CHARLES UNIVERSITY IN PRAGUE

FACULTY OF SOCIAL SCIENCES

Institute of Economic Studies

BACHELOR THESIS

Fuel Demand Elasticity on Car Fuel Taxes

Author: **Dalibor Vágner**

Supervisor: **Mgr. Lukáš Rečka**

Year of defence: **2016**

Declaration of Authorship

I hereby proclaim that I wrote my bachelor thesis on my own under the leadership of my supervisor, that the references include all resources and literature I have used and that this thesis has not been used to obtain any other university diploma.

I grant a permission to reproduce and to distribute copies of this thesis document in whole or in part.

Prague, July 28, 2016

Signature

Acknowledgement

I would like to express my gratitude to Mgr. Lukáš Rečka for relevant literature tips, valuable advice, helpful comments and overall leadership of my thesis.

I would also like to thank Šárka Křížková for her emotional support, and Petr Kašpar for LaTeXtemplate that one could only dream of.

Bibliography reference

VÁGNER, Dalibor. *Fuel Demand Elasticity on Car Fuel Taxes.* Prague, 2016. XX p. Bachelor thesis (Bc.) Charles University, Faculty of Social Sciences, Institute of Economic Studies. Supervisor: Mgr. Lukáš Rečka

Extent of the thesis

60,050 characters (with spaces)

51,108 characters (without spaces)

# Abstract

The main focus of this thesis is to estimate the fuel demand elasticity on excise tax levied on gasoline and diesel. This work utilizes and subsequently develops the model and data set already published in the literature devoted to fuel taxation. The main contribution is the close analysis of the data from the Czech Republic and following comparison with the results from other countries. Furthermore, this paper extends the model by allowing it to filter out interstate shifts in purchases induced by different fuel price levels in neighboring countries. The relationship between interstate price differences and domestic fuel demand is consequently analyzed.

JEL Classificiation	C23, H23, L91, Q31
Keywords	fuel, demand elasticity, car fuel tax, Europe, price
Author's email	dalibor.vagner@gmail.com
Supervisor's email	lukasrecka@gmail.com

Abstrakt

Hlavním cílem této práce je určit elasticitu poptávky po spotřebních hmotách na spotřební dani ve 12 vybraných evropských zemích. Panelový model je nejprve rozšířen o česká data. Výsledky prokazují nejvyšší elasticitu poptávky v České Republice. Dále je model doplněn o možnost vyfiltrovat data o spotřebě od nákupů vyvolaných rozdílem cenových hladin pohonných hmot mezi sousedními zeměmi. Následně je zkoumán samotný vliv rozdílu cen pohonných hmot mezi zeměmi na domácí poptávku po pohonných hmotách. Ve většině zemí z vybraného vzorku byla tato souvislost prokázána.

JEL klasifikace	XXX C23, H23, L91, Q31
Klíčová slova	pohonné hmoty, elasticita poptávky, spotřební daň, Evropa, cena
Email autora	dalibor.vagner@gmail.com
Email vedoucího práce	lukasrecka@gmail.com

Contents

Acronyms

EU	European Union
US	The United States of America
l	liter
ton	metric ton
CZK	Czech Republic Crown
OLS	Ordinary Least Squares
2SLS	Two-Stage Least Squares
FGLS	Feasible generalized least squares
FE	Fixed Effect
p. c.	Per Capita

