CHARLES UNIVERSITY
FACULTY OF SOCIAL SCIENCES
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Analysis of Consumers' Preferences for Cars on Slovak Market

Bachelor's thesis

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Study program: Economics and Finance

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Year of defense: 2022

Declaration of Authorship

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Prague, August 2, 2022

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Abstract

This thesis investigates the effect of registration tax and fuel prices on the car market in Slovakia. Using the dataset provided by the Department of Evidence and Papers of Slovak Police Force with information about vehicles that entered the national car evidence, we compute monthly registrations of passenger vehicles. Given the nature of our data, we estimate pooled OLS model with fixed effects, focusing on different vehicle segments. We also analyse fuel price elasticity when prices were mostly decreasing or increasing to examine asymmetric response of car buyers. Results suggest a negative impact of the registration tax on the number of registrations of petrol vehicles with a stronger response of fuel efficient cars compared to less efficient. In the segment of diesel vehicles, only registrations of used and less efficient cars are affected by the tax. The elasticity of registrations with respect to fuel costs is negative for all car segments except for the new efficient petrol-fueled vehicles. Registrations of diesel vehicles are more sensitive with respect to fuel price changes than petrol cars in most segments. We also find an asymmetric response to fuel prices during the periods of price increases and decreases and declining responsiveness over time.

JEL Classification	C23, O18, Q31, R41, R48
Keywords	Car market, Slovakia, preferences, vehicle fleet, panel data analysis
Title	Analysis of Consumers' Preferences for Cars on Slovak Market

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Abstrakt

Tato práce zkoumá vliv registračních poplatků a cen paliv na automobilový trh na Slovensku. Použitím dat poskytnutých Odborem dokladů a evidencí Slovenské policie s informacemi o vozidlech, které vstoupili do národní evidence automobilů, vypočteme měsíční registrace osobních vozidel. Na základě našich dat používáme metodu spojených nejmenších čtverců s fixními efekty se zaměřením na různé segmenty vozidel. Taktéž analyzujeme elasticitu cen paliv v obdobích, kdy tyto ceny stoupaly nebo klesaly, abychom prověřili asymetrickou odezvu kupců automobilů. Výsledky naznačují záporný vliv poplatků na registrace benzínových vozidel s odezvou větší pro úsporná auta v porovnání s méně úspornými. V segmentu naftových vozidel jsou ovlivněná jedině neúsporná ojetá auta. Elasticita nových registrací s ohledem na cenu paliv je negativní ve všech segmentech kromě nových úsporných benzínových vozů. Registrace naftových vozů jsou ve většině segmentů víc citlivé na změny cen než vozů benzínových. Byly též nalezeny důkazy asymetrické reakce na změny v cenách paliv během období růstu a poklesu cen se snižující se citlivostí v čase.

Klasifikace JEL	C23, O18, Q31, R41, R48
Klíčová slova	Automobilový trh, Slovensko, preference, vozový park, panelová analýza dat
Název práce	Analýza preferencí spotřebitelů při koupě auta na slovenském trhu

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Acknowledgments

First and foremost, I would like to express my gratitude to my family and especially my parents, who have supported me throughout my entire life and without whom I would not be able to achieve this. I would also like to thank my supervisor Mgr. Milan Ščasný Ph.D. and to prof. Anna Alberini Ph.D. for their guidance, time and useful comments and remarks throughout the writing. Last, but not least, I highly appreciate the help and support of my fellow students and friends during the whole study.

This thesis is part of a project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 870245 (GEOCEP).

Typeset in LaTeXusing the IES Thesis Template.

Bibliographic Record

Nedeľka, Michal: *Analysis of Consumers' Preferences for Cars on Slovak Market.* Bachelor's thesis. Charles University, Faculty of Social Sciences, Institute of Economic Studies, Prague. 2022, pages 61. Advisor: Mgr. Milan Ščasný Ph.D.

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Acronyms

BEV Battery Electric Vehicle

CPI Consumer Price Index

EU European Union

FE Fixed Effects

GDP Gross Domestic Product

GHG Greenhouse Gases

HEV Hybrid Electric Vehicle

LPG Liquid Petrol Gas

NEDC New European Driving Cycle

OLS Ordinary Least Squares

PHEV Plug-in Hybrid Electric Vehicle

POLS Pooled Ordinary Least Squares

RE Random Effects

SUV Sport Utility Vehicle

VAT Value Added Tax

VED Vehicle Excise Duty

WLTP Worldwide Harmonised Light Vehicle Test Procedure

Chapter 1

Introduction

Massive technological progress accompanied by improving living conditions of the developed world in the 20^{th} century has brought a vast spread of an invention called a car. While at the beginning of the century car ownership was a sign of affiliation to the wealthiest social classes, at the dawn of the 3^{rd} millennium cars expanded all around the world and their accessibility and development accelerated even more in the first decades of 21^{th} century. As with any other progress, this one was redeemed with certain sacrifices too. Specifically, with greenhouse gases (GHG) and air pollutants emissions, and thence resulting contribution to the climate change and global warming.

In the European Union, the total amount of GHG emissions decreased by 24% between 1990 and 2019. Transport, however, had not followed the trend; the emissions of the transport sector in 2019 were 27% higher than the 1990 level. Within transport, cars are responsible for 44% of all CO_2 emissions in the whole sector (EEA 2020). Together with increasing concerns about the scarcity of non-renewable fuels, European Union members as well as other countries around the globe have taken actions to fight these issues. New regulations set goals for the upcoming period to reduce fleet-wide CO_2 emissions. Some countries have already taken steps to reduce emissions by implementing various policies aimed at the promotion of green vehicles and alternative transport options while others slowly try to resolve the problem. One such state is Slovakia, a very specific country with its small market and tremendous car production. A country that had roughly 5.45 million citizens in 2019 (Statistical Office of the SR 2020) produced approximately 1.1 million cars in the same year (Kia 2020; PCA 2020; Volkswagen 2020).

This thesis aims to examine the market for passenger cars in Slovak republic.

For this purpose, the Department of Evidence and Papers of the Slovak Police Force provided us with a dataset of cars that entered the evidence in Slovak republic. Combining the technical and administrative information about the fleet from this dataset with fuel prices in Slovakia we create a unique, rich dataset to help us study the car market. We focus particularly on two issues. Firstly, we would like to uncover the effect of registration fees on a number of passenger cars entering the national vehicle evidence. The scheme for fee calculation has undergone considerable changes in 2012 and 2017 that should allow us to study behaviour of Slovak car market customers. Secondly, we examine the response of consumers to the fluctuations in fuel prices when they decide to purchase a passenger vehicle.

Most of the studies in the field (Alberini & Bareit 2019; Cerruti et al. 2019; Alberini & Horvath 2021) examined mostly the annual taxes paid for vehicles, we focus on the nonrecurring registration tax that all vehicles are subject to when entering Slovak vehicle evidence. We also aim to fill the gap in the literature that is mostly focused on more economically developed countries with an increasing share of alternative vehicles and taxing systems that penalise highly polluting cars. By examining a former communist country from Eastern Europe with one of the lowest shares of alternative vehicles (ACEA 2021b), we hope to bring light to this research field from a different point of view.

The rest of the thesis is structured as follows: Chapter 2 provides the reader with insight into the existing literature on the topic. In Chapter 3 we describe the dataset used for this study and outline some interesting features of the Slovak car market. In Chapter 4 we specify model methods used to estimate it. In Chapter 5 results of the regressions are presented and in Chapter 6 we discuss the aforementioned results. Chapter 7 summarizes our findings.

Chapter 2

Literature Review

We organise this chapter as follows: in the first section, we briefly introduce available car types and summarize existing literature dealing with the impact of a car's characteristics on sales. In the second section, we briefly discuss the impact of fuel on passenger fleets. The third section provides insight into papers investigating the effects of various government policies.

2.1 Cars attributes and impact on sales

The automobile industry has experienced precipitous development since 1886 when Carl Benz was awarded the patent for his *Motorwagen*, the first car in the history. Nowadays, there is a wide range of vehicles with various characteristics that are offered on the market. People choose between models that differ in technical attributes, equipment or fuel.

Technical characteristics of the car are often interconnected: engine size usually increases with the car's weight, which in turn increases fuel consumption (Essenhigh et al. 1979). A bigger engine size also normally means higher engine power (as a larger engine can burn more fuel). Aging cars tend to emit more pollutants, not only due to catalytic converters but also due to technological progress - implementation of new technologies leads to lower emissions of cars (Zachariadis et al. 2001; Guo et al. 2021).

Weber (2019) analysed the sales of new cars in Switzerland using a set of technical parameters of the vehicles. The study was restricted to petrol and diesel cars between 2006 and 2015. The results of the paper suggest that consumers are willing to pay for lighter and more fuel efficient cars while at the same time they assign larger value to more powerful vehicles. There was also evidence of heterogeneous consumer preferences: those who bought lighter cars value fuel efficiency high, whereas owners of upper-end vehicles are less sensitive about it. Another important finding is the evolution of preferences in favour of more efficient and less powerful cars. Kok (2013) arrived to similar conclusion in his study that examined new car sales in the Netherlands between 2000 and 2011: there was a breaking point in 2008 in a trend of buying large, heavy and powerful cars to lighter and more efficient cars. The aforementioned change in preferences also contributed to the reduction of emissions.

Fuel and its consumption (and thence greenhouse gases emissions) has achieved increasing attention in the past years and become one of the key factors influencing the purchase decision. Fuels and vehicles powered by them can be divided into 2 basic categories: conventional[1] and alternative. To the conventional fuels belong petrol and diesel, the most widespread alternative fuels are electricity, LPG (liquid petrol gas) and CNG (compressed natural gas). Cars that are powered by a combination of fuels, usually by one conventional and one alternative, are considered ecological as well.

In 2019, 52.9% and 42.3% of all passenger vehicles in the European Union were petrol and diesel cars, respectively (ACEA 2021b). However, the shift to alternative fuels is apparent on new registrations: conventional cars accounted for 89.4% of all newly registered passenger vehicles in the EU (57.8% petrol, 31.6% diesel), while more than 10% were formed by alternative or hybrid cars (highest share formed by hybrid electric cars: 5.7% of all registrations) (ACEA 2021a).

Conventional cars are the most widespread and popular among drivers not only in the European Union but also worldwide. Burning petrol or diesel creates a number of greenhouse gases, nonetheless, the number of various pollutants emitted differs among them. The emissions of carbon dioxide are lower for petrol vehicles, whereas particles and emissions of nitrogen oxides, causing air pollution, especially in cities, are higher for diesel vehicles (Tanaka et al. 2012). Other drawbacks of diesel vehicles include higher acquisition prices and sound emissions. The maintenance is also more costly and complicated than for petrol vehicles. On the other hand, diesel vehicles provide appreciable benefits in terms of fuel economy, specifically lower consumption.

