are usually supported by national governments, as shown by Germany's obtaining an exemption for cars running on e-fuels (Abnett, 2023).

vehicle characteristics and consequently the emissions that can be attributed to these characteristics. Our objective is to better understand and quantify which is the mechanism through which consumer demand influences emissions, as well as the role that different policies can have. We use the decomposition equation to compute the estimated emissions caused by vehicle characteristics and regress these estimated emissions against a set of socioeconomic, geographical and policy variables. To do this, we work at municipal level exploiting the availability of detailed geographical information about the location of car buyers. Additionally, we look at the impact of policies such as fuel price changes, subsidies to the purchase of more efficient vehicles (including electric vehicles -EV- and scrappage programmes of older cars) and the implementation of Low Emissions Zones (LEZ). [2]

Our method is of practical utility for the analysis of public policies in this area, as it considers policy variables together with socioeconomic characteristics of the car buyers or the geographic environment where they live. Moreover, we obtain specific results for gasoline, diesel, hybrids, PHEV and BEV engine types.

Since the empirical analysis covers the period from 2015 to 2020, it has been necessary to homogenise CO_2 emissions to the measurement method implemented in 2017. Working with homogeneous emissions allows correcting the trend observed in previous years, which saw increasing discrepancies between real emissions and those obtained under laboratory conditions. Using such homogenised emissions data, we are able to estimate the contribution of technical change to emissions' reduction without being dependent on measurement errors.

The paper provides new results to the debate on transport decarbonization. Our results show that even in the context of increasing electrification, technological change has reduced CO_2 emissions of the new registered cars by around 9% between 2015 and 2020, with a more pronounced effect since 2019. However, consumers' preferences for larger, heavier and more powerful vehicles have counterweighed half of this reduction. For gasoline cars, hybrid technologies have contributed to further reductions of CO_2 emissions. However, for diesel cars, this effect is notably smaller and only significant after 2019. Regarding the influence on emissions of the demand for vehicles' characteristics, we find that the elasticity of emissions with respect to income level is close to zero due to two effects acting in opposite directions: higher income results in the purchase of more powerful vehicles, but also of more

[2] The analysed policies could also have a scale effect (affecting the total number of cars sold) and a rebound effect (modifying driven distances), which are not considered in this paper.

environmentally friendly ones. In terms of policies, higher fuel prices lead to lower CO_2 emissions through the purchase of more fuel-efficient gasoline cars but also by increasing the demand for electric and diesel vehicles (whose engines produce less CO_2 than their gasoline equivalents, but more nitrogen oxides and particulate matter). We also find that scrappage programmes implemented to subsidize the purchase of low emission cars can reduce the CO_2 emissions of gasoline, hybrid-gasoline and diesel cars by around 4%. Subsidies for the purchase of EVs have a positive but moderate effect. Finally, the LEZs in Madrid and Barcelona are found to increase the share of hybrid vehicles, but not that of BEVs. Even if our results are dependent on the Spanish data used to estimate our models, we consider that they can be relevant to other contexts, as the characteristics of the Spanish car market are very similar to those of other large European countries.

The paper is organised as follows. After this introduction, section 2 details the related literature and section 3 describes the data. In section 4 we present the methodological approach and the results of the decomposition analysis. In section 5 we estimate the determinants of CO_2 emissions due to car characteristics, that is emissions not explained by technical change. Section 6 discusses the main findings and policy implications of the study and section 7 concludes.

2. Related literature

There is a large body of literature that analyses the changes in the level of cars' CO_2 emissions from different perspectives. This section deals with those branches of such literature directly related to the aims of our paper. Firstly, we focus on the role that technological change plays in improving emissions and, secondly, on the impacts of specific policies addressed at reducing CO_2 emissions.

Many papers measure the extent to which technological improvements have contributed to reducing fuel consumption and, hence, CO_2 emissions (see, for instance, Knittel, 2011; Voltes-Dorta et al., 2013; Bento et al., 2015; Klier and Linn, 2016; Matas et al., 2017; Craglia and Cullen, 2019; Greene et al., 2020; Reynaert, 2021). It is difficult to compare the estimations of technological change obtained in different papers, as the covariates included in each model are not always the same. However, some common facts can be established from this literature. First, it is generally concluded that compulsory emission standards and fuel prices play a central role as determinants of technological improvements (Knittel, 2011; Voltes-Dorta et al., 2013; Bento et al., 2015; Klier and Linn, 2016; Reynaert, 2021). Second, a substantial part of the reduction in emissions due to technological change has been offset by increases in the size and the power of cars (MacKenzie and Heywood, 2015; Matas et al., 2017; Craglia and Cullen, 2019; Mosquim and Mady, 2021). In the case of Europe, it has been observed that part of the technological gain is explained by the ability of manufacturers to adapt their cars to the emissions' measurement tests (Craglia and Cullen, 2019; Reynaert, 2021).

Regarding the environmental effects of policies addressed to the car market, the literature is also very large. In order to focus on contributions more directly related to our research question, we review the studies that quantify the impact of policies on consumers' decisions regarding the choice of the type of car and on its emissions. The policies we look at correspond to the ones considered in our empirical model: changes in fuel prices, financial incentives to promote fleet renewal and implementation of LEZs. The review also concentrates on papers that have looked at the impacts on the Spanish market.

Given the fixed relation between fuel consumption and the amount of CO_2 emissions, we can expect that any increase in the price of fuel will reduce emissions through a shift towards ownership of more fuel-efficient cars.[3] Several papers report that higher fuel prices affect the composition of the fleet by increasing both the purchases of more fuel-efficient new vehicles and through the rate of scrapping old vehicles (Diamond, 2009; Li et al., 2009; Gallagher and Muehlegger, 2011; Beresteanu and Li, 2011; Burke and Nishitateno, 2013; Klier and Linn, 2013; De Borger and Rouwendal, 2014; Jacobsen and Van Benthem, 2015, Bento et al., 2018; Gerlagh et al., 2018). However, although significant, the effect is found to be inelastic. For instance, Li et al., 2009 estimate an elasticity of the fleet's fuel economy with respect to gasoline prices in US metropolitan areas to be 0.022 in the short run and 0.204 in the long run. Regarding the effects of fuel prices on emissions due to scrappage decisions, Jacobsen and Van Benthem, 2015 and Bento et al., 2018 find that an inelastic demand for scrappage with respect to car prices lowers the potential effects of gasoline prices, as that is the channel through which fuel prices influence scrapping decisions.

As the level of harmful emissions is related to the age of the car and the type of fuel used, governments have also been interested in promoting fleet renewal. In order to do so, in some countries it has been common to implement financial incentives related to scrappage and

[3] An increase in fuel prices will also reduce the distance driven. See De Borger and Rouwendal (2014) for a simulation of the expected effects of rising fuel prices and kilometre tax changes on the demand for kilometres and on overall fuel consumption.

renewal schemes ('cash-for-clunkers').[4] Although scrappage policies have been widely analysed, there seem to be no conclusive results about their effectiveness in reducing emissions. Whereas some authors find positive effects, others find that the effects are modest and, even if the programme is extended over time, they tend to disappear in the long run as the policy simply advances scrappage decisions (see Van Wee et al., 2011 for a review of these programmes). The results of the analyses carried out in Spain can illustrate the impacts of these policies. Given the relatively large importance of car manufacturing activities in Spain, different scrappage programmes have been implemented since the early 1990s. It is generally found that they have had a positive impact on sales (Licandro and Sampayo, 2006; Grigolon et al., 2016; Cantos-Sánchez et al., 2018; Laborda and Moral, 2019), although the effects fade out in the long run and part of the subsidy leaks out to higher producer prices (Jiménez et al., 2016). Laborda and Moral, 2019 dispute the idea that the effects of 'cash for clunkers' programmes in terms of lower emissions may disappear in the long run, as they observe that they facilitate the adoption of newer technologies which, as a result, become standard. Along the same lines, Grigolon et al., 2016 argue that targeted scrappage schemes, which condition the subsidy on the purchase of new vehicles in terms of their emissions levels, had significant environmental benefits in the form of improved fuel consumption, and therefore may act as long-term instruments to increase the demand for more fuel-efficient cars with environmental benefits.

More recently, government policies have been oriented towards providing financial incentives for the purchase of electric vehicles. Those incentives can include different instruments, such as rebates on the purchase price, tax benefits, and direct subsidies. Most of the empirical literature shows that financial incentives have a positive effect on sales of EVs (Hardman et al., 2017; Münzel et al., 2019). Nonetheless the magnitude of this effect tends to be moderate or small (Jenn et al., 2018; Wee et al., 2018; Clinton and Steinberg, 2019; Azarafshar and Vermeulen, 2020; Anghel et al., 2022). Besides, Alberini and Vance (2023) conclude that although rebates for BEVs have a significant positive effect on the share of such cars, the effect on CO_2 emissions is very low when accounting for lifecycle ones.

LEZs are increasingly favoured policies aimed at reducing emissions in urban areas. The policy consists in restricting the access of more polluting vehicles to a specific area, usually part of a city. As the restrictions are based on the vehicle's emissions, they can be expected

[4] The main aim of such programmes has very often been related to a willingness to support the car industry, as it boosts the sales of new cars during recessions. Empirical evidence shows that although this expected effect exists, it tends to be transitory (see, for instance, Adda and Cooper (2000))

to have an impact on the scrapping of old vehicles and the purchase of less polluting ones. Most of the literature concludes that LEZs succeed in improving air quality, although the intensity of the effect depends on local conditions and the details of the regulation (Wolff, 2014; Malina and Scheffler, 2015; Gehrsitz, 2017; Bernardo et al., 2021, Salas et al., 2021, Ellison et al., 2013). There is also evidence about how LEZs change the composition of the vehicle fleet towards one with lower emissions rates (Wolff, 2014 and Ezeah et al., 2015).
For the specific case of Spain, three studies have looked at the effects of the Madrid LEZ, which was implemented in 2018 in the city's central area. Peters et al., 2021 find that following its creation vehicle demand shifted towards alternative fossil fuel vehicles and PHEVs, but the share of zero-emission vehicles (BEV and Extended Range Electric Vehicles, EREV) did not increase. Consequently, it had a very limited effect on the average CO_2 emissions of purchased new vehicles. Balaguer et al., 2023 find that the LEZ encouraged the scrapping decisions in the districts surrounding the LEZ, consequently having a positive effect on air quality. This is particularly true for older diesel vehicles, which are not allowed to enter the restricted area. However, the effect seems to be transitory. Similarly, Tassinari, 2022 finds evidence of the LEZ's inducing fleet renewal, with a shift towards cleaner and non-restricted vehicles.