Chapter 1

Introduction

The 2015 United Nations Climate Change Conference held in Paris set the ambitious goal to limit global warming to less than 2°C compared to pre-industrial ages. European Union adopts a responsible approach to climate change. It aims to reduce greenhouse gas emissions by 80-95% by 2050 compared to 1990 levels, which corresponds to a reduction by 54-67% by 2050 in the transport sector (European Commission, 2011). Fuel excise duties, besides their public revenue purposes, are one of the tools how to motivate people to shift from conventional oil consuming vehicles to less polluting alternatives. In order to design a proper policy, policy makers need to know how people respond to fuel taxes in the short run as well as in the long run. A substantial number of previous studies is devoted to fuel price demand elasticity analysis but only a few of them also distinguish the tax elasticity (e.g. Dieler et al. (2015) and Li et al. (2012). This thesis enriches the literature focused on fuel price and tax elasticities. It extends the study by Dieler et al. (2015) by adding data for the Czech Republic. It also points out that the data does not satisfy the OLS assumptions and more robust methods have to be used. Furthermore, the thesis provides an analysis of impacts of fuel price differences between neighboring countries on fuel consumption in the home country. The beginning of chapter 2 provides a review of consumption drivers analyses in literature. We show that many factors increase the demand for fuel over time and the excise duty levied on gasoline and diesel is crucial policy which helps governments control the consumption of these products. Furthermore, chapter 2 introduces price and tax elasticity approaches published in previous literature and it shows the difference between short run and long run elasticity estimators. This section also presents the model which filters intertemporal shifting of fuel purchases invented by Dieler et al.(2015) that is subsequently utilized with extended data-set. Additionally, this model is developed by allowing to filter specific purchaser behavior associated with international traffic. Chapter 3 covers the empirical part of this thesis and contains two main sections: Data and Models and results. The data section describes our data and tests the fulfilment of the OLS assumptions. The second section of chapter 3 replicates the study of Dieler et. al (2015) using the data for the Czech Republic. The fuel demand elasticity on both price as well as tax was found to be very high compared to the rest of the countries in the data set. The last section of chapter 3 studies how differences in the fuel price between countries influence the fuel purchases and consumption in selected European countries. The difference in the price of fuel proved to have a statistically significant impact on the consumption of at least one type of fuel in 9 of the 12 countries. The last chapter concludes and discusses the application and limitation of this thesis.

Chapter 2

Literature review

2.1 Drivers of consumption

Policy makers need to observe multiple indicators to model the fuel demand. Consumption mostly depends on the price of fuel, the efficiency of vehicles, the disposable income of consumers, the number of vehicles and the need for transport of goods and passengers. (Odeck and Johansen, 2016). We examine each indicator closer to gain an insight into the topic and see how the fuel demand can be influenced.

2.1.1 Income elasticity

The wages in China are rising extensively. In fact, nominal wages in China grew almost ten times in eighteen years between 1995 and 2013 (National Bureau of Statistics of China). Lin and Zeng (2013) studied the income elasticity of demand for gasoline in China over the period of 1997-2008. The authors found that a certain increase in disposable income results in roughly an equal increase in gasoline demand. (Statistically significant coefficients equal to 1.01 and 1.05 depending on model specification). These estimates correspond with the findings of Graham and Glaister (2004) who collected 333 short run and 150 long run estimates of income elasticity from literature. The short run estimate mean was 0.47 and 0.93 for the long run. The income elasticity is driven by two factors. Firstly, wealthier customers can afford to buy more gasoline because it is relatively cheaper for them. Secondly, drivers who earn more money have higher opportunity cost of time spent in the car. Thus, they tend to drive faster which is less fuel efficient. Additionally, they buy larger and more powerful cars in the long run. (Graham and Glaister, 2005) Romero-Jordán et al. (2010) found even larger long run estimates (0.92 - 1.45) from the data on household expenditure from Spain. In last three decades, household expenditure has been increasing globally, even during the financial crisis in 2008 and 2009. (See figure 1 World household expenditure) Consequently, we can assume that economic growth leading to higher income and subsequent spending will stimulate the demand for fuel.