Cars with powertrains powered by alternative fuels or by hybrid fuel sys-

[1]We deliberately do not label petrol and diesel as 'fossil fuels' as our main goal is to divide the cars by fuels that are currently considered ecological and those that are considered 'dirty'. LPG and CNG are fossil fuels as well, but due to their substantially lower GHG emission they are considered 'green fuels'.

tem are recently gaining more and more popularity. They are either powered purely by an ecological fuel (electricity - these cars are often referred to as BEV (battery electric vehicle), LPG, CNG) or together with one less environmentally friendly fuel. These are called hybrid vehicles. Commonly, hybrid vehicles with electricity as one of the fuels are distinguished apart and referred to as HEV (hybrid electric vehicle) and PHEV (plug-in hybrid electric vehicle), depending on whether the battery of the car can be charged directly from the grid or not.

The main and most frequent argument for massive adoption is their great ecological advantage over conventional cars, specifically little to no greenhouse gases emissions during driving. While this is true, one should also consider the production of the fuel and the associated emissions. Manufacturing and end-of-life phase are potential sources of environmental burden too. Available studies came to different results: while some suggest the CO_2 emissions through the whole life cycle of alternative and hybrid cars are lower than conventional vehicles (Chatzikomis et al. 2014; Puig-Samper Naranjo et al. 2021), others found that alternative (especially battery electric vehicles) are responsible for more CO_2 emissions than conventional cars (Guo et al. 2021; Petrauskienė et al. 2021). Variation in the results can be explained by differences in electricity production - some countries heavily rely on coal power plants, while other use more ecological ways to produce electricity such as solar or hydropower plants. Future scenarios with environmentally friendly electricity production suggest decrease in these emissions. Moreover, studies that examined other environmental burdens indicated higher carcinogenic and non-carcinogenic toxicity and higher ecotoxicity connected to the production of electric cars compared to conventional ones (Petrauskienė et al. 2021; Puig-Samper Naranjo et al. 2021).

Notwithstanding the massive campaign for the adoption of alternative vehicles, the share of registrations and in passenger car fleets varies greatly across EU member states. Many barriers discouraging potential customers from buying alternative cars have been described: insufficient number of charging stations, high purchase prices, performance and durability (Ščasný et al. 2018; Tarei et al. 2021).

The reason behind the higher purchase price of alternative cars is usually the powertrain - either it is the battery and its exceptionally high cost (Bundesministerium fur Wirtschaft und Klimaschutz 2022), or the necessity to build in system for 2 different power units. Alberini et al. (2019) analysed prices from 8 European countries and found evidence of additional charge (‘battery premium'), slight for regular hybrids (2000€ at most), but notable for plug-in hybrids and BEVs (some 10,000€ and 12,000€ respectively), not explained by additional weight, size of car or fact that many plug-ins are sports utility vehicles. These costs were above the potential fuel cost savings, and since this royalty was mostly offset by government incentives only partially, hence another reason must be present for consumers to pay the difference.

A similar phenomenon was also observed in the conventional car segment in Switzerland, where a label system was used to rate a vehicle's fuel efficiency and CO_2 emissions. The effect of labels on the price of a car was negligible for all labels except the highest label (for the most efficient cars) that had a significant effect on the car's price, suggesting that importers were aware of the fact that people who valued fuel economy were willing to pay more for more efficient cars (Alberini et al. 2016).

An important aspect is consumer awareness and public campaign promoting less-polluting cars. O'Neill et al. (2019) interviewed people associated with car manufacturing and dealership, and staff from government departments responsible for electric vehicles policy formulation and interpretation. The results suggest that there was little effort from the government to promote electric vehicles and raise public awareness about them. Ščasný et al. (2018) surveyed a representative sample of the adult population in the Czech republic and among other things 64% and 73% of respondents admitted that they knew little about electric vehicles and plug-in hybrids, respectively.

2.2 Fuel

In the previous section, the most common fuel options for cars are listed. Apart from the type of powertrain in the vehicle, the fuel itself might have an impact on the car choice. Fluctuations in costs of fuels influence consumers' decisions on the car market.

Most widespread fuels, petrol and diesel, and their respective prices usually experience rises and falls together. Both are subject to fuel tax (the former is often burdened with higher tax than the latter), but the co-movements of prices are not affected by taxes (Mutascu et al. 2022). The changes in the price of diesel also have only a negligible effect on diesel car shares (Klier & Linn 2013).

Shifts in passenger vehicle sales concerning for fuel price fluctuations are no novelty; effects similar to those in the 2000s could be observed in the 1970s as well (Ramey & Vine 2011). Variations in the price of fuel directly alter the cost of a car ride. The owners of fuel-inefficient cars are therefore more affected by fluctuations in fuel prices. Thus, fuel-inefficient vehicles become less desirable with high fuel costs. Klier & Linn (2010) found a negative effect of fuel prices on shares of large SUVs and US automakers (who rely on sales of large cars). Falvey & Rogers (1986) suggested that the rise in fuel prices did not deviate demand towards smaller cars, but rather led to a shift towards the centre, i.e. middle-sized cars.

Consumers must not necessarily change the class of their car, but may switch to an alternative that boasts of higher mileage. Klier & Linn (2013) compared the effect of fluctuations in fuel prices in the USA and the eight biggest European car markets. Results suggest a significant effect of positive fuel prices on fuel economy, although the response of the US market was twice stronger than in Europe. Note that differences between European countries were present as well.

One should also distinguish between business and private cars. There is evidence that buyers from the commercial sector responded to changes in fuel prices slower than households (Givord et al. 2018), who also reacted to changes in fuel prices stronger than to shifts in fuel efficiency. Moreover, higher fuel prices prompted households to switch car (Borger et al. 2016).

What is more, not only demand is affected by fuel price fluctuations, but also the supply side. To mitigate the losses, producers have to decrease price of fuel-inefficient cars (Mcmanus 2007).

2.3 Government policies and their influence on the passenger fleet

Global warming and commitments of governments in developed countries to reduce emissions of pollutants force politicians to act. Since road transport contributes to total emissions by a considerable amount, it is logical that government policies aim at this sector. There are several methods how to reduce emissions: driving less by a car and using alternative transport options, using fuels that emit fewer pollutants when they are burned in the powertrains or increasing the fuel efficiency of the fleet of road vehicles. Due to the nature of our study, we focus in this section mainly on the third mechanism.

As mentioned in the previous section, change in emissions is inversely proportional to the mean age of the fleet (Zachariadis et al. 2001). Lawmakers can use a variety of tools that motivate (either positively or negatively) their citizens to change their cars or to influence their choice.

2.3.1 Taxes

In each EU country, the owner of the car has to pay a registration tax or fee when registering the car for the first time in the home country. Some countries have unified tax for all types of cars, but the majority has in force a progressive fee system based on some indicators (such as CO_2 emissions or cylinder capacity). Many member states have entrenched ownership taxes too. By the end of 2019, some form of a tax on passenger car ownership was instituted in 23 out of 28 European Union member states. These are largely based on similar indicators (CO_2 emissions, cylinder capacity, engine power etc.) as acquisition fees (ACEA 2020). Similar rules are in place in other countries (not only in European) as well.

Falvey & Rogers (1986) found rather an insignificant effect of registration tax rate changes on car registrations in New Zealand from 1963 to 1978..

Cerruti et al. (2019) studied the effect of VED[2] tax in the United Kingdom. By comparing fleet structure between 2005 and 2010 (during the aforementioned period the scheme was tightened), they uncovered a significant influence of VED on registrations of least and most polluting cars. The effect was positive for the former and negative for the latter group, however, the overall change in average emissions among newly-registered passenger vehicles was negligible due to the low share of the previously mentioned cars on market.

Germany took actions similar to those in the United Kingdom. Between 2011 and 2019, there were 2 tightening policies regarding emission-based taxes and one change in the emission estimation process. Consumers did respond to these adjustments - the car sales drop by 2-5% (the extent varied over time). Still, the effect on average CO_2 emissions was limited (Alberini & Horvath 2021).

An interesting specimen of diverse vehicle tax schemes is Switzerland. The political organization of the Alpine confederation allows every canton (territorial entity subordinated to the federal government) to set its tax policy. This results in tax systems that vary in both rates and calculation bases across the cantons, which creates a natural experiment. Two main questions arise: how

[2] Vehicle Excise Duty; annual tax paid for vehicles in the United Kingdom

the systems shape passenger car registration and retirement (and corresponding average CO_2 emissions).

Alberini & Bareit (2019) investigated the former issue and concluded that malus on highly-polluting cars reduces sales and associated emissions, however, the effect is negligible. On the other hand, a bonus on low-emitting vehicles prompts new car sales that increase net CO_2 emissions. The elasticity of car sales with respect to registration fees was estimated at -0.0844.

The latter problem was scrutinized by Alberini et al. (2018). Analysis targeted mainly at 3 cantons with miscellaneous annual taxes. Geneva and Ticino cantons burdened newly registered high emitters with increased fees (the threshold was not identical and the malus ranged between 20% and 50%). Malus implemented by canton Obwalden was retroactive; it applied not only to newly registered cars but also to cars already in evidence. The amount of the additional charge was 60 CHF. All 3 cantons also introduced a bonus for new cars with low enough emissions. Other cantons with no policy in place served as a control in the study. The consequences of the changes were vastly different. No statistically significant effect was found in Ticino. In Geneva, the new system led to deregistration postponement (approx. by 3%) of vehicles with high CO_2 emissions, whereas in Ticino, the new scheme accelerated the retirement of the most polluting cars by some 5%.

The findings of Alberini et al. (2018) perfectly illustrate the importance of appropriate fee system design. All cantons investigated in the paper introduced the changes and malus for high-emitters with the ultimate goal to decrease CO_2 emissions, but good intention is sometimes not enough and as it turned out, the outcome might be opposite to the intended one. Therefore national or local authorities responsible for rules should always think twice when imposing new regulations.

2.3.2 Subsidies

Another way how to turn car buyers towards less polluting vehicles is through government subsidies, both financial and non-financial. As already mentioned before, the high price of the alternative vehicles is an obstacle for many potential buyers and thus government subsidy (that would practically decrease the price of the car for a buyer) would increase the demand for them (Ščasný et al. 2018).

Scrapping subsidy is usually offered for the owners of older cars and should encourage them to scrap their old, high-polluting car (so that it does not reenter the market as a second-hand car) and replace it with a more efficient one. The effects, however, are questionable. Van Wee et al. (2011) reviewed a number of studies concerned with scrapping subsidies. Several interesting concluding remarks were made: firstly, most of the studies that investigated ecological consequences found only moderate effect. Moreover, in papers that also examined the durability, the effect of the scrapping programme appeared to be only short-term. Another observation of this review point to the low cost-effectiveness of the programmes.

The US scrapping programme 'Cash for Clunkers' in 2009 was addressed by several studies that tried to evaluate its effects on car purchases. While (Hoekstra et al. 2017) used regression discontinuity design and estimated that nearly 60% of households who bought a new car would do it anyway, (Li et al. 2013) used difference-in-differences approach with Canadian sales as control and evaluated the share to 45%. Both studies indicate little to no long-term effects. Marin & Zoboli (2020) found that only 1 of 3 scrapping programmes in Italy between 2007 and 2009 was effective in accelerating the retirement of old cars.