3. Data

We exploit detailed data on registered new vehicles in Spain for all the years between 2015 and 2020 (both included), which is made publicly available by Dirección General de Tráfico (DGT), the traffic authority responsible for all vehicle registrations. We select passenger cars (including four-wheel-drive ones[5]) and exclude vans, minibuses and other vehicles that clearly are not meant to be used as passenger cars. We also exclude brands that sell less than 50 vehicles during the period of analysis.

DGT data includes variables that make it possible to identify the following types of engine: gasoline, gasoline-hybrid, diesel, diesel-hybrid, plug-in hybrid (PHEV, which may use either gasoline or diesel) and battery electric cars (BEV). Liquified Petroleum Gas (LPG), natural gas and hydrogen powered cars also exist, but are excluded from our dataset due to their very low market share and high volatility in registration figures. This also applies to EREVs, so that the resulting dataset consists of 6.83 million observations. DGT also provides

[5] The Spanish official statistics on vehicle registration differentiate between standard cars and four-wheel drive ones (FWD). The latter refers to a specific technology capable of providing power to all wheel ends of a two-axle vehicle simultaneously. In our sample, we identify FWD from the information contained in the database.

variables with information on individual vehicles, from which at some point in our analysis we use the registration date, make, model, variant, version, segment[6], type of engine, displacement (cm^3), engine power (kW); weight (kg); CO_2 emissions (g/km) and, for non-combustion engines, electric energy consumption (Wh/km). The number of cylinders is computed from the values of fiscal horsepower and displacement.

Table 1: Distribution of registered cars by year and engine type

Full sample	Gasoline	Gasoline hybrid	Diesel	Diesel hybrid	Plug-in hybrid	Battery electric	Registrations
2015	36.1%	1.1%	62.5%	0.0%	0.1%	0.1%	908,523
2016	39.4%	2.6%	57.7%	0.0%	0.1%	0.2%	1,162,776
2017	45.1%	4.3%	50.0%	0.0%	0.3%	0.3%	1,271,318
2018	55.4%	5.5%	38.1%	0.1%	0.4%	0.5%	1,342,090
2019	59.6%	7.3%	30.6%	1.1%	0.6%	0.8%	1,280,392
2020	48.4%	12.8%	31.2%	2.8%	2.7%	2.1%	871,405
Total							6,836,504
Registered by individuals	**Gasoline**	**Gasoline hybrid**	**Diesel**	**Diesel hybrid**	**Plug-in hybrid**	**Battery electric**	**Registrations**
2015	41.0%	1.4%	57.5%	0.0%	0.0%	0.1%	595,967
2016	46.3%	3.3%	50.2%	0.0%	0.1%	0.1%	644,021
2017	53.7%	5.9%	40.0%	0.0%	0.2%	0.1%	672,381
2018	63.9%	7.0%	28.6%	0.0%	0.2%	0.2%	688,598
2019	64.3%	8.9%	25.0%	1.0%	0.3%	0.5%	614,642
2020	56.7%	14.9%	24.1%	2.2%	1.1%	1.1%	447,499
Total							3,663,108

Additionally, DGT reports whether each car was registered by a private individual or by a firm. The latter case corresponds mainly to company cars, rental firms and leasing intermediaries. This category of firms' registrations creates a problem in terms of the reliability of the reported location of the owner, as it is known that for fiscal reasons firms owning large vehicle fleets tend to register them at some specific municipalities with much

[6] We identify the segments by merging DGT vehicles' data with the categories provided by Aniacam, an association of vehicle importers.

lower tax rates. Therefore, when in Section 5 we analyse how the preferences for car characteristics affect emissions at municipal level, the data is necessarily limited to cars registered by individuals, as these are the only ones where we can reliably identify the owner's municipality of residence. Table 1 shows the annual distribution of types of engine of registered new cars both for the full sample and for vehicles owned by individuals.

A declining trend of sales of diesel vehicles is observed during the whole period. Since 2015, the year when Volkswagen's emissions scandal erupted, the market share of diesel cars has continuously fallen, so that its 2020 level is less than half that of 2015. Diesel cars have been replaced by gasoline ones, partly due to the continuous increase in the demand for gasoline hybrid vehicles. BEVs and PHEVs still show very low market shares, which are even lower for individually-owned cars. However, a significant increase is observed in 2020 in the share of cars using alternative technologies (from hybrid to electric vehicles), which is related to the manufacturers' need to meet the new emission targets set by the EU[7], as they were partially met by increasing the number of new models in the market using alternative technologies. One example of such a response is the appearance of diesel hybrids in the market after 2019.

As CO_2 emissions is our main variable of interest, we have to deal with the implications of the change in their measuring procedure in EU countries. Following the European Commission's 2017/1151 regulation, the New European Driving Cycle (NEDC) has been replaced by the Worldwide harmonised Light vehicles Test Procedure (WLTP), which provides higher accuracy in reflecting changes in driving trends as well as development in technology. Consequently, WLTP yields higher CO_2 emissions than NEDC did, which has direct implications for both the EU efficiency policy based on CO_2 targets and the national registration taxes set according to CO_2 emissions. In order to smooth the impact of applying the new procedure, the EU agreed to phase in its implementation[8] as well as setting a transition period until the end of 2020 during which the NEDC-based CO_2 target was kept. Therefore, a mechanism was needed in order to translate the results of the WLTP into the terms of the NEDC. This was the so-called 'WLTP NEDC correlated' (NEDC*) procedure, established by EU Regulation 2017/1153. NEDC* stands for measurements that follow the WLTP, but which are translated into NEDC terms. It could be expected that the values of the

[7] The EU target for cars decrease from 130 CO_2 g/km for the period 2015-2019 to 95 CO_2 g/km for 2020-2021.

[8] Starting in September 2017, all new passenger car models have been being tested according to WLTP. Since September 2018, all registrations of passenger cars require the WLTP, except for end-of-series models. The transition period ended in January 2021.

NEDC* be similar to those of the NEDC. However, NEDC* values have been found to be higher than those obtained under the previous NEDC test cycle (JATO, 2018).

Given those changes in the testing procedure used to report CO_2 emissions, it is necessary to obtain homogeneous values for the period under analysis. Our strategy to do so takes advantage of the phasing-in approach the EU established when applying the new test cycle together with the information on the exact date of registration contained in the dataset. We provide the details in Appendix A.

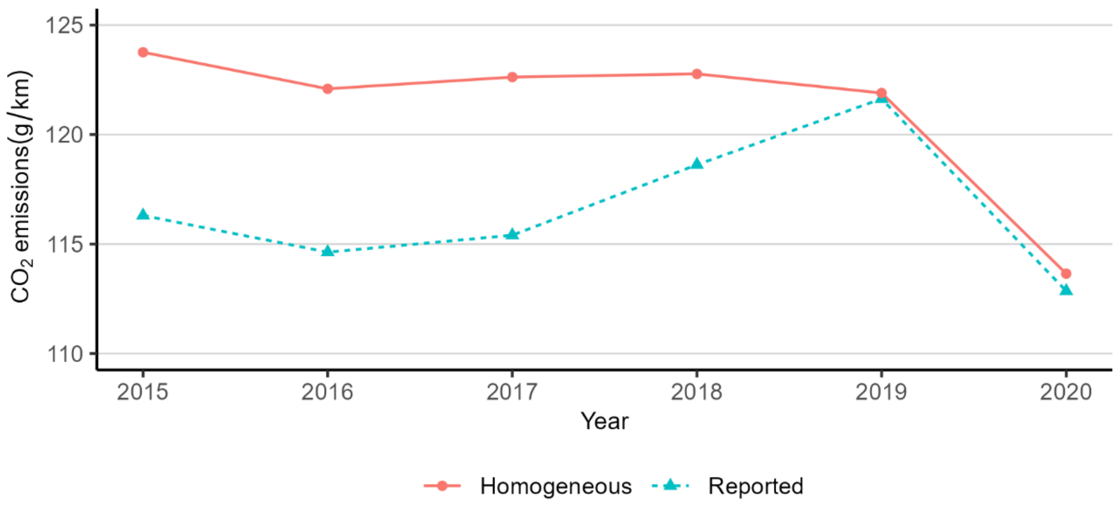

Figure 1: Evolution of homogeneous and reported CO_2 emissions

Figure 1 shows the evolution of the average CO_2 emissions per vehicle with an internal combustion engine (including plug-in hybrids), according to both the reported emissions and the ones homogenised to NEDC*. As can be observed, the original uncorrected data shows a continuous increase in emissions up to 2019. However, with homogenised measures, the upward trend is replaced by a stable evolution during that period, followed by a sharp decline in 2020, which is explained by the appearance of new models with improved energy efficiency as well as the increase in the share of hybrid vehicles. In what follows, we only work with homogenised NEDC* CO_2 emissions.

A second problem with the data that needs being addressed is by how much the emissions obtained in laboratory tests deviate from those in real driving conditions. Tietge et al., 2015, using consumption data, find not only that these two measures do not match, but that the gap between the NEDC test fuel consumption and the real-world consumption widened until

2015. For our sample period, Dornoff et al., 2020 show that in 2015-2016 the gap between real-world and laboratory tests results remained approximately constant. From that date on, the gap narrows progressively as new cars with NEDC-correlated reported emissions enter the market. This implies that our homogenisation of NEDC emissions into NEDC-correlated ones would, at least partially, correct for this gap. Therefore, although they may not reflect the actual emissions in the real world, the car-level emissions used in our data can be considered homogeneous across time.