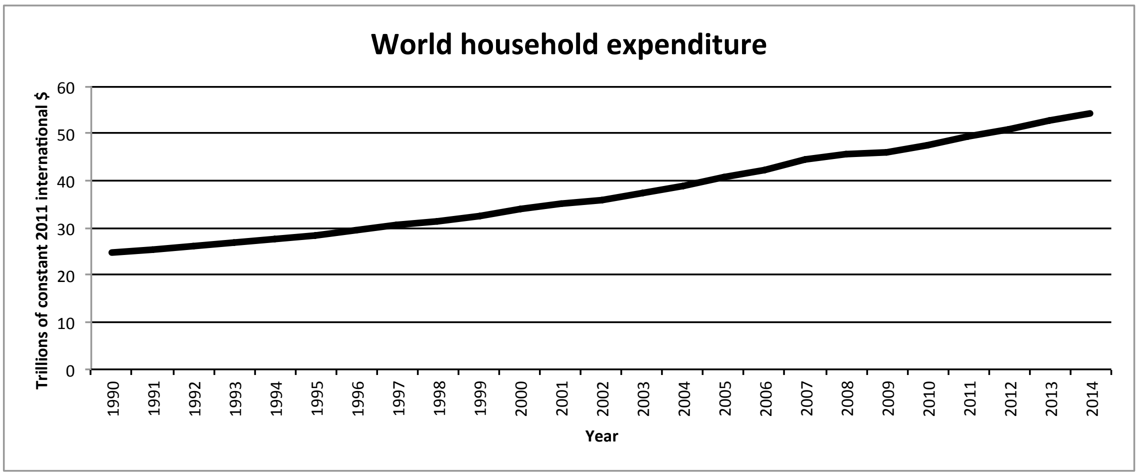

Figure 1: World household expenditure
Source: World Bank

2.1.2 Car ownership

Car ownership has also increased substantially over time. Figure 2 World car registration shows us that the number of registered cars increased globally by 2.6% each year within period 1960-2013. Liddle (2012) studied the influence of gasoline prices, income and vehicle ownership on gasoline demand with panel data from 14 OECD countries. His estimators for car ownership fall between 0.273 and 0.673 using variables in natural logarithms. Economic growth and number of cars are closely linked, and with the steadily increasing trend, we can assume that these two factors will only raise demand for fuel.

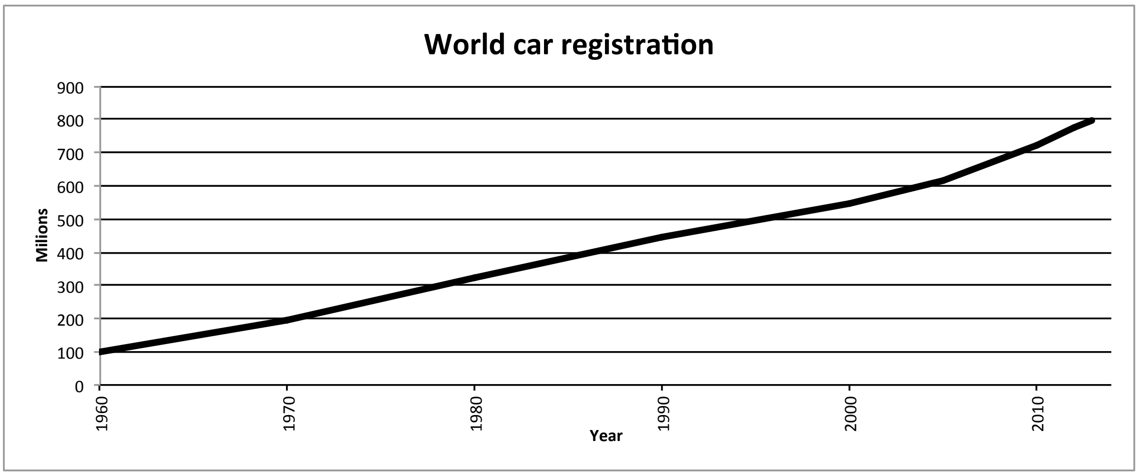

Figure 2: World car registration

Source: Davis et al. (2014)

2.1.3 Need for transport

Contradictory causes drive the need for transport. Telecommunication technology and internet development allow us to realize various activities remotely, without the need of transport. On the other hand, people's lifestyle is changing, they desire to travel more, the world is opening and business is more connected throughout the world. Salmon (1985) explains that the desire for moving is rooted in the principle of human nature meaning that communication only changes the way of using transport rather than the overall demand therefor. Salmon admits that these two can be substitutes in certain individual cases. However, he claims that they are also complements and that the complementary effect prevails. Communication creates links between distant places which would never exist. Thus the need of travel actually increases.