When lawmakers do not support the purchase of new eco-friendly cars directly, they can attract potential buyers by lowering the operational costs. In Norway, the government offered several benefits to the owners of electric cars: using transit lanes, taxes and road toll exemption, free public parking and charging (Holtsmark & Skonhoft 2014). This led to a soaring amount of electric and alternative vehicles in the country. In 2019, electric cars accounted for 9.3% of all new registrations; all alternative cars together for some 17.5% (Statistisk sentralbyra 2022). Thanks to all the incentives from the government, it simply became reasonable to drive an EV from an economical point of view. Aasness & Odeck (2015) estimated the yearly savings from driving an EV compared to conventional vehicle to equal 3,275€ taking into account various operational costs including government incentives.

2.3.3 Spillover effect

It should be noted that there are other factors than domestic policies that may influence the behaviour of customers on the domestic car market. Policies in a country might create a spillover effect and affect the market in other states as well. O'Neill et al. (2019) mentioned a steep rise in imports of used diesel cars to Ireland as a consequence of Brexit. Kahn & Davis (2009) found interesting consequences of elimination of trade restrictions between USA and Mexico in 2005. This change led to second-hand car flow from the USA to Mexico. While the vehicles exported from the USA had higher than average emissions per mile, compared to the Mexican vehicle fleet, emissions of the cars imported to Mexico were lower than average, resulting in a decrease in average emissions per mile in both countries. However, due to the low retirement rate of Mexican vehicles, total emissions in this Central American country increased.

A similar international motion of used cars is present in Europe. The lifespan of passenger cars differs extensively among European vehicle fleets; in Luxembourg, an average lifespan of a passenger car is about 8 years, whereas cars in Poland are expected to retire more than 35 years after being produced. It should be expected that second-hand vehicles from western European countries often find new owners in eastern countries (Held et al. 2021).

Chapter 3

Data

Data for this study are collected from several sources. The main dataset provided Slovak Police Force, The Department of Papers and Evidence. The original file stores 3,986,218 observational units of 49 variables representing vehicles of all categories that were registered in the Slovak republic between 1.1.1993 and 20.7.2020. It contains information about the date when a vehicle was registered for the first time in any country and when in Slovakia (the dataset also includes information about the office where the vehicle entered the Slovak Police evidence). Thanks to that information we were able to distinguish between brand new vehicles that entered the evidence and used or second-hand vehicles (we use the terms 'used' and 'second-hand' interchangeably). Note that we can only observe used vehicles entering the fleet (stock), not the changes within the fleet (e.g. old car sold from Slovak to another Slovak owner). Besides vehicle brand, model, trim and version, it also reports technical characteristics of the vehicles including fuel type and consumption, engine power and displacement, various emission indicators and more. However, the dataset encompasses a considerable number of missing values, mainly due to the absence of central electronic evidence.

Therefore we have decided to restrict our study to the period of 2009 to 2019 (included) which offers rather complete data with relatively few missing values. Data from the first half of 2020 were omitted as well due to possible effects of COVID-19 pandemic that could distort the results. Nevertheless, as can be seen in table 3.1, the dataset is far from being 100% complete and correct. For instance, the variable *age* that denotes the age of car when registered (computed as a difference between date of first registration overall and first registration in Slovakia) for the first time in the Slovak republic, has at least

Chosen summary statistics, 2009-2019						
Variable	*Unit*	*Mean*	*Std Dev*	*Min*	*Max*	*NA's*
Horsepower	kW	90.38	36.11	1	6,300	7
Weight	kg	1,918	329.07	499	20,430	0
Displacement	cm^3	1,713	497.18	0	19,686	0
Consumption	$l/100km$	5.73	4.34	0	999	156,427
Age	day	1,269	1,925.45	-2,032	115,222	177
Emissions	g/km	140.6	31.25	0	2610	180,131

Table 3.1: Chosen variables from the dataset and their summary statistics.

one negative value which is obviously a faulty input. The situation is even more complicated for deregistered vehicles. Therefore we focus only on registration in our analysis, although some statistics include deregistered vehicles as well (deeper clarification is provided in Section 3.2).

3.1 Newly registered vehicles in Slovakia

In this thesis, we focus on personal motor vehicles, i.e. vehicles that are defined in the Slovak system as category *M1 - osobné vozidlo, max. 8 miest na sedenie okrem miesta pre vodiča* (personal vehicle, max. 8 seats excluding the driver's seat). During the study period, the number of passenger cars registered in the Slovak republic that satisfy the aforementioned conditions reached 1,512,555 units in total (figure 3.1 and 3.2).

The yearly figures fluctuated over the study period. At the beginning of our research period, in 2009, there were 144,305 cars registered in Slovakia for the first time, out of which more than 53% were newly produced. Followed by a drop and relatively stable period between 2010 and 2013, registrations of new cars fluctuated around 65,000 pieces per year. The number of second-hand cars also remained stable, but only until 2013. While in previous 3 years the amount and share of used cars on total registrations remained consistent with approximately 58,000 cars and 46% share respectively, in 2013 it was barely 46,000 vehicles and the share on total registrations fell to 41.5%. In the following years, both new and second-hand car registrations experienced a gradual rise. The growth rate of new vehicles declined after 2017, similarly to used ones. In the aforementioned period the share of used cars floated between 40.5% and 43%, but in 2019, the yearly registrations of second-hand vehicles,

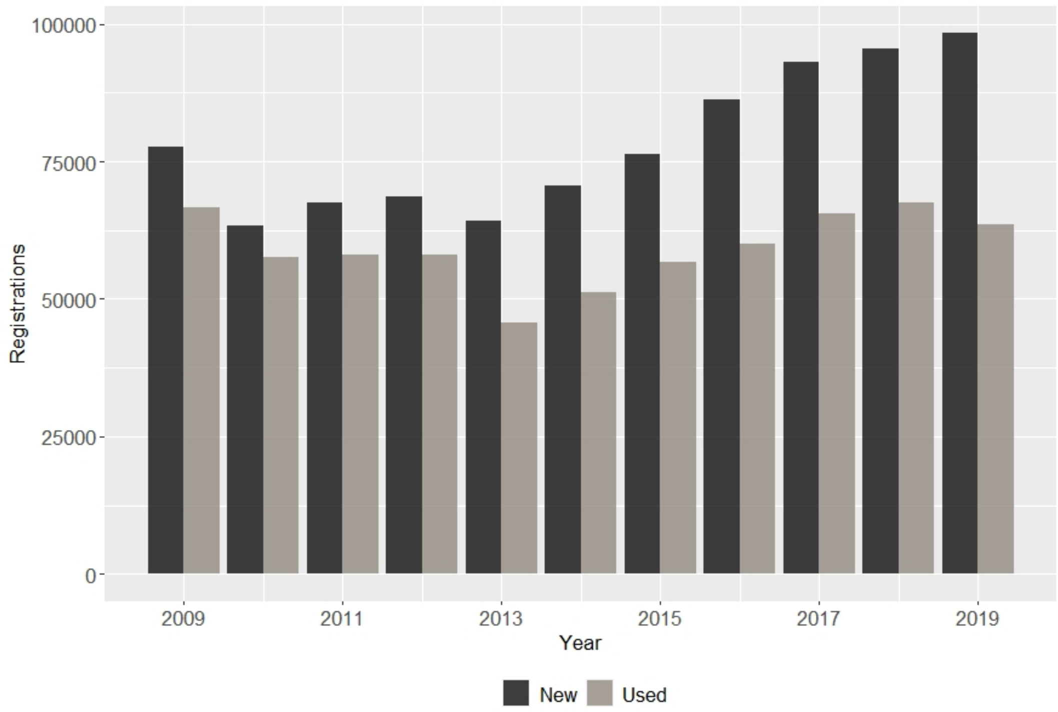

Figure 3.1: Registrations of passenger vehicles in Slovakia by years.

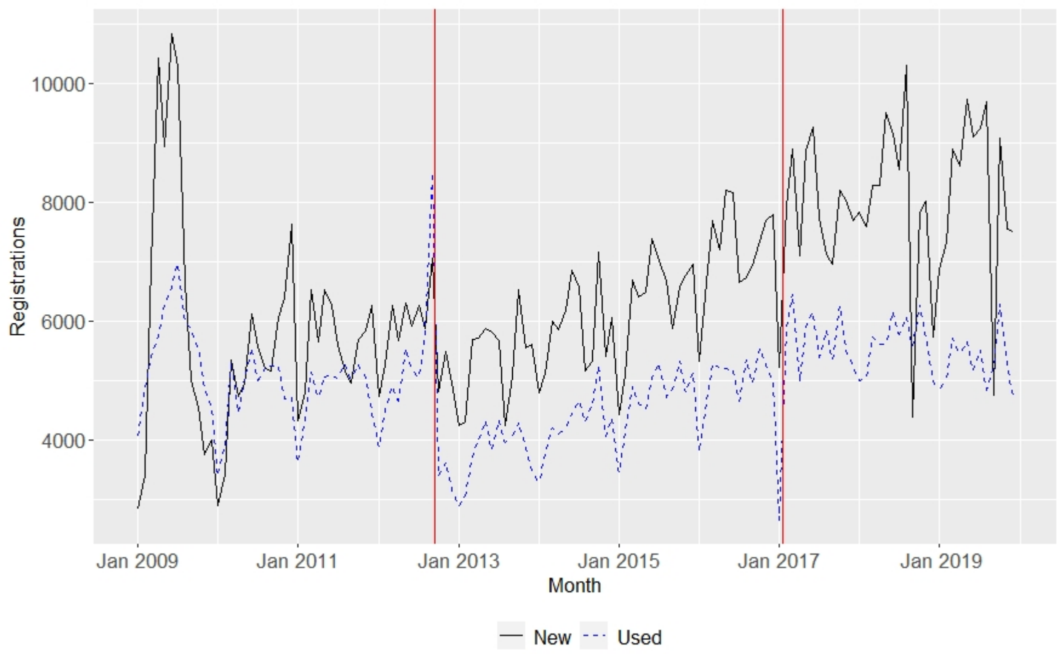

Figure 3.2: Registrations of passenger vehicles in Slovakia by months. Vertical red lines represent changes in the fee system.

unlike newly produced ones, dropped by 6% and their share to some 39%. In 2019, almost 162,000 cars were entering the evidence in the Slovak republic, which was a negligible decrease compared to the previous year, when the highest number of registrations in our study period was recorded with approximately 163,000 newly registered passenger vehicles.

Registrations of new cars are higher than used vehicle registrations also on the monthly basis, with only a few rare exceptions. The registrations within a year are distributed unevenly. During the winter months, especially in Januaries, amount of vehicles entering the evidence was lower than the yearly average, similarly the period of summer holiday. On the other hand, the highest amount of newly registered cars was usually recorded before and after the summer holiday (June, September/October). What should be also noted is the effect of fee modification: in September 2012 (last month before the first fee change), people registered almost 8,500 second had cars, some 70% more than the average of the months before. In subsequent October, the amount plunged to 3,380. A similar effect (with opposite motion) happened also at the beginning of 2017: in January, registrations of both new and (especially) used cars dropped substantially to recover in the following month.