Table 2 provides the annual mean values of CO_2 emissions and of those characteristics included as explanatory variables in the emission equations: weight, horsepower (kW) and the number of cylinders, distinguishing by type of engine[9]. The highest CO_2 emissions correspond to gasoline cars, followed by diesel, hybrids, plug-in hybrids and, finally, battery electric ones[10]. However, it should be noted that the reported emissions for hybrid vehicles greatly depend on the assumptions regarding the distances run using electric power. Tietge et al., 2015 show that emissions in real driving conditions are considerably higher than those obtained in the laboratory tests. For the case of plug-in hybrid electric vehicles Plötz et al., 2022 report real-world CO_2 emissions two to four times larger than those obtained from NEDC values, whereas for WLTP, the difference ranges between three and five times. Such a high discrepancy is explained by the fact that the real-world share of electric driving is much lower than that assumed in the laboratory tests. Since this gap varies greatly between vehicle models and type of drivers, it has not been possible to correct for it. For electric cars, we only consider emissions related with driving (tank-to-wheel).

For all types of vehicles, emissions remain relatively stable over time. As already mentioned, the only significant change is the sharp decline in 2020 observed for gasoline, diesel and, to a lesser extent, plug-in hybrid cars.

In the cases of gasoline non-hybrid, diesel and BEV, a continuously increasing trend in horsepower and weight is observed over the sample period. The number of cylinders for gasoline cars shows the practice of engine downsizing carried out by manufacturers trying to provide more energy efficient vehicles while maintaining power. However, this practice is not observed for diesel vehicles.

[9] Due to space constraints, the distribution of car registrations among segments and FWD are shown in Table A.1 in Appendix E

[10] For electric vehicles we convert electric consumption (kWh per km) into CO_2 emissions according to the average Spanish CO_2 intensity of the electric mix. In order not to distort the comparisons, we used the average conversion rate for the sample years weighted by the number of electric cars sold in each year (0.197 CO_2 tn/MWh). The average CO_2 intensity of the Spanish electric mix has decreased from 0.29 (equivalent CO_2 tn/MWh) in 2015 to 0.15 in 2020 (REE, 2024)

Table 2: Average emissions and characteristics. Registered new cars in Spain, 2015-2020.

	2015	2016	2017	2018	2019	2020
Gasoline (not hybrid)						
CO_2 (g/100 km)	127.9	127.3	127.5	126.9	126.1	118.6
Horsepower (kW)	77.0	79.3	82.8	85.8	89.0	90.9
Weight (kg)	1203	1210	1232	1262	1286	1287
Cylinders (no)	3.68	3.67	3.63	3.52	3.47	3.38
Gasoline (hybrids)						
CO_2 (g/100 km)	94.0	101.8	100.7	99.5	98.6	98.9
Horsepower (kW)	72.2	84.2	81.5	81.3	92.2	95.0
Weight (kg)	1405	1529	1520	1492	1494	1450
Cylinders (no)	4.02	4.04	4.02	4.02	4.02	3.85
Diesel (not hybrid)						
CO_2 (g/100 km)	122.0	119.6	120.4	120.7	119.9	115.1
Horsepower (kW)	90.1	92.5	94.1	96.2	98.0	98.4
Weight (kg)	1456	1468	1474	1497	1523	1526
Cylinders (no)	4.01	4.00	4.01	4.02	4.02	4.02
PHEV						
CO_2 (g/100 km)	77.0	79.5	74.6	72.8	77.6	67.0

4. Decomposing the shifts in CO2 emissions over time

In order to identify the role that technological change and product characteristics play in the CO_2 emissions of new registered cars we follow the framework proposed by Newell et al., 1999 and Knittel, 2011. Essentially, this amounts to estimating a reduced form equation in which CO_2 emissions are modelled as a function of the car's characteristics and a set of annual dummy variables that capture the technological improvements[11]. This can be expressed as

$$E_{it} = f(X_{it}, u_{it})T_t \tag{1}$$

where E_{it} are the emissions of a vehicle i in year t, which are a function of a vector of the vehicle's characteristics X_{it} multiplied by the impact of technological change T_t, captured by annual dummies. The empirical model obtained when taking logs of Equation (1) assumes

[11] Whereas in Knittel (2011) the dependent variable is fuel efficiency, we use CO_2 emissions. Given the direct relationship between these two variables, the same methodological framework can be applied.

that technological progress enters the emission equation as an additive term[12], and u_{it} is the error term of the estimated equation.

Expression 1 makes it possible to decompose the observed changes in CO_2 emissions into two components: the reductions due to technological progress and the potentially offsetting effect of the car's characteristics. The results of estimating this relation also allow computing the specific impact on a vehicle's emissions for each one of the characteristics included in X. When a linear logarithmic relation is assumed for Equation (1), we obtain an empirical model such as

$$\ln(E_{it}) = \underbrace{T_t}_{\ln(E_t^T)} + \underbrace{\beta' \ln(X_{it})}_{\ln(E_{it}^C)} + u_{it} \tag{2}$$

Here, the E_{it} are the emissions (CO_2 in g/km), T_t are year dummies, X_{it} are the characteristics of a car that are related to CO_2 emissions and u_{it} is an error term. The terms E_t^T and E_{it}^C measure the emissions' evolution due to technical change and car characteristics, respectively.

To estimate Equation (2) we use individual data of all types of vehicles that use an internal combustion engine (gasoline, diesel, hybrids and PHEV). Given the small number of battery electric cars in the market, we exclude them from the analysis in this section[13]. We allow for different coefficients for diesel cars for all the variables in the equation since they have a different fuel technology. Regarding HEV and PHEV, given the low number of car models in the market, particularly in the first years of the sample, the differences in emissions are captured by the constant term in the equation.

[12] Underlying the empirical work is a marginal cost function for producing a vehicle at time t with a given level of fuel economy and given characteristics. Knittel (2011) assumes a marginal cost function that is additive and separable in the car's attributes related to fuel consumption and the rest of the car's characteristics. For a given level of cost C, fuel consumption can be expressed as a function of the car's attributes. In this way, we estimate an iso-cost function using a reduced form equation.

[13] However, we estimate an equation for battery electric cars in order to compute the emissions variable to be used in Section 5. The dependent variable for BEV is the electric energy consumption (kWh/km) which is transformed into emission as explained in footnote 10. The estimated equation is presented in Table A.4 in Appendix E.

Table 3: Estimation results. Emissions models.
(estimated coefficients and t-statistics)

	(1)	(2)
ln(weight)	0.4737	0.4612
	7.43	11.49
ln(horsepower)	0.0687	0.0814
	3.75	4.56
ln(cylinders)	0.3229	0.2811
	9.88	6.87
HEV	-0.3436	-0.288
	-10.38	-7.72
PHEV	-0.8392	-0.8406
	-20.03	-20.04
FWD	0.0771	0.0795
	4.15	4.62
Constant	0.7925	0.9458
	1.71	2.97
ln(weight)*diesel	0.2701	0.2802
	3.36	4.13
ln(cylinders)*diesel	-0.2122	-0.18
	-4.4	-4.23
HEV*diesel	0.264	0.1963
	8.2	6.76
Constant*diesel	-1.8551	-2.0773
	-3.37	-4.34
Year		
2016	-0.0202	-0.0186
	-4.78	-5.06
2017	-0.0231	-0.0216
	-4.34	-4.52
2018	-0.0352	-0.0354
	-5.81	-6.59
2019	-0.0517	-0.0537
	-8.83	-10.24
2020	-0.0936	-0.0974
	-11.89	-14.62
Segments	Yes	Yes
Brands	No	Yes
Obs.	6,792,877	6,792,877
R^2	0.77	0.83

Note: Errors are clustered at brand level

We select the explanatory variables in (2) following the literature but conditioned by data availability. Thus, we include the cars' weight, engine power and number of cylinders, plus dummy variables accounting for the different types of car, brands, segments, and technologies: FWD, hybrid and PHEV. Table 3 presents the estimation results of equation (2) with (column 1) and without (column 2) brand fixed-effects[14]. Given that the estimated coefficients for the variables of interest are very similar in the two specifications, in what follows we use the results from the model without brands in order to capture the full trade-off between the characteristics of the cars and technological change.

The estimated coefficients take the expected signs and are statistically significant. Since all continuous variables are in logs, their coefficients can be interpreted as elasticities. The magnitude of the coefficients is generally consistent with those found in the literature (Klier and Linn, 2016; Matas et al., 2017; Gerlagh et al., 2018), although comparisons are conditional on the variables included in each case. Hybrid technology reduces the emissions of a gasoline car by 29%, while plug-in hybrid does this by 57%. The reduction is only 7.7% for diesel hybrid technology. For diesel cars, we obtain a higher elasticity with respect to weight and a lower one with respect the number of cylinders than for gasoline ones. FWD increases CO_2 emissions by almost 8%.

The estimated coefficients for the annual fixed effects show a continuously decreasing trend in CO_2 emissions. Given our specification, these coefficients can be interpreted as technological change. It may be the case that the coefficients capture potential divergences between laboratory tests and real-world consumption data. However, as explained in the data section, we can safely assume that this difference has remained approximately constant in our data and, hence, the annual coefficients should not be affected. According to our estimations, for both gasoline and diesel cars technological change has reduced CO_2 emissions by around 9% between 2015 and 2020, with a more pronounced effect since 2019.

To better show how the technical change and the change in characteristics have affected the evolution of emissions we have built separate accumulative annual indexes. The indexes have been computed using the estimated coefficients presented in Table 3 and the average annual value of the explanatory variables. Specifically, a cumulative index of technological progress is built using the estimated annual fixed effects, while a similar one for the

[14] In preliminary estimations for diesel cars, the variables that were found to have a significantly different impact on CO_2 emissions are weight, the number of cylinders, hybrid technology, and the constant term. For the rest of the variables, including annual dummies, the specific coefficients for diesel technology were not statistically significant. Consequently, in the specification presented in Table 3, only the significant variables for diesel are included in the equation. The low number of plug-in diesel models do not allow properly testing a different effect.

characteristics is built using the corresponding estimated coefficients multiplied by the change in the log of the explanatory variables[15].

Moreover, the contribution of cars' characteristics is decomposed into the contribution of each category of them, which we define as engine power (including weight, horsepower and number of cylinders), hybrid technology (HEV and PHEV), and type of car body (segments and FWD). Thus, we can measure by how much changes in the three different components of the attributes either offset or reinforce the reduction in emissions due to technological change. For each index the starting point is the average CO_2 emissions in 2015. In each successive year we add (or subtract) the estimated change in emissions due to the corresponding component. All the indexes are constructed separately for gasoline and diesel cars (including their hybrid variants). The results are plotted in Figure 2, while Table A.2 in Appendix E presents the values.