2.1.4 Fuel efficiency

Fuel efficiency of vehicles is the next indicator examined. Common sense makes us think the improved efficiency reduces consumption proportionally. However, it is not true due to the so-called rebound effect. As Greening et al. (2000) explains, an improvement in effectiveness is perceived by consumers as a reduction in price. The purchaser can achieve greater utility for the same cost leading him to buy more. Therefore, the rebound effect is directly linked to the price elasticity of fuel, which expresses how the purchases react to price changes. Greening et al. (2000) compared 75 studies devoted to this topic. The average rebound effect for automotive transport is presented as 20% - 30% in the long run meaning that fuel efficiency improvements are reflected by 70% - 80% savings in consumption. Additionally, the authors described a secondary rebound effect as an increase in fuel demand caused by savings induced by the increase in effectiveness. Although secondary effect is negligible for private sector, it might be important to commercial customers.

2.1.5 Price elasticity

The last factor influencing gasoline consumption is price. As prices can be influenced by taxation, it seems that the relationship between the price and consumption is extremely important to policy makers. This relationship can be expressed as price elasticity of fuel demand. Many papers published recently are devoted to this topic. Brons et al. (2008) compared 158 estimates of price elasticity of total gasoline demand from 43 papers in meta analysis. The short-run estimates fall between -1.36 and 0.37 with the mean of -0.34. The long run elasticity is substantially larger, ranging from -2.04 to -0.12 with the mean of -0.84. Graham and Glaister (2004) also analyzed literature in this field and they collected 387 estimates of short run price elasticity and 213 estimates of long run price elasticity. The means from their data set were -0.25 and -0.77 which is very similar to the above-mentioned meta analysis. However, Havranek and Kokes (2015) claim that published elasticity estimators might suffer from publication bias. As insignificant or counter intuitive results are more difficult to publish, estimators in the literature can be biased upwards. The average elasticity in their data set of elasticity estimates collected from primary studies was -0.28 in the short run and -0.66 in the long run. After the correction for publication bias, the results are -0.1 and -0.23, respectively. We can consider these numbers as a preferred benchmark for fuel price elasticity.

2.1.6 Tax elasticity

Decomposition of the price to tax and net price shows that consumers respond differently to price increases induced by taxation changes or by natural price changes. Li et al (2012) and Dieler et al. (2015) studied this phenomena. As presented in the next section, tax elasticity is larger than net price elasticity. Authors give us an interpretation that taxes are announced in advance and consumers expect them to last longer. Thus their reaction is stronger.

Dieler et al. (2015) explained that the monthly purchases of fuel do not reflect the actual consumption in the selected month completely because drivers can use their tanks as storage. Especially when a tax increase is anticipated, they tend to fill their tanks at the end of the month prior to the tax change (Anticipation effect). Consequently, they do not need to buy as much fuel as usual in the month of the tax change. However, their full tank probably gets empty in the month after the tax change (Catch-up effect). Which is why we expect increased consumption in that month as well as in the month prior to the tax change. Their findings are shown in section 2.2 Price and tax elasticity estimation approaches.

This thesis applies the method developed by Dieler et. al (2015) with further focus on the effect of international transit traffic. Small inland countries such as the Czech Republic are often just transit countries for international traffic. Truck drivers do not see the absolute price of diesel as important as the difference between domestic price and the price in neighboring countries. They can easily shift the consumption to a different country and thus influence the consumption data. Therefore, the model presented in section 3.2.2 Price difference analysis filters this effect out.

2.2 Price and tax elasticity estimation approaches

The fuel demand elasticity on price (this thesis often uses simplified term price/tax elasticity), in other words the relation between demanded fuel and the price of the fuel, has been studied extensively with different models, data from different countries and periods, different explanatory variables and with different types of data sets. Magnitude of estimators vary substantially across the literature. Espey

(1998) collected a vast database of elasticity estimators and he tried to explain their different magnitude by differences in data and model specifications. For example, using cross-sectional data yielded smaller long run price elasticity by about 30% than using time series data. However, most of the variance in the data set remained unexplained.

The crucial difference between estimators lies in the distinction between long term and short term elasticity. However, the distinction is not always strict. The model specification is very important (using variables in their natural logarithms or using their first difference of natural logarithms). Nevertheless, the time period matters as well and other explanatory variables are also relevant. Including an indicator of vehicle stock or fuel efficiency of vehicles makes the elasticity estimator measure more of short run response (Espey 1998) This section explains these differences in models on particular examples.