Other extraordinary fluctuations can be seen in 2009 and 2018. In the first case, the sharp variations in new car registrations were caused by the scrapping subsidy of the Slovak government in the spring of 2009. In the first half, the effect of scrapping subsidy rapidly increased new sales and registrations, but after the end of it, registrations dramatically declined, indicating intertemporal shift in sales. The reason behind the second case, i.e. high fluctuations in the second half of 2018, was the change in the emission test framework. The old New European Driving Cycle (NEDC) was replaced by a more advanced Worldwide Harmonised Light Vehicle Test Procedure (WLTP) that is able to measure emission rates of vehicles more realistically. In addition, as of September 2018, not only did all cars need to comply with the new WTLP test cycle, but also with the more strict emission standards. And therefore the car dealers tried to sell vehicles that were compliant with neither WTLP nor emission standards.

The most popular make among Slovak customers in the study period was Škoda with almost 287,000 cars of this brand registered in Slovakia. Second place belongs to Volkswagen with nearly 197,000 passenger vehicles and the third most favourite make in Slovakia was Ford with some 90,000 pieces (table 3.2). The top 10 most popular brands accounted for roughly 70% of all vehicles that entered Slovak evidence between 2009 and 2019. Remarkably, 6 out of 10 most popular brands have been represented by at least one model in domestic production (Škoda, Volkswagen and Audi in Bratislava, Pegueot and Citroen in Trnava, and Kia in Žilina).

Make	*Amount*
Škoda	286,922
Volkswagen	196,724
Ford	89,278
Pegueot	83,719
Kia	72,597
Hyundai	70,166
Renault	70,081
Opel	69,757
Audi	56,795
Citroen	55,747

Table 3.2: The top 10 makes registered in Slovakia, 2009-2019.

Figures 3.3 and 3.4 show great differences in fuel types of passenger vehicles newly registered. Most of the new cars were powered by petrol, although initially there was a downward trend and their share decreased successively from the original 78.6% in 2009 to 51.8% in 2012. At the same time, share of diesels rose from 18.4% to merely 47%. Then the trend deflected and the share of petrol cars began to grow and in 2019, almost 72% of new cars entering the Slovak evidence were powered by petrol, whereas share of diesels declined to some 23%. The rest of the vehicles were mostly petrol hybrids. Note that this group encompasses all vehicles with petrol and additional power source, i.e. not only petrol HEV and PHEV, but also petrol LPG and CNG hybrids (similar rule stands for diesel hybrids as well). Share of electric, diesel hybrid and other (mostly CNG and LPG) vehicles was negligible.

Second-hand cars sector was dominated by diesel cars, whose share never fell under 67%. Initial subsequent rise reached its highest level in 2019 when 84.1% of all used cars registered had diesel as their fuel. Since then, there was a gentle decrease and from 2017 to 2019 the share of diesel vehicles stabilised around 74%-75%. The share of petrol on used cars registrations mirrored the movements of diesel share and in 2019, the share of petrol reached 22.6%. Share of the other fuel types was again minimal, the most represented group were petrol hybrids with a 2.2% share in 2019.

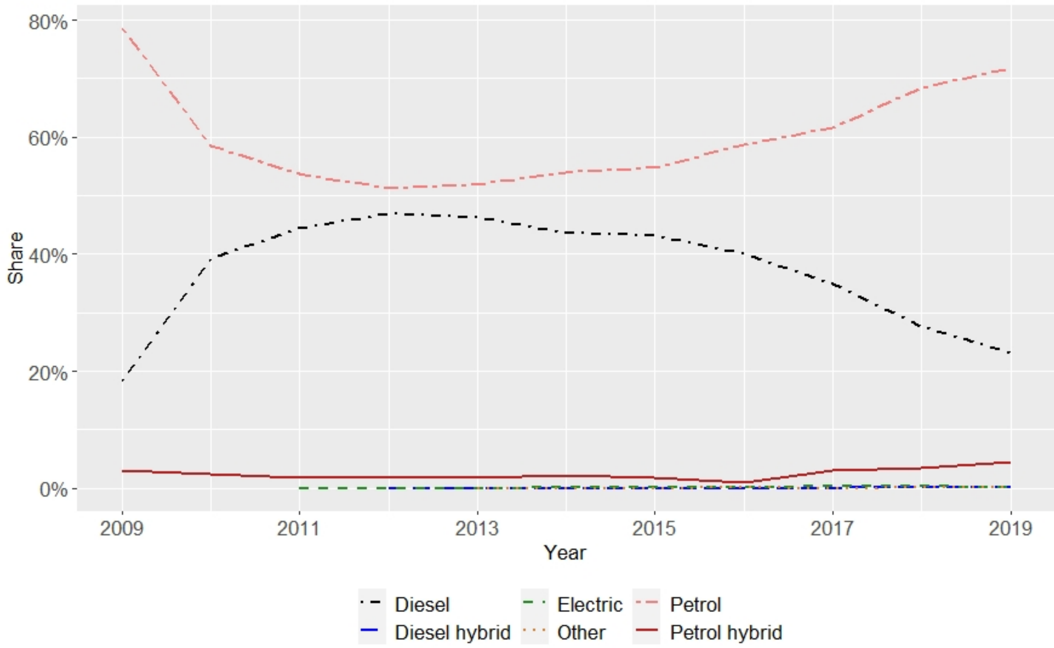

Figure 3.3: Fuel types' shares of new cars registered.

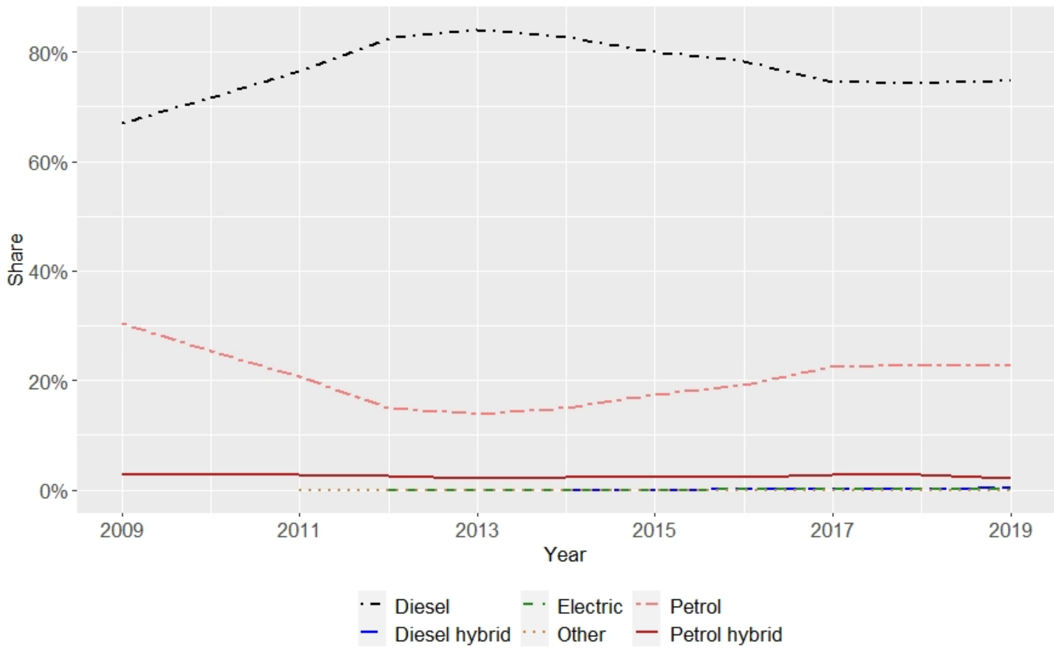

Figure 3.4: Fuel types' shares of used cars registered.

3.2 Cars characteristics

Firstly, as we mentioned in the previous chapter, there are some difficulties with the recognition of the vehicles that were retired from the Slovak registry. However, we include their characteristics in this section together with the newly registered cars. We are aware that the information from this specific vehicle group is not doubtlessly credible, but the aim is to provide a comparison with the technical attributes of the newly registered car and present the reader with yet another point of view.

We consider a vehicle being deregistered if one of the following conditions is fulfilled: the condition of the vehicle was equal to deregistered, deregistered abroad, retired from evidence, retired from traffic or the reason for the change of condition was retirement, retirement abroad, retirement from traffic or retirement from evidence. The date of deregistration is the date of the last change of condition.

The engine power of cars newly[1] registered and deregistered has grown over the years 2009-2019 (figure 3.5). The period before 2012 saw a rise for both newly registered and deregistered vehicles, later the growth rate became much slower. Average second-hand car horsepower has been higher overall than that of brand new vehicles. The exception is the period between October 2012 and February 2017, when all vehicles were subject to registration fees depending on their respective engine power. In the aforementioned period, the engine power of vehicles entering the evidence in Slovakia was level and that of second-hand cars decreased substantially compared to the period before the change. Changes in the amount of registration fees and the introduction of a discount for used vehicles in February 2017 reestablished the superiority of engine power of second-hand cars. The average engine power of retiring cars fluctuated more during the specific years, particularly before 2013, but overall remained more stable than that of registered vehicles with only a minimal increase over the whole study period.

The weight of the vehicles entering or leaving the evidence exhibited a similar pattern: rise before 2011, steep drop at the end of 2012 and rather slight growth with monthly fluctuations until the end of 2019 (figure 3.6). Note that, unlike engine power, the weight of newly registered used cars has not dropped

[1]We report the characteristics for the cars (de)registered in a given month, not the fleet as a whole in the given month.

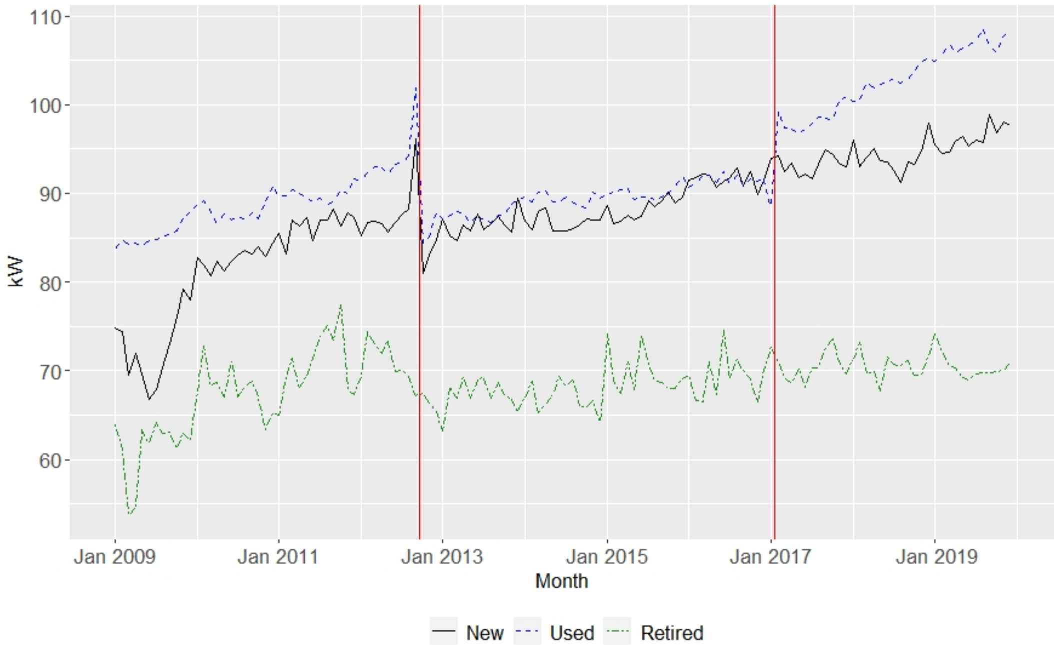

Figure 3.5: Average engine power of newly (de)registered vehicles by months.
Vertical red lines represent changes in the fee system.