As already mentioned, technological change has been continually contributing to reducing CO_2 emissions between 2015 and 2020. However, for both gasoline and diesel engine types, the shift to more powerful cars significantly pushed emissions upwards and thus partially offset the adoption of more fuel-efficient technologies[16]. The cumulative effect over the period 2015-2020 is 4.6% and 5.6%, respectively, for each fuel type. Hybrid technologies contribute to reducing emissions by 8.7% in the case of gasoline engines, whereas for diesel ones the presence of hybrid technology is much smaller and has only taken place since 2019. This can be explained by the fact that diesel HEV and PHEV models only appeared significantly in the Spanish market in 2019. Finally, changes in the composition of the fleet by car segment and FWD have made no significant contribution to changes in the level of emissions after controlling for weight and engine power. In addition, given that the actual

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[15] The estimated emissions for years *t* and *t+1* can be written as:

$$\ln(E_{it}) = \hat{T}_t + \hat{\beta}' \ln(X_{it}) + \hat{u}_{it}$$
$$\ln(E_{it+1}) = \hat{T}_{t+1} + \hat{\beta}' \ln(X_{it+1}) + \hat{u}_{it+1}$$

By averaging over individual observations, the arithmetic mean for each variable is obtained:

$$\overline{\ln(E_t)} = \hat{T}_t + \hat{\beta}' \overline{\ln(X_t)} + \overline{\hat{u}_t}$$
$$\overline{\ln(E_{t+1})} = \hat{T}_{t+1} + \hat{\beta}' \overline{\ln(X_{t+1})} + \overline{\hat{u}_{t+1}}$$

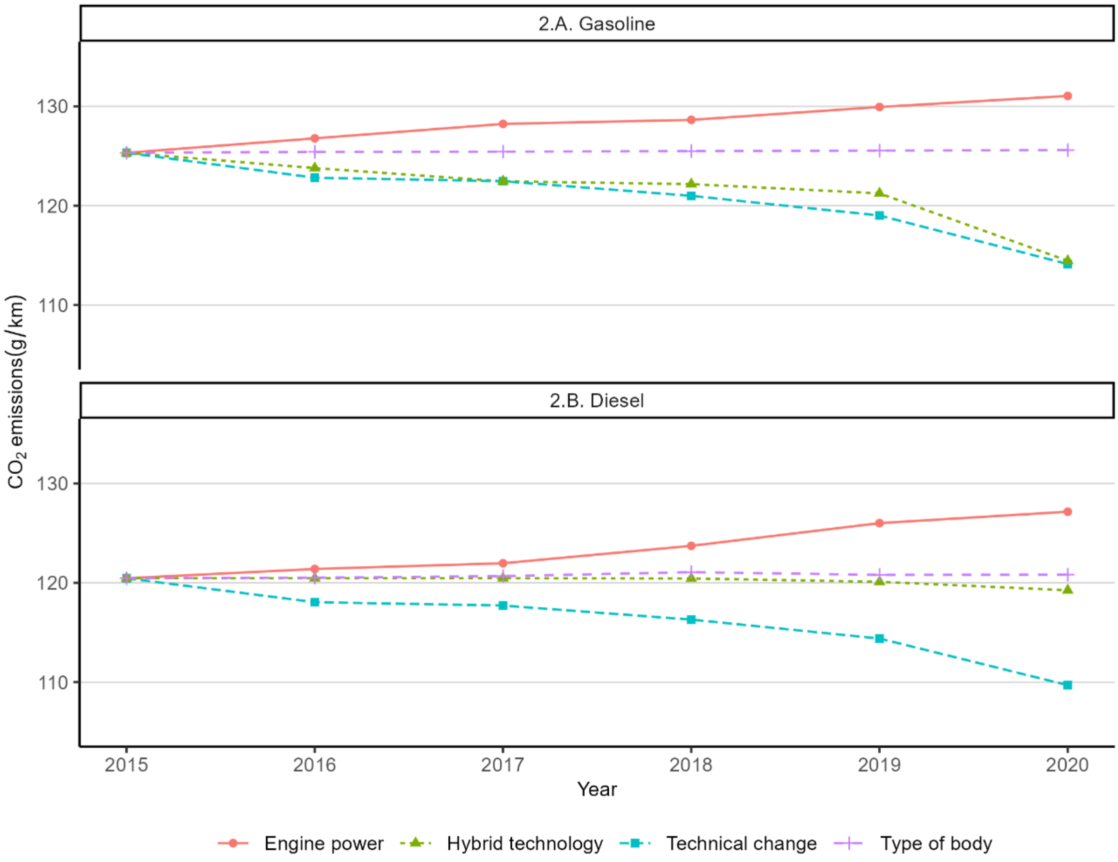
Then, taking differences between the two equations:

$$\underbrace{\Delta \overline{\ln(E_t)}}_{\substack{Variation\ of\\ emissions}} = \underbrace{\Delta \hat{T}_t}_{\substack{Variation\\ explained\ by\\ technology}} + \underbrace{\Delta \hat{\beta}' \overline{\ln(X_t)}}_{\substack{Variation\\ explained\ by\\ characteristics}} + \underbrace{\Delta \overline{\hat{u}_t}}_{Unexplained}$$

When averaging over all individual observations, $\overline{\hat{u}_t}$=0. However, as we take averages of gasoline cars and diesel cars separately, the average of OLS residuals can be different from zero and, thus, a small fraction of the observed variation remains unexplained.

[16] Our results are in line with those of Craglia and Cullen (2019), who, using data for British vehicles between 2001 and 2018, show that size and power increases offset technological change, and this effect is much more important in the case of diesel cars.

emissions of hybrid, and particularly plug-in hybrid, are higher than the ones reported by laboratory testing, a part of these gains may not have materialised.



5. CO_2 emissions due to car characteristics

Having estimated the technical change equation, we are able to measure which are the emissions due to the characteristics of registered new cars. Our interest now is to know how socioeconomic attributes of car buyers as well as policies have an impact on those emissions. In order to do that, we need to estimate the way in which consumers' socioeconomic attributes (such as income) impact on purchased cars' emissions (by increasing demand for more powerful vehicles) but also how they may have an effect on the type of car bought (for instance, increasing the relative demand for EVs). Hence, we also estimate the market share equations for the different types of cars. The answer to our questions will result from combining the estimation results of both effects.

Having estimated equation (2), we can measure the estimations due to vehicle's characteristics, and thus independent of technical change, as

$$\widehat{\ln(E_{it}^{C})} = \sum_{k=1}^{K} \hat{\beta}_k \ln(X_{kit}) \quad (3)$$

We regress those emissions against the set of explanatory variables that describe the socioeconomic, geographical and political determinants of car purchases.[17] Given that we do not have information about the individual attributes of car buyers, we exploit the variability of demand determinants at municipality level. The dependent variables (emissions due to car's characteristics and market share of each engine type) are computed at the municipal level for the whole of Spain, but at municipal district level for the largest cities of Madrid and Barcelona. In Appendix B we develop the analytical framework that supports the estimated relationship between predicted emissions and socioeconomic, geographical and policy variables. As the contribution of each explanatory variable to the CO_2 emissions depends on the type of engine, we carry out this analysis separately for gasoline, gasoline-hybrid, diesel, diesel-hybrid, PHEV and BEV. These are also the engine types for which we need to estimate the determinants of market shares. Hereby, it becomes possible to measure the effects that each explanatory variable has on emissions, both through their influence on the demand for the vehicles' characteristics and on the purchasing decisions on various types of engine.

Socioeconomic characteristics include income per capita and total residential population. It can be expected that the demand for certain characteristics is dependent on the income level, and certain types of engine or car may be more or less attractive depending on the size of the municipality. Geographical attributes are summarised by the distance to the provincial capital, which is usually the largest city at a distance of 100 km. We consider this variable as a proxy for the urban/rural character of the municipality, as those closer to the capital will tend to have a stronger urban character, which is expected to have an impact on the demand for the type of car engine and its characteristics.

Finally, the policy variables that we consider include the average annual price of gasoline and diesel fuel at provincial level, different regionally scrappage programmes targeted at low emission vehicles, subsidies available for purchasing electric cars (whose implementation varies by region) and, in the cases of Madrid and Barcelona, the

[17] Preliminary estimations of equation (3) indicated a correlation between the random disturbance term and the socioeconomic characteristics. To address this issue, we substitute the observed emission values for their expected values, thereby purging the correlation. As a proxy for the expected emission values, we use the predicted values computed as shown in equation (3). This approach provides a consistent estimation of the model parameters.

implementation of LEZs[18]. Additionally, we include provincial and year fixed effects. Descriptive statistics for these variables and their sources are presented in Table A.3 in Appendix E.

Two different types of scrappage programmes[19] have been in force during the considered sample period. The first one applied during some months in 2015 and 2016, whereas the second one was launched in July 2020, almost at the end of the sample period. Both are targeted programmes, as the eligibility of a car depends on aspects such as its price and CO_2 emissions. In parallel with scrappage programmes (but incompatible with them) the purchase of electric vehicles has been subsidised by different plans, the characteristics of which vary from year to year. Additionally, since 2019 the decision on the temporary implementation of such plans has been transferred to the regional governments, with the central government being responsible for the design of the plans. As a result, the actual starting date of the period and the number of months during which the plan is in force vary by region. Besides, we also take into account the plans introduced by some regional governments to promote the purchase of low emission vehicles and electric cars. Therefore, our identification strategy for this policy relies on both its temporal and regional variation. The monetary incentive variables have been created on a yearly basis considering the amount of the subsidy, the time the subsidy has been in force, and the place of residence.