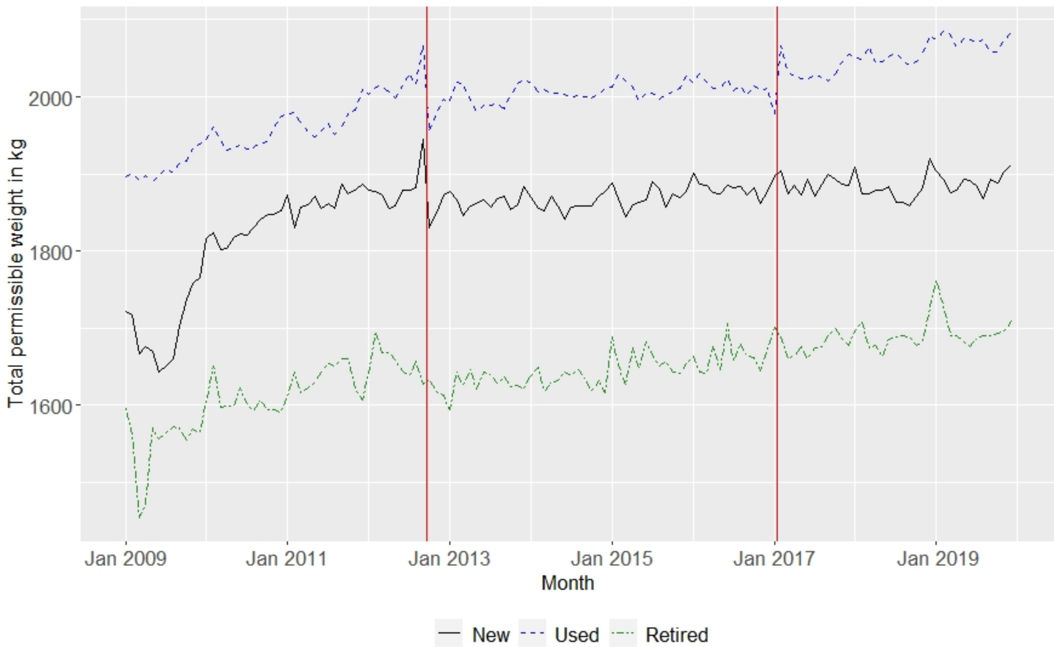

Figure 3.6: Average weight of newly (de)registered vehicles by months.
Vertical red lines represent changes in the fee system.

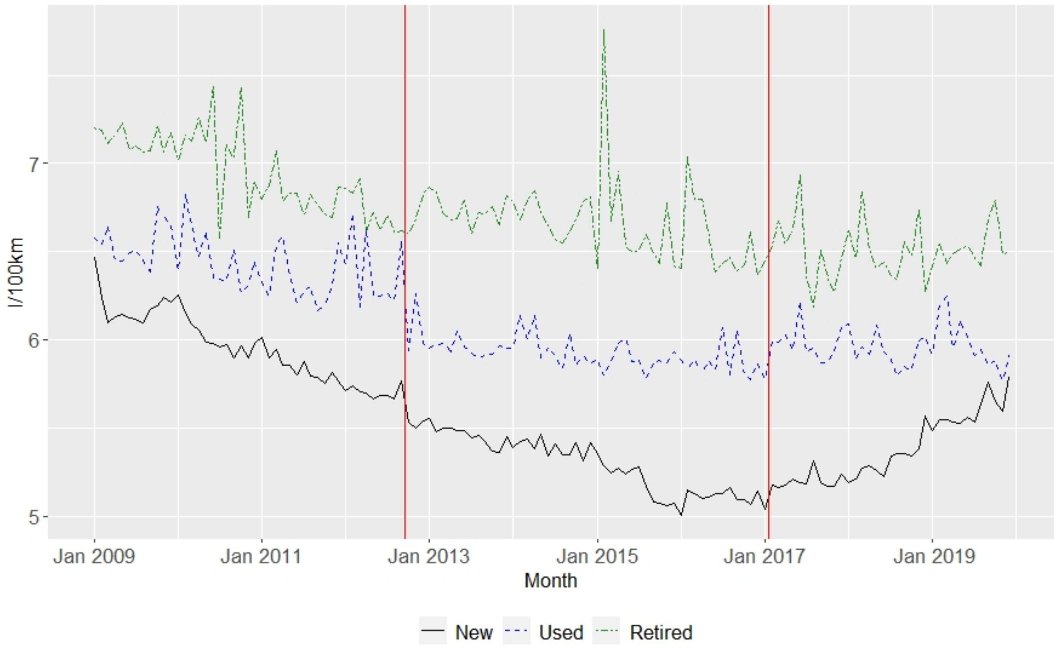

Figure 3.7: Average fuel consumption of newly (de)registered vehicles by months.
Vertical red lines represent changes in the fee system.

to the level of brand new vehicles in the time between the first and second change to registration fees, but remained substantially higher.

On the contrary, the fuel consumption of cars displays a downward trend (figure 3.7). The average fuel consumption of brand new cars plunged from approximately 6.5l in January 2009 to roughly 5l in January 2016. Mileage of the second-hand vehicles remained higher for the above-mentioned time, but also recorded a decrease, although not so sharp as by new vehicles. Moreover, the downward trend slowed down over time. Consumption of retired vehicles showed a similar pattern to that of second-hand cars. Nevertheless, the average consumption of decommissioned cars was greater than that of used cars and much higher than the mileage of brand new passenger vehicles, meaning that the average fuel consumption of the Slovak passenger fleet has been decreasing, although the trend became slower in 2016. Even though the mileages of deregistered and second-hand cars maintained their respective levels, new vehicles entering evidence recorded relatively steep growth in fuel consumption. By the end of 2019, the average mileage of new and second-hand cars reached almost equal levels.

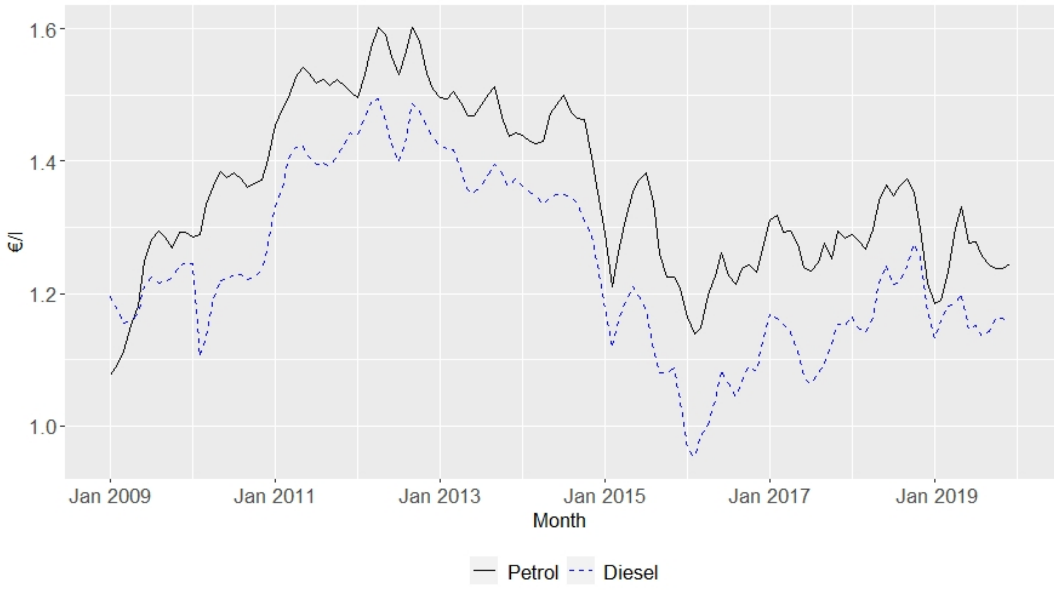

Figure 3.8: Monthly CPI adjusted fuel prices in Slovakia (2015=100).

3.3 Fuel prices

Fuel prices were gathered from the Slovak Statistical Office. Monthly figures of average prices of petrol 95 and diesel include both excise tax and VAT. Since 2009, the main source of fuel prices is data from the weekly survey of the State Material Reserves of the Slovak Republic prepared by the Slovak Statistical Office. VAT for petrol and diesel in the Slovak republic was 20% during the whole study period. Excise tax on the 1st of January 2009 was equal to 514.5€ and 597.49€ for 1000l of petrol (depending on the specific type of it) and 481.31€/1000l for diesel. On 1st of February 2010 excise tax for diesel was lowered to 368€/1000l and the last change during our study period took place on the 1st of January 2019, when the rates for petrol were changed to 547€ and 597.49€ and for diesel to 393€ for 1000l. Prices used in this paper are adjusted using the monthly Consumer Price Index (CPI) for the Slovak republic available from the OECD database, with 2015 being the base (OECD 2022).

Figure 3.8 displays the average adjusted monthly prices of diesel and petrol 95 in the Slovak republic. Both petrol and diesel prices show a similar pattern and often move together. Real prices of diesel have been lower than petrol except for a short period in the first quarter of 2009. A drop in excise tax for diesel from February 2010 is also visible. Both petrol and diesel prices grew from values under 1.2€ per litre in January 2009 to more than 1.6€ and 1.49€

per litre in the second half of 2012, followed by a period of steady decline. In the second half of 2014 prices plummeted and except for a climb in the first half of 2015, the sharp decline continued until February 2016, when petrol and diesel real prices fell below 1.14€ and 0.95€ per litre, respectively. Subsequently, the prices of both fuels again started to rise to reach their highest levels since 2015 in September and October 2018. Strong fluctuations (especially of petrol price) in the first half year of the following year caused that by the end of 2019, the real prices of petrol and diesel approached 1.24€ and 1.16€ per litre, respectively.

3.4 Tax and fee system

As mentioned previously, there are various types of taxes and fees paid for the purchase and/or ownership of a car. In terms of taxes, there is an annual tax for owners of (not only passenger) vehicles in Slovakia, but subject to this tax are only those used for entrepreneurship or other business activities.

Engine power (kW)		*Registration fee (€)*	
from	*to (included)*	*2012-2017*	*2017-*
0	80	33	33
80	86	167	90
86	92	217	110
92	98	267	150
98	104	327	210
104	110	397	260
110	121	477	360
121	132	657	530
132	143	787	700
143	154	957	870
154	165	1157	1100
165	176	1397	1250
176	202	1697	1900
202	228	2047	2300
228	254	2467	2700
254		2997	3900

Table 3.3: Registration fees in Slovak republic.

On the other hand, all cars, private or commercial, are subject to the registration fee that has to be paid upon the time of entering the vehicle evidence of the Slovak republic. It is a lump payment charged only by the vehicle's first registration. Firstly introduced in 1995 by Act No.145/1995, the registration fee was unified for all cars, although the value of the fee itself had changed over the years. When Slovakia adopted the euro as its official currency (1^{st} of January 2009), the fee was set on 33€ per vehicle.

Unified fee for all vehicles was altered for the first time with Act No.286/2012. This amendment established a new scheme for the computation of the payment for registration (table 3.3). Coming into force on the 1^{st} of October 2012, this new system created 16 classes that were dependent upon the vehicle's engine power measured in kilowatts. The fee paid was directly proportional to the engine's performance. The disparities in fees were quite significant: from 33€ paid by the vehicles with an engine power of 80kW or less to 2997€ for vehicles with the most powerful engines (254kW and more). The only exception from this scheme was granted to battery electric vehicles which had the fee set on 33€, regardless of the engine power.

Years since the first evidence	*Coefficient*
first evidence	1
1	0.82
2	0.68
3	0.56
4	0.46
5	0.38
6	0.32
7	0.26
8	0.23
9	0.19
10	0.16
11	0.14
12	0.12
13	0.1
14	0.09
15	0.08
16	0.07
over 16	0.06

Table 3.4: Coefficient table of the amortised cost.

The next change was introduced in September 2016 with Act No.342/2016 and became effective on the 1^{st} of February 2017. The first adjustment was the modification of fees for vehicles. The amount of fee decreased for vehicles with less powerful engines and increased for vehicles with more powerful powertrains (for details see table 3.3). A 50% discount on the fee was proposed for the plug-in electric hybrid, electric or other hybrid, CNG-, LPG- and hydrogen-powered passenger vehicles. The reason behind the discount for alternative vehicles is taking into account the environmental aspect of the registration fee so that it lowers the emission from transport (Národná rada Slovenskej republiky 2016).

Another important change was adding coefficients for fee calculation (table 3.4), mainly to account for the decreasing value of cars with their increasing age (Národná rada Slovenskej republiky 2016). On the contrary, older cars tend to be less fuel efficient than newer cars, making them more polluting and thus less environmentally friendly. That seems contradictory to the declared purpose of the aforementioned discount for alternative vehicles as well as the goals of the Slovak republic in the field of pollution and ecological sustainability.

The new formula for fee computation takes the following form:

$$RF = P_{kw} * AV_{1-n}$$

where RF equals the registration fee of a car, P_{kw} is the tariff based on the engine power of the vehicle in kW and AV_{1-n} is the coefficient of the amortised cost of the vehicle. However, after applying all discounts and/or coefficients, the value of the fee that is due to pay cannot fall below 33€.

Chapter 4

Methodology

In this chapter, we firstly propound the research questions we want to answer using our model. Secondly, we determine the methodology, specifically the method of estimation we use to evaluate our model, the selection of dependent and independent variables and their specification.

4.1 Research questions

In this work, we want to primarily examine two issues: the effect of registration fees and fuel prices on consumers' choice on the Slovak car market.

The first question is how an increase in fuel prices influences demand for vehicles. We hypothesize that rising fuel prices lower the demand for fuel inefficient cars. We also aim to examine whether the demand for efficient cars increases or drops as for inefficient vehicles.

The second question is related to the effect of the fee on registrations. We assume that higher fees lead to lower registrations of passenger vehicles. We want to study whether the effect is stronger for new cars (that are subject to higher fees) or used cars (higher price-fee ratio).

4.2 Methodology

For the purposes mentioned above, we calculate the number of registrations of cars in a given month and year. We define a car (from now on we will refer to it as a unique car) as a combination of make, model, fuel type, horsepower and condition (i.e. new or second-hand).

In the original dataset, there are 36 unique types of fuel. For the purpose of this study, we group them into six different classes: petrol, diesel, petrol hybrid, diesel hybrid, electric and other. Petrol includes vehicles powered by all petrol types (90, 91, 95, 98 and sub-variants). Petrol hybrid encompasses all vehicles that combine petrol with some other type of fuel. We distinguish neither electric and non-electric hybrids nor PHEV and HEV (for some cases in the original dataset, the information about fuel is insufficient to determine). An analogous procedure is applied for diesel hybrids. Electric include only BEVs and to group others belong vehicles powered by LPG or CNG.

Before we computed the number of unique cars registered, the amount of fee paid was calculated for each car in the original dataset. Thanks to the information about registration date overall and in Slovakia we were able to distinguish a second-hand car from a new car and compute the proper fee vehicle was subject to. A problem arises for second-hand vehicles registered since February 2017. Due to our definition of the unique car that does not identify age as a specific feature, fees for these unique cars may not be identical. We decided not to include the fee as a criterion and instead compute the fee as the mean of the fees of all cars within the group.

4.2.1 Method choice

Processed dataset exhibits the nature of longitudinal data, in our case, since we do not have observations equal to zero for years when a specific unique car was not registered once, we are dealing with an unbalanced panel dataset. To examine this type of data, possible methods include pooled OLS (POLS), fixed effects or random effects method. As Wooldridge (2015) points out, the main difference in the aforementioned methods is the treatment of individual effect. Let

$$y_{it} = \beta_0 + \beta_1 x_{it1} + ... + \beta_k x_{itk} + \alpha_i + \epsilon_{it}$$

be the general panel data model. If we believe the individual effect α_i is observed, POLS is consistent and efficient. If the individual effect is unobserved and correlated with explanatory variables, then an appropriate fixed effects method should be used. If there is no correlation between them, random effects methods become the preferred option.

With a pure POLS approach, we would not be able to capture time and vehicle-specific effects. However, due to the relatively high number of cross-sections and time dimensions (31,919 and 132, respectively) in the dataset, applying traditional FE methods such as within-estimator for both time and individual effects would be computationally profoundly demanding. Thus, we adopt the approach used in similar studies by Alberini & Bareit (2019), Cerruti et al. (2019) and Alberini & Horvath (2021), who employed the standard OLS method with numerous fixed effects added. For this purpose, we embrace the estimator proposed by Correia (2016) for linear fixed effect models that allows us to include various fixed effects.

The estimation process is following: let

$$\boldsymbol{y} = \boldsymbol{X\beta} + \boldsymbol{D\alpha} + \boldsymbol{\epsilon}$$

be the model specification where $\boldsymbol{y}$ is a matrix of explained variable, $\boldsymbol{X}$ matrix of explanatory variables, $\boldsymbol{D}$ dummy matrix and $\boldsymbol{\epsilon}$ is the error term. The dummy matrix $\boldsymbol{D}$ consists of F fixed effects and can be written as $\boldsymbol{D}$=[$\boldsymbol{D_1}$ $\boldsymbol{D_2}$ ... $\boldsymbol{D_F}$]. To estimate $\hat{\boldsymbol{\beta}}$, we first regress each predictor against all fixed effects and then we regress residuals of these variables. More formally, let $\boldsymbol{P_D} = \boldsymbol{D}(\boldsymbol{D}^\top\boldsymbol{D})^{-1}\boldsymbol{D}^\top$ be the projection matrix with respect to $\boldsymbol{D}$ and $\boldsymbol{M_D} = \boldsymbol{I} - \boldsymbol{P_D}$ the corresponding residual-maker matrix annihilator. Then residuals of $\boldsymbol{y}$ and $\boldsymbol{X}$ with respect to fixed effects are computed as

$$\tilde{\boldsymbol{y}} = \boldsymbol{M_D y}$$

$$\tilde{\boldsymbol{X}} = \boldsymbol{M_D X}$$

By applying Frisch-Waugh-Lovell theorem (Frisch & Waugh 1933; Lovell 1963), we get

$$\hat{\boldsymbol{\beta}} = (\tilde{\boldsymbol{X}}^\top\tilde{\boldsymbol{X}})^{-1}\tilde{\boldsymbol{X}}^\top\tilde{\boldsymbol{y}}$$

$$\hat{\boldsymbol{e}} \equiv \boldsymbol{y} - \boldsymbol{X}\tilde{\boldsymbol{\beta}} - \boldsymbol{D}\hat{\boldsymbol{\alpha}}$$

Lastly, $(\boldsymbol{D}^\top\boldsymbol{D})\hat{\boldsymbol{\alpha}} = \boldsymbol{D}^\top\boldsymbol{y}$ is solved to obtain the OLS residuals of a model that takes the form $\boldsymbol{y} = \boldsymbol{D\alpha} + \boldsymbol{\epsilon}$ (Correia 2016).

From now on we refer to the aforementioned estimator as POLS with fixed effect or Correia estimator. The advantages of the previous estimation method are the possibility to include a number of fixed effects as well as short computation time. If we used the unique car as an individual and registration date as time fixed effect, the results of Correia and within estimator would be identical.

4.2.2 Model specification

The aim of this study is to analyse the effect of fees and fuel prices on the choice on the Slovak car market, therefore monthly registrations of unique cars serve as a dependent variable in the model. Independent variables include the amount of real fee paid for registration (i.e. fee that is CPI adjusted)[1] and cost per 100 kilometres of a ride.

Rather than using fuel prices as such, we substitute them with the price of the drive. We combine the information about fuel consumption in litres per 100 kilometres of the unique car with the real price of corresponding fuel in the month of registration to create the costs of fuel consumed per 100 kilometres of driving. Since our definition of the unique car encompasses various sub-variants with possibly different fuel economies, we use the mean value for each unique car. For vehicles that are grouped as electric and other (and whose costs per ride are independent of petrol/diesel prices), we use the average fuel prices for the given month instead of the price per kilometre driven. Related studies also used some form of driving costs instead of fuel prices (Alberini & Bareit 2019; Cerruti et al. 2019; Alberini & Horvath 2021).

Thus, we design the base model as follows:

$$\begin{aligned} ln(regs\_no_{mit}) = \\ \alpha + \beta_1 ln(rfee_{mit}) + \beta_2 ln(pkm_{mit}) + \nu_m + \phi_t + \epsilon_{mit} \end{aligned} \tag{4.1}$$

where m stands for make and model, i for fuel, horsepower and condition, t for year and u for month of registration, $regs\_no$ is number of unique cars registered, $rfee$ is CPI adjusted registration fee paid for the vehicle in €, pkm fuel price per 100 kilometres of drive and ϵ is the idiosyncratic error term. We also include a set of fixed effects for month and year of registration to account for time fluctuations as well as for make and model to control for unobserved consumer preferences and vehicle characteristics.

Other researchers (see for example Cerruti et al. (2019)) include technical characteristics of the car as independent variables in the model. Since our dataset allows us to perform regression with technical info, we extend specification of our model and with added car characteristics it looks following:

[1]We will refer to the CPI adjusted fee from now on simply as a fee.

$$\begin{aligned}
ln(regs_no_{mit}) = \\
\alpha + \beta_1 ln(rfee_{mit}) + \beta_2 ln(pkm_{mit}) \\
+\delta_1 ln(kw_{mit}) + \delta_2 ln(disp_{mit}) + \delta_3 ln(tpw_{mit}) \\
+\delta_4 seats_{mit} + \delta_5 alt_gbox_{mit} \\
+\nu_m + \phi_t + \epsilon_{mit}
\end{aligned} \tag{4.2}$$

with kw being average horsepower of the unique car, tpw average weight, $disp$ average engine displacement, alt_gbox a dummy variable equal to 1 if both automatic and manual gearbox were available for unique car (0 otherwise) and $seats$ the median of seats in a unique vehicle.