LEZs exist in the cities of Madrid and Barcelona, making it possible to test the impact of this policy on the emissions of registered new cars, considering its potential impact on shifting demand towards less polluting ones. The Madrid LEZ covers only 4.7 km^2 in the central district of the city, but its entry requirements are very restrictive. The one in Barcelona covers a larger area but with less restrictive requirements regarding which vehicles can access it. As detailed in Appendix D, the Madrid LEZ was effectively implemented in November 2018, but since 2016 a non-permanent zone had been in force, whereas Barcelona established a non-permanent zone in 2017 that was made permanent in January 2020. Nonetheless, in both cities measures such as toll exemption or free parking in the city centre for BEVs were already in force. LEZs are accounted for using annual dummy variables for the districts of Madrid and Barcelona (subdivisions of the municipality as a whole).

[18] Certainly, there are other policy variables that also affect the demand for new cars, such as the registration tax which in Spain has a nationally determined rate that regional governments can increase to some extent. Since these rates have been constant since 2008, it cannot be included in the analysis. Besides, provincial dummy variables included in the equation absorb whatever variability may exist at the regional level. Regarding the share of electric cars, a relevant variable is the number and characteristics of the charging points. The lack of territorial information about this variable for all the years in the sample precludes its inclusion.

[19] The detailed characteristics of the scrappage programmes, incentives for the purchase of electric vehicles, and LEZs are provided in Appendix C and Appendix D.

Disaggregating car registrations at the district level allows us to test the null hypothesis with a higher degree of reliability.

The models used to explain emissions and the shares of the types of engine have the same explanatory variables, with three exceptions. Scrappage programme subsidies for the purchase of low emission cars are only included in the emissions model, as all types of engines are eligible to receive them, and therefore they are not expected to impact on market shares. Nor is this variable included in the emissions model for electric cars, as the specific programmes subsidising their purchase are more attractive than scrappage ones. Finally, the specific subsidy for the purchase of electric cars is only included in the share equations for PHEVs and BEVs.

The estimation results of the emissions and share equations are presented in Tables 4 and 5, respectively. Observations are weighted by the square root of the number of car registrations in each municipality. In this way each municipality is weighted according to its representativeness in the underlying population.[20]

Regarding the emissions model, the estimation results show that, with the only exception of electric vehicles, higher income levels result in larger and, thus, more polluting cars. Moreover, car emissions increase with population and the rural character of the municipality (farther from the provincial capital). The latter can be interpreted as preferences for larger and more powerful cars when the driving distances are longer. In contrast, income reduces emissions for electric cars, reflecting the fact that richer people are able to buy more energy efficient BEVs. Regarding fuel prices, only gasoline has a significant effect on emissions. Scrappage programmes focused on subsidising low-emission vehicles succeed in reducing emissions for gasoline, diesel and gasoline-hybrids cars. The coefficients for LEZs, which are jointly statistically significant, will be discussed in the next section.

The results of the models explaining the market shares of each type of engine (Table 5) show that the share of gasoline cars (including hybrids) is higher in more populated municipalities, whereas the opposite happens with diesel cars. PHEVs and BEVs are more demanded the further away from the provincial capital, and the smaller the size of the municipality. This result can be related to the greater difficulty of having access to domestic charging facilities in larger cities. Income per capita plays the expected role, as it increases

[20] We have used the 'analytical weights' option in Stata, which weights observations with inverse proportions to their variance.

the share of alternative technologies (hybrid, plug-in and BEV), and reduces that of diesel cars. Both gasoline and diesel prices take the expected signs- as own-price elasticities. More expensive gasoline increases the share of electric vehicles, but not that of hybrids. In contrast, the price of diesel does not affect the share of vehicles using cleaner technologies. Subsidies for purchasing electric vehicles have a positive and significant effect on the share of both PHEV and BEV. As in the emissions results, dummies for the LEZs in Madrid and Barcelona districts are jointly statistically significant.

Table 4: Estimation results. Emissions' determinants (estimated coefficients and *t*-statistics)

Dep. var.: $\widehat{\ln E^C}$

Variable	Gasoline	Gasoline hybrid	Diesel	Diesel Hybrid	PHEV	BEV
ln(population)	0.001907	0.000581	0.003100	0.006652	0.004699	-0.001644
	6.83	1.47	5.91	2.87	1.19	-1.77
ln (income per capita)	0.030401	0.016631	0.081075	0.080397	0.031086	-0.028092
	16.15	4.65	15.37	2.72	3.2	-12.61
ln (distance to capital)	0.001469	0.002619	0.003601	0.004637	-0.000250	-0.001205
	3.36	4.66	3.6	1.27	-0.05	-1.32
ln (gas price)	-0.122659	0.053834			-0.635619	
	-3.23	0.7			-1.69	
ln (diesel price)			-0.003308	-0.367628		
			-0.10	-0.62		
Incentives (euros)	-0.000021	-0.000028	-0.000017	0.000025	0.000041	
	-5.37	-3.75	-3.52	0.64	2.00	
LEZ coefficients						
Madrid 2015	0.004105	0.003771	-0.001762	-0.002967	0.014821	-0.000183
	3.47	1.29	-0.85	-0.13	0.44	-0.05
Madrid 2016	-0.002911	0.007096	-0.002478	(omitted)	-0.024691	0.003055
	-2.91	3.75	-1.32		-1.34	0.5
Madrid 2017	0.002838	0.004292	0.003060	-0.004545	-0.041633	-0.026555
	2.49	2.44	1.4	-0.2	-3.37	-4.68
Madrid 2018	0.000906	0.002500	0.010851	-0.109147	-0.064797	-0.017610
	0.68	1.65	5.85	-4.09	-5.25	-5.85
Madrid 2019	0.004396	0.002316	0.010837	0.008468	-0.072552	-0.022032
	2.73	1.08	6.44	0.9	-6.17	-5.48
Madrid 2020	0.003678	0.009121	0.008541	0.008487	-0.013377	-0.004123
	2.2	3.2	5.35	0.9	-1.13	-1.19
Barcelona 2015	0.016694	0.029490	0.011778	-0.109524	0.103313	-0.045238
	14.9	9.48	5.76	-4.2	3.27	-13.14
Barcelona 2016	0.016439	0.012540	0.013385	(omitted)	0.068293	0.001581
	16.62	6.98	7.06		4.07	0.24
Barcelona 2017	0.016378	-0.000360	0.021367	(omitted)	-0.013228	0.011691
	14.09	-0.23	10.11		-1.06	2.08
Barcelona 2018	0.016936	0.005232	0.015145	0.032042	0.008996	0.009023
	12.02	3.29	8.43	0.98	0.86	3.45
Barcelona 2019	0.015765	0.007087	0.022131	-0.001072	-0.021283	0.002578
	11.65	4.88	12.84	-0.13	-1.67	0.74
Barcelona 2020	0.004267	0.011924	0.009977	0.011362	0.013503	0.016847
	3.68	6.78	6.04	1.00	1.19	5.71
Constant term	4.60276	4.42692	4.01642	4.05695	4.07317	3.76436
	197.47	99.53	75.77	18.28	32.09	198.59
Year fixed effects	yes	yes	yes	yes	yes	yes
Province fixed effects	yes	yes	yes	yes	yes	yes
Observations	33983	16333	36190	3847	3031	3538
R^2	0.4812	0.3118	0.5926	0.2661	0.1408	0.3336

Note: Errors are clustered at the provincial level.

Table 5: Estimation results. Shares' determinants (estimated coefficients and *t*-statistics)

Dep. var.: *Share$_i$*

Variable	Gasoline	Gasoline hybrid	Diesel	Diesel Hybrid	PHEV	BEV
ln(population)	0.022752	0.003286	-0.025475	-0.000140	-0.000085	-0.000338
	12.25	7.82	-13.03	-3.57	-1.52	-4.34
ln (income per capita)	0.011274	0.064642	-0.098106	-0.000455	0.010960	0.011759
	0.67	11.73	-8.86	-1.02	4.27	6.75
ln (distance to capital)	-0.001347	0.000005	0.000739	0.000014	0.000296	0.000297
	-0.48	0.01	0.26	0.23	2.52	2.81
ln (gas price)	-2.108673	0.181843	1.859903	-0.047989	0.041005	0.063787
	-2.83	0.82	2.06	-0.76	1.69	2.37
ln (diesel price)	0.976107	0.153320	-1.195541	0.038530	0.017325	0.009406
	1.65	0.97	-1.73	0.54	0.67	0.33
Incentive PHEV					8.43E-07	
					3.77	
Incentive BEV						6.13E-07
						5.42
<u>LEZ coefficients</u>						
Madrid 2015	-0.011945	-0.049990	0.070409	-0.001212	-0.003742	-0.002962
	-1.45	-9.63	6.27	-1.63	-7.28	-5.28
Madrid 2016	-0.007721	-0.029545	0.044928	-0.001195	-0.003281	-0.002607
	-1	-8	5.28	-1.81	-7.35	-5.42
Madrid 2017	-0.021283	0.010705	0.012821	-0.001138	-0.001119	0.000605
	-2.83	5.39	1.64	-1.61	-3.14	1.52
Madrid 2018	-0.063269	0.033094	0.029944	-0.000824	0.000946	0.000533
	-7.75	29.5	3.61	-1.48	4.6	2.02
Madrid 2019	-0.095864	0.057835	0.031253	0.002511	0.002109	-0.000693
	-9.36	8.29	2.28	2.04	2.18	-1.18
Madrid 2020	-0.112344	0.070161	0.029992	0.003819	0.008242	0.000701
	-9.2	7.73	1.84	1.99	4.76	0.47
Barcelona 2015	-0.059076	-0.023463	0.084970	0.001959	-0.001797	-0.002714
	-7.38	-8.45	9.02	5.79	-11.91	-9.16
Barcelona 2016	-0.054820	-0.009518	0.065396	0.001697	-0.000843	-0.002086
	-7.51	-3.92	8.55	4.14	-3.76	-6.93
Barcelona 2017	-0.046460	0.008806	0.034843	0.001577	0.000434	0.000676
	-6.62	5.76	4.55	3.83	1.74	2.92
Barcelona 2018	-0.063067	0.002185	0.059807	0.001743	0.000413	-0.000875
	-7.04	0.7	5.78	4.69	1.05	-2.72
Barcelona 2019	-0.086723	0.014660	0.066079	-0.000567	0.001720	0.005104
	-10.5	7.49	7.65	-1.38	9.27	10.4
Barcelona 2020	-0.102088	0.042381	0.063240	-0.007530	0.001755	0.002123
	-7.86	12.67	5.33	-6.43	2.7	2.87
Constant term	0.4678	-0.7126004	1.4781	0.0153	-0.1208	-0.1301
	2.3	-6.36	8.53	1.46	-3.72	-6.24
Year fixed effects	yes	yes	yes	yes	yes	yes
Province fixed effects	yes	yes	yes	yes	yes	yes
Observations	39326	39326	39326	39326	39326	39326
R^2	0.7973	0.7677	0.855	0.4354	0.3942	0.3301

Note: Errors are clustered at the provincial level

6. Discussion and policy implications

The coefficients of the models presented in Tables 4 and 5 are used to compute the overall impact of changes in the variables of interest (socioeconomic, geographical and policy measures) on emissions. In this section, we highlight the most relevant results and carry out some simulations on the impacts of the different policies.

The expected impact on CO_2 emissions of changes in income and the price of fuel can be best interpreted by computing the respective elasticities taking into account the effect of those variables both on the demand for various characteristics of registered new cars and on the share of each type of engine. We consider the effect of a 1% increase in each variable, taking 2020 as the year of reference. As shown in Table 6, the income elasticity estimate is close to zero. Although higher incomes result in higher CO_2 emissions through the purchase of more powerful cars, this effect is compensated for by an increase in the share of more environmentally friendly cars, as well as by a decrease in the demand for diesel vehicles.

Table 6: CO_2 elasticities

Income	0.023
Gasoline price	-.372
Diesel price	0.026
Gasoline and diesel price	-0.345

The estimated value for the elasticity of CO_2 emissions with respect to gasoline prices is equal to -0.37. This effect takes place through two channels: higher gasoline prices affect the demand for certain characteristics of the car, reducing its emissions, and they also lead to a larger share of fuel-efficient cars, such as PHEV, BEV or diesel engines. The latter could be considered as a negative counter-effect as, although diesel engines emit lower amounts of CO_2, they harm the public health through higher emissions of nitrogen oxides and particulate matter. Changes in diesel prices do not affect the levels of emissions. There is no effect through the demand for the characteristics of the car, which can be related to the relatively low share of diesel cars (around 24% for individually purchased cars) in 2020. Moreover, the rise in emissions due to the substitution of diesel for gasoline vehicles is compensated for by the increase in the demand for hybrid and electric models. Raising both gasoline and diesel prices would reduce the CO_2 emissions of the registered new cars, although the relation is shown to be inelastic. However, in Spain there is scope for increasing fuel taxes with environmental objectives, since the excise duties on gasoline and diesel fuel are slightly below the EU average, and much lower than those of Italy, France, Germany, or Portugal.[21]

Scrappage programmes that subsidise the purchase of low-emission cars have the desired effect on gasoline, gasoline-hybrid and diesel cars. Taking the year 2020 as a reference, we compute their annual effect as the simulated impact of supressing the scheme during the five months it was enforced and, alternatively, extending it to the whole year.[22] Table 7 presents the percentage change in emissions that would result from a year-long programme compared with the scenario without it. Scrappage schemes conditional on the level of emissions of new cars have an estimated impact on CO_2 emissions of around 4%, which coincides with the findings of Grigolon et al., 2016.

Table 7: Simulated changes in CO_2 emissions compared to 2020

Engine type	Supressing the scheme	Extending the scheme	Full effect*
Gasoline	1.75%	-2.36%	-4.12%
Hybrid-gas	2.45%	-3.25%	-5.69%
Diesel	1.42%	-1.91%	-3.32%

*The full effect is computed as the difference between the no-subsidy and full-subsidy situations

Likewise, also for 2020, we have simulated the impact on the shares of PHEV and BEV of suppressing the subsidies for electric vehicles compared to making available the maximum subsidy (5,500€ for BEVs and 2,600€ for PHEVs) all year-round. As detailed in Table 8, the effects of subsidies on electric vehicle shares are substantial, with a 24% and 33% increase in the shares of PHEV and BEV, respectively. Nonetheless, as the combined share of these types of cars was only 2.1% in 2020, the magnitude of the effect is low. The share of BEV would increase from 1.1% (without subsidy) to 1.3% with the full subsidy. Using data on sales of new cars in Germany, Alberini and Vance (2023) find that the effect on sales of the rebate program implemented for BEVs ranges from 23% to 43%, depending on their specifications of the shares equations. Our results can also be presented in a comparable way to those reported in the literature by computing the impact on 2020 shares of implementing a 1000€ subsidy for both BEV and PHEV. The effect would be an increase in the share of electric cars by 7.4%. This percentage aligns with available literature. For instance, Münzel et al., 2019, using data on EV registrations from 32 European countries from 2010 to 2017, estimate that a 1000€ higher subsidy increases the EV sales share by

[21] Increasing fuel prices would probably face opposition from consumers. Loureiro et al. (2013) report that 81% of Spanish households considered that gasoline taxes were already too high. However, Galarraga et al. (2014) find that Spanish consumers value energy efficient vehicles and would be willing to pay higher prices for them.

[22] Recall that the scheme was only in force from the month of August.

between 5.1% and 6.8%. Similar results have been found for the U.S. (Jenn et al., 2018; Wee et al., 2018; Clinton and Steinberg, 2019) and Canada (Azarafshar and Vermeulen, 2020). For Spain, Anghel et al., 2022 look at the effectiveness of the subsidy programme launched in 2020 and conclude that the effects of the subsidy were very heterogeneous across regions. Whereas in some regions the programme increased the share of electric vehicles from 1% to 2%.

Table 8: Simulated percentage change in electric vehicles shares for 2020

Engine type	Supressing the subsidy	Extending the subsidy	Full effect*
PHEV	-6.39%	17.07%	23.90%
BEV	-9.38%	22.71%	33.06%

*The full effect is computed as the difference between the no-subsidy and full-subsidy situations

Finally, we examine the extent to which the LEZs established in Madrid and Barcelona have affected the emission levels of new cars according to their type of engine. The estimated coefficients for the LEZ annual dummy variables in the emissions and shares equations presented in Tables 5 and 6 must be interpreted as the differential effect of the new cars registered in each of these two cities with respect the rest of the country, taking 2015 as the year of reference. Regarding emissions, no clear temporal pattern emerges in the case of Madrid. In Barcelona, a significant decrease in emissions for gasoline and diesel vehicles is observed in 2020, which might be related to the implementation of the permanent LEZ. On the other hand, LEZs have the expected effects on vehicle shares. The estimated coefficients for HEV and PHEV, plotted in Figures 3 and 4, show that whereas at the beginning of the period the shares of each type of vehicle were below the sample average, from 2017 onwards the difference is positive and increasingly higher. The effect is larger in Madrid, whose LEZ is smaller but with more restrictive requirements than that of Barcelona. Compared to the Spanish average, between 2015 and 2020 the share of gasoline-hybrid vehicles increased by 12 percentual points in Madrid, while it only increased by 6.6 points in Barcelona. In the case of PHEVs the increases are of 1.2 and 0.4 points, respectively. No clear pattern can be identified for electric vehicles in Madrid, which is in accordance with the results found by Peters et al., 2021, but in Barcelona the share of electric vehicles becomes clearly above the average since 2019.

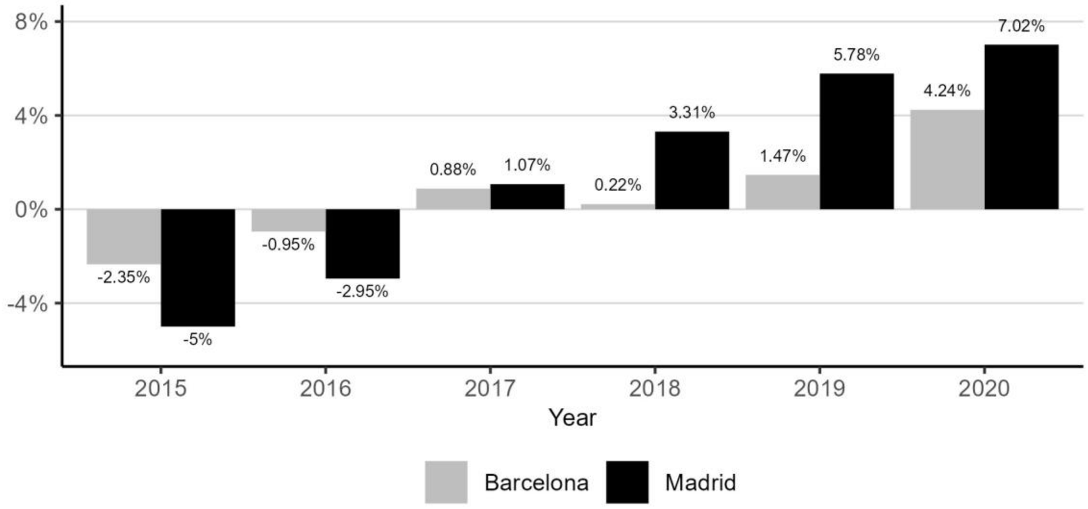


Figure 3: Share of gasoline hybrid vehicles with respect to the Spanish average

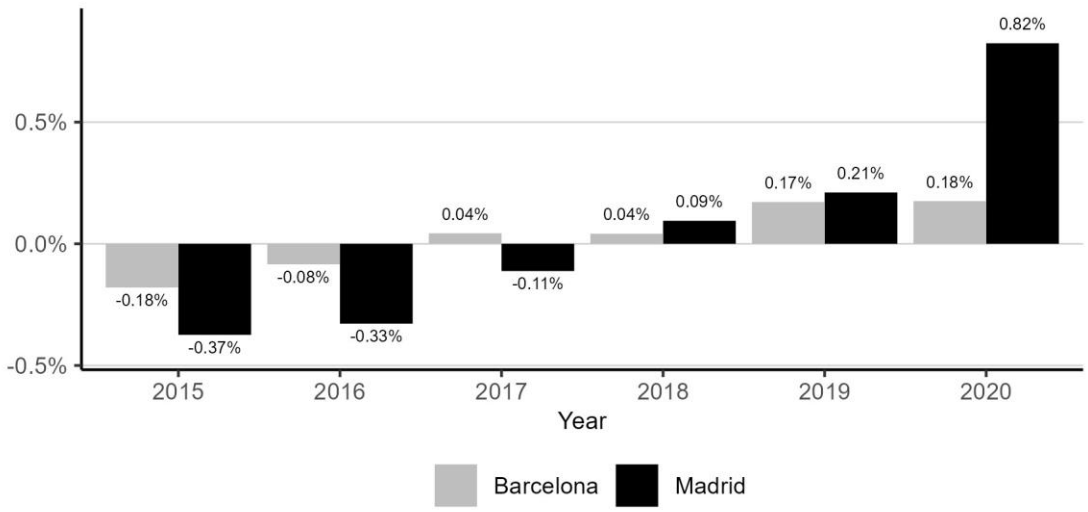


Figure 4: Share of PHEV with respect to the Spanish average

7. Conclusions

The CO_2 emissions of new registered cars in Spain, when measured in a homogeneous way, remained constant between 2015 and 2019, and only fell significatively in 2020. Over this period, a 9% reduction has been achieved thanks to technical change improvements. However, the demand shift towards larger and more powerful vehicles has offset half of those gains. Moreover, increasing sales of gasoline hybrids have made it possible to reduce emissions by a further 8.7% during the period, with a clearer impact in 2020. In a context in which the penetration of electric vehicles is limited by their price and limited range, hybrid technology will still play a relevant role to significantly reduce emissions.