Log-log specification is chosen primarily for two reasons: firstly, we believe that percentage changes in dependent and independent variables are more meaningful than absolute change would be in this case. Secondly, using natural logarithms allows us to interpret the results as elasticities.

Even though we expect fixed effects to be present in the model, we will estimate the model using POLS, within-estimator (for FE) and FGLS (for RE). To choose between POLS and FE methods, we utilize the F-test to uncover fixed effects. To determine whether RE or FE are better, we will follow the advice of Wooldridge (2015) and apply Hausman test (Hausman 1978).

The occurrence of heteroskedasticity or serial correlation might invalidate inference from regression results, thus we will perform tests to detect them and eventually optimise the estimation procedure using robust standard errors. Wooldridge (2010) suggests Durbin-Watson test (Durbin & Watson 1950) to detect serial correlation and Breusch-Pagan test (Breusch & Pagan 1979) for heteroskedasticity.

4.2.3 Segment analysis

Since we expect differences in behaviour on market for new cars and used cars, for fuel efficient and inefficient cars as well as for diesel and petrol vehicles, we create a new variable *veh_type* that divides cars from our dataset according to their condition (new/second-hand), fuel efficiency (efficient/inefficient) and fuel (petrol/diesel) into eight groups. We set the threshold of less than 5.5l fuel burned per 100 kilometres to be the criterion for a car to be considered fuel efficient. We interact this new variable with both the fee and the driving costs (by driving costs we mean the costs related to the fuel prices and fuel consumption of the car, not the costs of maintenance) and inspect the variation among segments and compare the results with the base model. We include only petrol and diesel vehicles in this part, but that should not particularly restrict the dataset as the majority of the cars are powered by either petrol or diesel (see table 3.3 and 3.4).

4.2.4 Response asymmetry

An occurrence of periods of rising and falling fuel prices is detectable in figure 3.8. Similarly to Alberini et al. (2022), our goal is to compare the response of customers during the different periods to the changes in fuel prices and thence resulting driving costs. We focus on the following three periods. The time intervals from January 2009 to March 2013 and from March 2016 to October 2018 were accompanied by an upward trend in fuel prices, whereas between September 2013 and February 2016, the prices of motor fuels were decreasing. We estimate the base specification of our model separately for each period and observe whether car buyers' reaction differs or not for distinct periods.

4.2.5 Data cleaning

Before we run any regression, we check data for possible defect values. There should be no problem regarding the number of registrations and fees. One could object that observations with faulty horsepower might influence the calculated fee, but we argue that if a faulty value of horsepower appeared (either too low or too high), it would not bias the result significantly. The minimum fee a car is subject to, regardless of horsepower, powertrain and discounts, is 33€. On the other side, the fee is unanimous for all vehicles whose horsepower exceeds 254 kW. Thus, no problem with the fee should occur even in presence of a faulty input that is either low or high.

The same does not stand for fuel consumption and thereof the cost of the drive. Extraordinary values caused by wrong input or the missing decimal pointer might distort the results of the regression. To filter such values, firstly we have to find a threshold for consumption high enough to consider it a false value. After inspecting the consumption of some of the most luxurious car brands (Ferrari, Lamborghini, Bugatti, Rolls-Royce), cars produced by Bugatti exhibit the worst fuel economy. As reported by the manufacturer, Bugatti Chiron burns 25.2 litres and Bugatti Veyron 23.1 litres of fuel per 100 kilometres.

Higher fuel consumption of any passenger car registered in Slovakia is therefore highly unlikely. Therefore we set the threshold to 20l/100km and omit all cars with higher consumption from the dataset. Analogically we proceed with pure petrol and diesel vehicles whose consumption is lower than 3.5l/100km and hybrids with consumption lower than 1l/100km.

Chapter 5

Results

By applying data cleaning mentioned in the previous chapter to the original dataset, we are left with 277,984 observations that include 1,350,187 newly registered cars (approximately 89.27% of all passenger cars registered during the study period).

In this chapter, we firstly run a set of tests to inspect the unobserved individual effect and to uncover the eventual presence of heteroskedasticity and serial correlation. Secondly, based on the results of the tests, we report the outcome of our models using the whole dataset of registered cars. Lastly, we use subsets of the dataset to examine differences between market segments.

5.1 Choice of method

Firstly, we estimate our model using three different methods: pooled OLS, fixed effects (within estimator) and random effects (FGLS). Fixed and random effects models contain both individual and time effects. Next, we perform tests to decide which method is the most suitable for our problem.

F test for twoway effects
Data: $log(regs\_no) \sim log(rfee) + log(pkm)$
F = 17.8, df1 = 32049, df2 = 245932, p-value < 2.2e-16
Alternative hypothesis: significant effect

Table 5.1: F-test results (individual and time effects).

We compare the FE model with standard POLS model by performing F-test. Under the null hypothesis, there are no fixed effects and POLS model is consistent, alternative hypothesis suggests inconsistency of POLS and present unobserved effects. Results in table 5.1 imply the latter; individual and time effects are present in our model.

As a next step, we execute the Hausman test to see whether unobserved effects are correlated with independent variables or not. The null hypothesis of this test states that both models are consistent, but RE is asymptotically more efficient. The alternative hypothesis says that only FE model is consistent. The result of the test is displayed in table 5.2. The p-value is approximately 0.0054, thus we reject null hypothesis and conclude that fixed effects are more suitable in our case than random effects.

Hausman test
Data: $log(regs\_no) \sim log(rfee) + log(pkm)$
chisq = 10.455, df = 2, p-value = 0.005367
Alternative hypothesis: one model is inconsistent

Table 5.2: Hausman test results.

To detect serial correlation in residuals, we perform the Durbin-Watson test. Under the null hypothesis, errors are not serially correlated. However, this is not our case. Given the outcome of the test shown in table 5.3 we reject the null hypothesis and assume a serial correlation of residuals.

Durbin-Watson test for serial correlation in panel models
Data: $log(regs\_no) \sim log(rfee) + log(pkm)$
DW = 1.2393, p-value $<$ 2.2e-16
Alternative hypothesis: serial correlation in idiosyncratic errors

Table 5.3: Results of the Durbin-Watson test.

Another problem we might face is heteroskedasticity. The null hypothesis of the Breusch-Pagan test says that the variance of the error term is constant, i.e. homoskedastic. The alternative hypothesis assumes heteroskedastic errors. With respect to the results of the test (table 5.4), we once again reject the null hypothesis and conclude the presence of heteroskedasticity in the residuals.

In conclusion, we find evidence supporting the presence of individual and time fixed effects in our model. Moreover, error terms are serially correlated and heteroskedastic. Therefore we will use robust standard errors to conduct valid inference.

Studentized Breusch-Pagan test
Data: $log(regs\_no) \sim log(rfee) + log(pkm)$
BP = 7844.6, df = 2, p-value < 2.2e-16

Table 5.4: Results of the Breusch-Pagan test.

5.2 Whole market analysis

	Dependent variable:			
	log(regs_no)			
	(1)	(2)	(3)	(4)
log(rfee)	0.0182	0.0362^{**}	-0.0439^{***}	-0.00275
	(0.0115)	(0.0144)	(0.00662)	(0.00918)
log(pkm)	-0.670^{***}	-0.785^{***}	-0.414^{***}	-0.686^{***}
	(0.0453)	(0.0518)	(0.0613)	(0.0779)
Year-month FE	No	Yes	No	Yes
Make-model FE	No	No	Yes	Yes
Observations	277,984	277,984	269,752	269,752
R^2	0.041	0.049	0.272	0.285
Adjusted R^2	0.041	0.049	0.256	0.269
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 5.5: Estimates of the base model.

Table 5.5 presents the results of the whole market analysis (i.e. all cars included) of the base model using POLS with time and make-model fixed effects. We also added estimates of the base model with a variation of fixed effects for comparison to demonstrate the influence of fixed effects and prove the correctness of their incorporation in the model. Our tests suggest both individual and time effects, therefore we consider model (4) the most trustworthy and report the results for it. Heteroskedasticity- and autocorrelation-robust clustered standard errors are reported in parentheses under the estimates.

For the base model, both variables have negative signs as expected. The estimated effect of the fee on the number of registered cars appears to be very low and is not significant at the 10% level. Price per 100 kilometres, on the

	Dependent variable:			
	log(regs_no)			
	(1)	(2)	(3)	(4)
log(rfee)	-0.00381	0.0184*	-0.0146***	0.0301***
	(0.00690)	(0.0108)	(0.00545)	(0.00847)
log(pkm)	-0.400***	-0.526***	-0.199***	-0.453***
	(0.0406)	(0.0470)	(0.0475)	(0.0628)
log(kw)	0.114**	0.131**	-0.410***	-0.336***
	(0.0520)	(0.0562)	(0.0685)	(0.0754)
log(stroke)	-0.694***	-0.706***	-0.101	-0.169
	(0.0945)	(0.0977)	(0.118)	(0.122)
log(tpw)	0.568***	0.557***	0.453**	0.218
	(0.116)	(0.119)	(0.194)	(0.197)
seats	-0.0320**	-0.0292**	-0.0390*	-0.0325
	(0.0144)	(0.0146)	(0.0211)	(0.0212)
alt_gbox	1.461***	1.455***	1.306***	1.290***
	(0.0488)	(0.0484)	(0.0387)	(0.0379)
Year-month FE	No	Yes	No	Yes
Make-model FE	No	No	Yes	Yes
Observations	36,619	50,949	50,750	130,303
R^2	0.336	0.427	0.353	0.304
Adjusted R^2	0.324	0.406	0.338	0.280
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 5.6: Estimates of the extended model.

other hand, is statistically highly significant and a 1% change corresponds to a 0.69% change in registrations.

When technical characteristics of a car are added (table 5.6), the results change significantly. As for the base specification, we consider model (4) the best choice. In the extended model, the fee has a positive sign and value of 0.0301 and is statistically highly significant. Although the price per 100 kilometres keeps its negative sign, its value decreased compared to the base model but remained significant at a 1% level. The effect of a 1% change in the cost of driving on the number of registrations according to this model specification is estimated to be 0.453%. When we look at the technical characteristics of the car, engine displacement and the number of seats have both negative signs, whereas the weight of the car has a positive sign. All three variables are statistically insignificant even at the 10% level. On the contrary, the engine power of the car has a negative and significant effect on the number of registrations; a 1% increase in horsepower decreases the registrations by 0.336%. The option to choose between manual and automatic gearbox is significant at 1% level as well and implies that the availability of alternative gearbox types increases sales by more than 267%.

5.3 Segment analysis

As we mentioned in Chapter 4, we suspect the heterogeneous behaviour of customers among various segments of the Slovak car market. Therefore we grouped cars into 8 smaller ones based on the car's condition at the time of registration, declared fuel consumption and fuel type. At the same time, we restrict the fuel to petrol and diesel only, which results in 1,314,763 cars represented in this model. Table 5.7 displays the frequency of the vehicles in the groups.