Our results also show that in rural areas, defined as those which are more distant from large cities, cars with higher emissions are predominant. A possible explanation of this can be the need to drive over longer distances in rural areas.

Achieving the objective of full decarbonisation of new vehicles in 2035 demands policies much more effective than current ones. Our results can contribute to improving the design of those policies for a mature car market such as Spain's. In terms of the effect of socioeconomic variables, increases in disposable income will contribute to the penetration of vehicles with less polluting technologies (hybrid and electric), but at the same time drives the demand for heavier and more powerful vehicles, which increase emissions per unit of distance. In order to limit such undesirable effects, tax policies that penalise emissions more strictly are needed. If necessary, they should prohibit vehicles surpassing certain thresholds.

Our results also show that emissions can be further reduced by increasing fuel prices. Consumers react to price increases by both buying cars that emit less, within a given type of engine, and increasing the share of more technologically efficient vehicles, with a global elasticity of emissions with respect to fuel prices of -0.35. This policy, however, becomes less effective as the market share of hybrid and electric vehicles increases.

Additionally, scrappage programmes oriented to subsidise low emission cars contribute to the reduction of emissions as long as they facilitate the adoption of new technologies, and may have long-run permanent effects. In the Spanish case, this effect is a reduction in emissions by around 4%. Given their modest impact, those programmes should be carefully assessed.

We also have found evidence for the effectiveness of subsidies in increasing the share of electric vehicles. However, household income and difficulties in access to domestic charging facilities, which is especially the case in the largest cities, have been shown to be significant deterrents. Policies should therefore set the subsidies as a function of household income and, simultaneously, emphasise the development of charging points where their availability is more constrained. In any case subsidies must be set taking into account life-cycle emissions of the vehicle, so that they avoid subsidising very large and powerful cars that end up generating more CO_2 emissions than smaller internal combustion cars would.

Low Emission Zones (LEZs) contribute to reducing the pollution in cities and, at the same time, promote fleet renewal towards vehicles with cleaner technologies. We estimate that the market share of gasoline hybrid vehicles increased by 12 percentage points in Madrid and 6.6 in Barcelona as a result of the creation of their LEZs. It seems that a smaller area with stricter entry requirements, such as Madrid's, is more effective at achieving this objective

Our results highlight the effect on emissions of the different policies considered. It seems evident that in order to reach full decarbonization more intense policies are needed that change car purchase habits. However, as part of the decision-making process, the detailed costs and benefits of each one of them should be fully assessed and a specific analysis should be carried out of their effects in their dependence on the local context.

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Appendix A. Computing homogeneous emissions

In order to homogenise CO2 emissions measured according to different procedures, we first identify models in the sample by their variant, version, engine capacity, power, weight, hybrid or plug-in hybrid technology and CO2 emissions. Then, according to the emissions' tests phasing-in requirements and each car's registration date (month and year), for all models registered between 2017 and 2020 we label the reported CO_2 emissions either as the outcome of an NEDC or NEDC- correlated (NEDC*) method. We assume that cars registered before 2017 report NEDC emissions.

We find 584 cases of identical models for which CO_2 emissions are available according to both the NEDC and the NEDC* procedures. Using these observations, a regression is estimated relating the NEDC* emissions to the NEDC ones, adding the car's weight as an explanatory variable. The results are:

$$NEDC^{*} = \underset{(0.013037)}{1.016224} \cdot NEDC + \underset{(0.001118)}{0.00407} \cdot Weight$$

R2 = 0.996

(Standard errors in parentheses)

We use these results to impute an NEDC* value to all NEDC emissions in the sample for internal combustion engine cars, including hybrids. On average, the difference between the CO_2 emissions reported following the NEDC test and those following the NEDC* transformation is 6.4%. This is a value below the 9.6% estimated by JATO, 2018, but within the 5%-10% range given by Autovista, 2018. For the emissions of the internal combustion engine of PHEV cars, Tsiakmakis et al., 2017 report an equivalent level of emissions for WLTP and NEDC methods. Therefore, we do not correct the reported CO_2 emissions of PHEV vehicles. For the case of BEV and PHEV, finding the relation between NEDC and NEDC* for the electric energy consumption is more complicated, given the very low number of models sold. In this case, we have computed a 7% difference from the available observations.[23]

Appendix B. Relationship between CO_2 emissions and the determinants of car characteristics

In order to relate the vehicle emissions due to vehicle characteristics to those socioeconomic, geographical, and policy variables that drive the demand for those characteristics, we need to identify the impact that different individuals' attributes have on

[23] For PHEV and BEV, the sample contains some observations that report WLTP for the years before 2021. We correct these emissions' values using the WLTP/NEDC ratio for BEV of 1.27 provided by Tsiakmakis et al. (2017), which is transformed to NEDC* as 1.07/1.27=0.842

the demand for a specific characteristic of a car. From Equation (2), the emissions explained by the vehicle's K characteristics can be computed as:

$$\widehat{\ln(E_{it}^{C})} = \sum_{k=1}^{K} \hat{\beta}_k \ln(X_{kit}) \quad \text{(A.1)}$$

Then, the impact of the $h = 1, \dots, H$ individual's attributes (Z_h) have on the emissions generated by each vehicle characteristic k can be expressed as:

$$\hat{\beta}_k \ln X_k = \sum_{h=1}^{H} \gamma_{kh} \ln Z_h \quad \text{(A.2)}$$

Here, h indexes the set of socioeconomic, geographical and policy variables that explain the demand for each specific car characteristic k. Substituting (A.2) into (A.1), we obtain an expression that relates the estimated CO_2 emissions due to the car characteristics to the individuals' attributes we are interested in.

$$\begin{aligned}\widehat{\ln(E_{it}^{C})} = \sum_{k=1}^{K}\sum_{h=1}^{H} \gamma_{kh} \ln Z_h &= (\gamma_{11} \ln Z_1 + \gamma_{12} \ln Z_2 + \cdots + \gamma_{1H} \ln Z_H) \\ &+ (\gamma_{21} \ln Z_1 + \gamma_{22} \ln Z_2 + \cdots + \gamma_{2H} \ln Z_H) + \cdots \\ &+ (\gamma_{K1} \ln Z_1 + \gamma_{K2} \ln Z_2 + \cdots + \gamma_{KH} \ln Z_H) \\ &= \underbrace{(\gamma_{11} + \gamma_{21} + \cdots + \gamma_{K1})}_{\pi_1} \ln Z_1 + \underbrace{(\gamma_{12} + \gamma_{22} + \cdots + \gamma_{K2})}_{\pi_2} \ln Z_2 + \cdots \\ &+ \underbrace{(\gamma_{1H} + \gamma_{2H} + \cdots + \gamma_{KH})}_{\pi_H} \ln Z_H = \pi_1 \ln Z_1 + \pi_2 \ln Z_2 + \cdots + \pi_H \ln Z_H\end{aligned}$$

where the π_h add the impact of each individual attribute on emissions.

Appendix C. Description of the incentive programmes

In order to reduce cars' harmful emissions, the Spanish government (and some regional and local authorities) have introduced a set of programmes aimed at incentivising the purchase of low-emission cars. Two different types of programmes have been active during the sample period. The first one consists of scrapping programmes aimed at replacing old cars by new ones with lower emissions, of which there have been two plans. The first one comprises the last two editions of the PIVE plan started in 2012, which tried to stimulate the car industry after it was severely hit by the 2008 economic crisis (For a description of the PIVE scrappage programmes, see Laborda and Moral, 2019). PIVE-7 and PIVE-8, which were in force during some months of 2015 and 2016, subsidised the purchase of any type of car that met specific emission limits. The subsidy amounted to 2,000€ for PIVE-7 and 1,500€ for PIVE-8. The second plan (RENOVE) was launched in July 2020, to counteract the effects of Covid-19 on car sales. The plan subsidises the purchase of cars meeting certain emission requirements. Again, it includes any type of engines, but the subsidy ranges from a maximum of 5,000€ for BEVs to 800€ for the more polluting admitted types of gasoline or diesel cars. A maximum car price, which depends on the car type and engine, determines whether it is or is not eligible. In all cases, it is necessary to scrap a vehicle that is at least 10 years old.

In parallel, some other subsidy-based plans have been designed to promote the purchase of vehicles with alternative fuels, independently of scrappage decisions. Since 2015, six different plans have been in force at the national level, joined by complementary plans set up by some regional or local governments. Unlike the first type of plan, scrappage of an old car is not a requirement, although in some cases the amount of subsidy increases if that decision is taken. These plans cover all types of alternative-fuel vehicles (BEV, PHEV, REEV, CNG, LPG, hydrogen and biofuel) and all types of vehicles (passenger cars, vans, trucks, buses and motorcycles). They also (partially) subsidise the installation of electric vehicle charging infrastructure. Since 2015 until 2018 the plans were financed and managed by the central government, so their starting and expiring times were identical for all the Spanish regions. Both in 2017 and 2018 the allocated budget was depleted in a few days. However, although since 2019 the central government has continued defining the conditions of the plans (MOVES), the decision about when to put them in force was taken by each one of the regional governments. As a result, the starting date to apply for the subsidy and the period during which the plan was in force vary by region. This staggered implementation leads to some extreme examples in the cases of Murcia and Extremadura, where the application period for the 2019 subsidies did not start until 2021. The amount of subsidy for electric vehicles with a battery range above 90 km lies between 5,500€ and 7,000€, while for ranges between 40 and 90 km, it falls to between 2,600€ and 3,600€.

Appendix D. Description of the Low Emission Zones of Madrid and Barcelona

In February 2016 the city of Madrid created a non-permanent low emission zone (LEZ), which applied only during periods of high air pollution. The idea of establishing a permanent LEZ was first mentioned in the city's air pollution plan in September of 2017 (Peters et al., 2021). Since mid-July of 2018, the City Council advertised the creation of a 4.72 km^2 LEZ in the city centre, which came into force on November 30, 2018 under the name of 'Madrid Central'. Although the area it covers is relatively small, the requirements to enter it are very restrictive and based on the vehicles' environmental labels. With the exception of residents, only zero-emissions vehicles (BEV, REEV and PHEV with a range above 40 km) can enter the area without any restriction, and they are also granted free parking in the restricted areas. ECO vehicles (PHEV with a range below 40 km, HEV, CNG and LPG) are allowed into the LEZ but are limited to two hours on-street parking. Gasoline and diesel vehicles complying, respectively, with Euro 3 or Euro 4 regulations (which can show an environmental label by DGT) can enter the zone but are forbidden to park on the street. Entering is forbidden to vehicles with other internal combustion engines. According to Tassinari, 2022 about 70% of non-resident drivers driving inside or close to the city centre were affected by the implementation of the LEZ.

In Barcelona, the implementation of a LEZ as a mechanism to reduce air pollution was first included in a municipal plan in 2015. In December of 2017, a non-permanent LEZ came into force whenever NO_2 levels reached a given threshold. Unlike Madrid's, the Barcelona LEZ covers a large area (95 km^2 that includes almost the entire municipality of Barcelona and parts of 4 neighbouring ones) but entrance conditions are less restrictive, as they only apply to vehicles without a DGT environmental label (a vehicle categorisation shown by means of a windshield sticker according to their energy efficiency and emissions' intensity of each model, not given to the older and most polluting ones) and only between 7 am and 8 pm Mondays to Fridays. The decision to implement the temporary LEZ was followed by advertising campaigns during the years 2017-2020 aimed at making drivers aware of the increasing restrictions on polluting vehicles, so that they would react in advance. This campaign was reinforced as of November 2019, as the LEZ restrictions became permanent on January 1, 2020.

Appendix E. Tables

Table A1: Shares of car sales by segment and FWD. Gasoline and Diesel, 2015-2020 (%)

Gasoline Segments	2015	2016	2017	2018	2019	2020
Sedan	0.15	0.13	0.15	0.15	0.23	0.34
Compact	22.15	21.49	20.90	20.69	20.14	20.79
Sports	0.58	0.74	0.65	0.35	0.33	0.31
Family	1.54	1.62	1.66	1.84	2.59	2.74
Executive	0.11	0.08	0.09	0.10	0.09	0.07
Compact MPV	5.89	6.28	5.47	5.17	4.08	3.20
Family MPV	0.08	0.11	0.30	0.30	0.37	0.22
Large MPV	2.69	1.89	1.86	1.42	1.17	0.22
Supermini	10.92	10.09	8.37	7.01	6.38	5.34
Compact SUV	8.01	11.47	16.83	19.43	21.60	20.14
Mid-size SUV	0.86	1.04	1.27	1.68	1.91	2.67
Small SUV	6.00	6.44	8.48	12.61	15.38	20.33
Full-size SUV	0.26	0.39	0.49	0.53	0.64	0.86
Subcompact	40.21	37.70	33.05	28.26	24.61	22.35
FWD	0.35	0.44	0.50	0.97	0.86	1.11
Other	0.54	0.55	0.43	0.47	0.50	0.42

Diesel Segments	2015	2016	2017	2018	2019	2020
Sedan	1.14	1.33	1.57	1.72	1.77	1.59
Compact	27.14	25.20	23.01	19.00	19.04	19.05
Sports	0.09	0.08	0.06	0.01	0.02	0.03
Family	10.40	10.83	10.38	9.60	9.61	9.22
Executive	0.13	0.15	0.16	0.21	0.20	0.19
Compact MPV	10.53	10.40	10.82	11.82	14.67	15.59
Family MPV	1.33	1.29	1.49	1.31	1.10	0.91
Large MPV	2.07	1.63	1.90	1.58	0.94	1.18
Supermini	2.21	2.48	2.27	1.53	0.71	0.56
Compact SUV	17.22	17.96	18.51	21.89	21.14	22.34
Mid-size SUV	4.03	5.19	5.64	6.44	7.65	6.67
Small SUV	5.05	5.64	6.01	7.38	8.36	7.61
Full-size SUV	1.80	2.41	2.66	2.59	2.78	3.63
Subcompact	11.92	10.28	9.70	8.60	7.76	7.11
FWD	3.31	3.60	3.93	5.82	6.34	6.72
Other	4.95	5.13	5.85	6.33	4.24	4.31

Table A2: Decomposition of actual emissions (CO_2 g/km)

Gasoline

	Actual	Technical change	Engine power	Hybrid PHEV	Segment FWD
2015	125.3	125.3	125.3	125.3	125.3
2016	124.2	122.8	126.8	123.8	125.4
2017	123.4	122.5	128.2	122.5	125.4
2018	122.4	121.0	128.6	122.2	125.5
2019	120.9	119.0	129.9	121.2	125.5
2020	110.4	114.1	131.0	114.5	125.6

Diesel

	Actual	Technical change	Engine power	Hybrid PHEV	Segment FWD
2015	120.5	120.5	120.5	120.5	120.5
2016	118.3	118.0	121.4	120.5	120.5
2017	119.1	117.7	122.0	120.5	120.7
2018	119.3	116.3	123.7	120.4	121.1
2019	118.6	114.4	126.0	120.1	120.8
2020	114.0	109.7	127.2	119.3	120.8

Table A3: Descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
2015					
Population	6,576	18,795	189,409	90	3,141,991
Income per capita (€)	6,576	10,897	2,446	3,533	27,460
Distance to capital (km)	6,576	46	29	1	220
Gasoline price (€)	6,576	1.30	0.041	1.00	1.39
Diesel price (€)	6,576	1.19	0.036	0.93	1.27
Scrapping incentive (€)	6,576	594	0	594	594
Incentive BEV (€)	6,576	3667	0	3667	3667
Incentive PHEV (€)	6,576	2467	0	2467	2467
2016					
Population	6,586	18,833	190,558	34	3,165,541
Income per capita (€)	6,586	11,142	2,431	5,528	27,782
Distance to capital (km)	6,586	46	28	1	220
Gasoline price (€)	6,586	1.23	0.041	0.92	1.30
Diesel price (€)	6,586	1.09	0.035	0.83	1.16
Scrapping incentive (€)	6,586	875	0	875	875
Incentive BEV (€)	6,586	521	0	521	521
Incentive PHEV (€)	6,586	371	0	371	371

2017					
Population	6,503	19,145	192,840	34	3,182,981
Income per capita (€)	6,503	11,318	2,395	6,026	31,791
Distance to capital (km)	6,503	46	28	1	220
Gasoline price (€)	6,503	1.27	0.041	0.97	1.34
Diesel price (€)	6,503	1.16	0.037	0.89	1.22
Scrapping incentive (€)	6,503	0	0	0	0
Incentive BEV (€)	6,503	521	5	521	896
Incentive PHEV (€)	6,503	281	21	279	529
2018					
Population	6,521	19,239	194,721	21	3,223,334
Income per capita (€)	6,521	11,707	2,432	3,872	31,723
Distance to capital (km)	6,521	46	28	1	220
Gasoline price (€)	6,521	1.32	0.040	1.03	1.39
Diesel price (€)	6,521	1.24	0.038	0.97	1.32
Scrapping incentive (€)	6,521	0	0	0	0
Incentive BEV (€)	6,521	1,003	1,169	458	5,458
Incentive PHEV (€)	6,521	480	781	217	2,883
2019					
Population	6,451	19,647	198,275	30	3,266,126
Income per capita (€)	6,451	12,098	2,390	6,062	28,289
Distance to capital (km)	6,451	46	28	1	220
Gasoline price (€)	6,451	1.33	0.038	1.03	1.39
Diesel price (€)	6,451	1.26	0.036	0.98	1.32
Scrapping incentive (€)	6,451	7	31	0	146
Incentive BEV (€)	6,451	3,670	1,426	0	7,979
Incentive PHEV (€)	6,451	1,651	546	0	3,575
2020					
Population	6,689	19,231	198,711	7	3,334,730
Income per capita (€)	6,689	12,387	2,402	5,757	32,645
Distance to capital (km)	6,689	46	28	1	220
Gasoline price (€)	6,689	1.21	0.032	0.96	1.28
Diesel price (€)	6,689	1.11	0.030	0.91	1.18
Scrapping incentive (€)	6,689	850	88	833	1,302
Incentive BEV (€)	6,689	1,723	1,040	0	6,604
Incentive PHEV (€)	6,689	742	249	0	1,279

Data sources: Population and data on income per capita are obtained from the Spanish National Statistics Institute (INE). Income per capital refers to net income (gross income – taxes and social security contributions) and is computed at census tract level based on administrative information on Personal Income Tax. Data on fuel prices are taken at provincial level according to the information published by the Ministry of Energy Transition. Income per capita and fuel prices are CPI-deflated.

Table A4: Estimation results for battery electric vehicles (BEV)

Variable	Coefficient *t*-stat
ln (weight)	0.3628 2.82
Constant	0.8169 0.86
Year:	
2016	-0.0528 - 2.53
2017	-0.0891 - 3.24
2018	-0.0236 - 0.37
2019	-0.0790 - 1.11
2020	-0.1345 - 3.93
R^2	0.1799
Obs.	41,841