	Efficient	*Inefficient*
New petrol	210,014	313,596
Used petrol	7,614	76,736
New diesel	226,158	82,493
Used diesel	193,526	204,626

Table 5.7: Number of vehicles in each category.

Table 5.8 shows the results of the regression we performed using the vehicle type interacted with the fee and driving costs. We use Correia estimator with time and make-model fixed effects to calculate the coefficients. Standard errors are again robust to heteroskedasticity and serial correlation. The explanatory notes to the vehicle types abbreviations are available in table A.1.

	Dependent variable:		
	log(regs_no)		
log(rfee)*ned	0.00703	log(pkm)*ned	-0.380^{***}
	(0.0284)		(0.116)
log(rfee)*nid	-0.00328	log(pkm)*nid	-0.415^{***}
	(0.0179)		(0.0919)
log(rfee)*uid	-0.0381^{***}	log(pkm)*uid	-0.530^{***}
	(0.0128)		(0.0918)
log(rfee)*ued	-0.0323	log(pkm)*ued	-0.603^{***}
	(0.0274)		(0.121)
log(rfee)*nep	-0.238^{***}	log(pkm)*nep	0.547^{***}
	(0.0665)		(0.191)
log(rfee)*nip	-0.0933^{***}	log(pkm)*nip	-0.145^{*}
	(0.0191)		(0.0850)
log(rfee)*uip	-0.0337^{***}	log(pkm)*uip	-0.681^{***}
	(0.0124)		(0.0822)
log(rfee)*uep	-0.216^{***}	log(pkm)*uep	-0.400^{***}
	(0.0520)		(0.150)
Observations	253,405	Year-month FE	Yes
R^2	0.388	Make-model FE	Yes
Adjusted R^2	0.374		
Note:			$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 5.8: Estimates of the segment analysis.

The sign of fee estimate is negative for all 8 groups except for new efficient diesel cars. While the estimates are statistically significant at a 1% level for all subgroups of petrol cars, only used inefficient diesel passenger vehicles seem to be affected by the fee among the diesel subgroup. The highest effect can be seen for efficient petrol cars (-0.238 and -0.216). For inefficient petrol vehicles, the estimates are substantially lower: -0.0933 for new and -0.0337 for second-hand cars.

The effect of driving costs on registrations seems much stronger. All coefficients are statistically significant at 1% level except for new inefficient petrol cars; the estimate is significant only at 10% level. Apart from used inefficient vehicles, all coefficients are stronger for the diesel subgroup compared to petrol. Remarkably, the elasticity of registrations with respect to driving costs for new efficient petrol cars has a positive sign. A 1% change in driving costs should thus lead 0.547% increase in registrations of the new efficient petrol cars. The magnitude of other highly significant coefficients varies from -0.380 (new efficient diesel vehicles) to -0.681 (used inefficient petrol cars).

5.4 Response asymmetry analysis

	Dependent variable:		
	log(regs_no)		
	(1)	(2)	(3)
	Jan 09–Mar 13	Sep 13–Feb 16	Mar 16–Oct 18
log(rfee)	-0.0338^{***}	-0.0909^{***}	-0.00135
	(0.00933)	(0.0162)	(0.0171)
log(pkm)	-0.985^{***}	-0.749^{***}	-0.542^{***}
	(0.103)	(0.0952)	(0.0816)
Fuel prices	Rising	Falling	Rising
Year-month FE	Yes	Yes	Yes
Make-model FE	Yes	Yes	Yes
Observations	98,784	55,357	73,732
R^2	0.311	0.317	0.301
Adjusted R^2	0.283	0.292	0.281
Note:			*p<0.1; **p<0.05; ***p<0.01

Table 5.9: Estimates of the asymmetric response model

Table 5.9 provides the reader with estimates of the base model for the specific time. Once again we use POLS with make-model and time fixed effects with clustered standard errors. The estimates for the fee are in all 3 cases negative, although insignificant for the last period. Our primary interests are nonetheless the estimates for driving costs. For the first period time span, a 1% increase in driving costs corresponds to a 0.985% drop in passenger vehicle registrations in Slovakia. The response is completely different in the other period of rising fuel prices (column 3). Between March 2016 and October 2018, a 1% growth in costs per 100 kilometres of a ride resulted in a 0.542% decrease in newly registered cars. Both coefficients are statistically highly significant.

For the period of declining fuel prices between September 2013 and February 2016, the elasticity of registrations with respect to driving costs estimated by our model equals -0.749, meaning that a decrease in driving costs by 1% increased the registrations of passenger vehicles in the Slovak republic by 0.749%.

Chapter 6

Discussion

We begin with the discussion of the analysis of the whole market. The results of the base specification are not surprising, negative signs were expected in both cases. An insignificant estimate of the fee can be explained by the amount of fee most vehicles are subject to. Compared to their purchase price it is rather negligible for the majority of cars. Relatively high values of the fee are only for the most powerful cars, whose owners most probably can afford such expense. When fuel prices (and thereof driving costs) increase, people might be willing to switch to another transport option and use (and batter) their car less. Eventually, it might postpone the purchase of a new car, thus the negative and significant effect of price per 100 kilometres.

The sign and significance of driving costs estimate remained unchanged by the extended model too, even though the magnitude is lower. On the other hand, the effect of fees became significant, but with a positive sign. This is very counterintuitive, even more, when we realise that engine power (that is a base for calculation of fee) has a negative effect. This is possibly due to the correlation between the explanatory variables. As we mentioned in chapter 2, heavier cars tend to have larger engines and those are usually more powerful. This might explain the illogical sign of the fee coefficient. Therefore we do not consider the model specification with technical characteristics trustworthy.

Segment analysis brought some interesting results. The impact of registration payment on registrations of passenger vehicles was negative for seven out of eight vehicle types. For three out of four subgroups of diesel vehicles, the estimates were insignificant at the 10% level. On the other hand, coefficients for all 4 petrol subgroups were significant. A surprising finding is that both subgroups of the efficient petrol cars have higher elasticity than the inefficient ones. Efficient cars usually bear less powerful engines and therefore are subject to lower fees. On the other hand, potential owners of inefficient and powerful new cars belong to wealthier social classes and thus the nonrecurring fee is no significant expense for them. Used cars that are inefficient (according to our threshold) might be significantly older (particularly in comparison to the used efficient ones) and therefore take advantage of the fee system imposed in 2017. Another reason might be relatively low variation in the segment of used petrol vehicles compared to other segments.

Potential owners of diesel vehicles seem not to care about fixed costs of fee payment and focus more on the life-cycle costs. The results of estimates for driving costs support this notion. When we compare all four subgroups with different fuels, we observe higher elasticity of driving costs in three out of four segments. The only exception is segment of used inefficient vehicles; the elasticity for the petrol subgroup being -0.681 and for diesel -0.530. Note that the elasticity is higher for used cars compared to their new counterparts. Strangely, the estimate of elasticity for new petrol vehicles is positive. This would suggest that when fuel prices and subsequently driving costs increase, so does the number of new efficient petrol cars registered. While it may seem counterintuitive, the logic behind this finding might be the need to decrease the costs of driving by buying a car with better fuel economy than the one owned previously.

Nevertheless, the results suggest that while petrol vehicle owners react to fees stronger than diesel car drivers, those, in turn, respond stronger to the fluctuations in driving costs.

Regarding the response asymmetry model, the effect of the fee differed greatly among the periods. The coefficient in the first period was almost three times lower than in the second. We credit this variation to the changes in the fee system - until October 2012, all cars were subject to the unanimous fee and the consequences of the system update did not externalise until the second study period. In the third period, the estimate for fee is insignificant and very low, which may bear relation to the second update of the fee scheme that brought lower fees for most of the categories as well as a discount for second-hand vehicles.

The estimates for the effect of driving costs were all significant. Moreover, we get results that vary greatly. Not only was the reaction of customers on the Slovak car market different between periods of rising and falling fuel prices, but the response was distinct also among the separate periods of growing fuel costs: the elasticity estimated in the first period was almost twice as high as the one in the third period. The elasticity during falling fuel prices time was in-between the aforementioned ones. We believe that this downward trend was caused by an improvement in the living standards of the Slovak citizens: the real GDP per capita was increasing yearly on average by some 3% from 2009 to 2019 in Slovakia.

Chapter 7

Conclusion

Increasing number of private passenger vehicles and therewith related greenhouse gases emissions and non-renewable fuels dissipation have raised awareness in the previous decades. Governments and other organisations have taken steps to fight climate change and fossil fuels depletion. A certain type of tax for car ownership is a measure adopted by many countries. Although the Slovak republic has no annual tax for private car owners, however, there is a registration fee all cars are subject to upon the first evidence to the Slovak vehicle registry. We have taken advantage of the two changes to the fee calculation scheme as well as fuel price fluctuations to observe the effect of the aforementioned variables on the number of registered passenger cars.

Using the data provided by Slovak Police Force, we were able to create the dataset of car registrations per month. We computed the fee each vehicle was subject to and added the information about fuel price in the given month to compute the price of fuel per 100 kilometres. A regression was performed on the dataset using pooled OLS with fixed effects with robust standard errors.

The findings of this thesis are the following: we found a negative significant effect of the registration fee on petrol vehicles, while people who purchase cars powered by diesel appear not to be affected. Fuel prices and to related driving costs influence potential owners of diesel cars more than petrol car buyers. The effect of driving costs was positive only for new efficient petrol vehicles, suggesting a switch to the petrol vehicle with good fuel economy when driving costs are rising. We also found evidence of asymmetric response to driving costs changes during different periods of rising and falling fuel prices. The effect decreased over time, which we credit to the improving living standards of the Slovak citizens.

While the existing literature focused mostly on Western European countries. Our work contributes to the field with an analysis of a former communist Eastern European country with different purchase power and preferences. Furthermore, Slovakia is a special case with relatively small demand yet immense production of cars. Our research also includes the analysis of different segments of the car market based on the fuel efficiency and condition of the car.

Nonetheless, this study has several drawbacks. Due to the nature and quality of the dataset provided, our analysis focuses solely on the number of newly registered cars in the Slovak republic, but not retirement. The availability of credible data with information about retired cars would create a space for analysis that would extend the knowledge on the topic. Registration fees, fuel prices and their effect on the retirement rate in the fleet might bring yet another helpful insight to the problem. Moreover, it would be beneficial to examine the fuel price influence on the number of kilometres driven. All in all, there is plenty of opportunities for future research.

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Appendix A

Tables

Abbreviation	*Meaning*
ned	New efficient diesel
nid	New inefficient diesel
ued	Used efficient diesel
uid	Used inefficient diesel
nep	New efficient petrol
nip	New inefficient petrol
uep	Used efficient petrol
uip	Used inefficient petrol

Table A.1: Abbreviations used in the segment analysis.

Year	*Amount (€)*
2009	12,270
2010	13,012
2011	13,435
2012	13,588
2013	13,660
2014	14,019
2015	14,736
2016	15,007
2017	15,428
2018	15,990
2019	16,385

Table A.2: Real GDP per capita of the Slovak republic in 2015 prices.
Source: Author's computation based on Statistical Office of the Slovak republic (2022a;b).