2.2.1 Basic specifications

Table 1 compares four regressions with net price and tax combined together into a final price as the main explanatory variable. Specifications for these models follow these equations:

$$ln(y_{it}) = \alpha_0 + \alpha_1 ln(p_{it}) + Z_1 + \epsilon_{it} \tag{1}$$

Hereinafter referred to as the log model and

$$ln(\frac{y_{it}}{y_{it-1}}) = \beta_0 + \beta_1 ln(\frac{p_{it}}{p_{it-1}}) + Z_1 + \omega_{it} \tag{2}$$

hereinafter referred to as the diff-log model. Here y_{it} represents the level of fuel consumption in month t and country i, p_{it} equals to the level of the average price of fuel in the relevant country, Z_1 represents a vector of other explanatory variables including month of the year fixed effect, country fixed effect and year fixed effect and ϵ_{it}, ω_{it} are unobserved errors. Baranzini and Weber (2012) used aggregated data from Switzerland in the time-series model.

$$ln(y_t) = \alpha_0 + \alpha_1 ln(p_t) + Z_2 + \zeta_t \tag{3}$$

Dieler et al. (2015) as well as Davis and Killian (2011) rather used growth rates the diff-log model 2 in order to contend with long-term trends in consumption and price. Using first difference in logarithms allows authors to estimate direct response to price change in the current month regardless of previous levels. Thus we can mark their results as short run elasticity. Baranzini and Weber (2012) and Li et al. (2012) used the log model 1.

Table 1 Fuel demand elasticity on final prices compares OLS estimates from various analysis. As we see in this table, elasticity estimated from these very similar models ranges from -0.092 to -0.339. The highest elasticity was estimated from the log model 1 presented by Baranzini and Weber (2012). The employed data come from Switzerland from the period between 1971 and 2008 and they are collected on a quarterly basis. These data were used for the diff-log regression as well. Results are also shown in the same Table 1. The short-run elasticity was estimated as -0.092 for gasoline and -0.082 for gasoline and diesel combined, both statistically significant at 1% level. We can see that the same data produced the highest as well as the smallest estimators from the selected sample just because of different model specifications. This shows us a significant difference between short-run and long-run elasticity.

Li et al. (2012) used log model 1 as well. However, their price elasticity estimation for gasoline, -0.097, is the second smallest in the selected group, even though they used annual data which made their analysis capture rather the long-run response (Dahl and Sterner, 1991, p. 205). A probable explanation is that they utilized various explanatory variables which change gradually over time, which subsequently made the estimator express rather the short run response. (Espey 1998) Baranzini and Weber (2012) did not utilize these explanatory variables. Which means that their elasticity estimator also captures the changes in car efficiency and other long run responses implicitly.

Dieler et al. (2015) used monthly data from the EU and US, respectively. European data were collected throughout years 1990-2012 for 11 countries. US data are from all states covering the period between 1989-2008. The elasticity of -0.21 and -0.19 corresponds with the already mentioned findings of Brons et al. (2008). This

Table 1: Fuel demand elasticity on final prices OLS

	Dieler, Jus, Zimmer (2015)	Li et al. (2012)	Baranzini, Weber (2012)	Baranzini, Weber (2012)	Davis and Kilian (2001)
Gasoline final price elasticity	-0.211 (0.071)	-0.097 (0.037)	-0.339 (0.027)	-0.092 (0.028)	-0.19 (0.04)
Diesel final price elasticity	-0.181 (0.065)	-	-0.267 (0.022)[a]	-0.082 (0.025)[a]	-
# of countries/states	11 EU	50 US	Switzerland aggregated	Switzerland aggregated	51 US
Data	1990-2012 monthly	1966-2008 annually	1971-2008 quarterly	1971-2008 quarterly	1989-2008 monthly
Equation	diff. in logs diff. in logs	log log	log log	diff. in logs diff. in logs	diff. in logs diff. in logs
Additional explanatory variables	month FE country FE year indicator working days unemployment	month FE country FE state spec. quad. trends covariates[b]	GDP p. c. cars p. c. foreign price[c] linear trend	GDP p. c. '73 & '79 shocks foreign price[c] others[d]	month FE country FE

a: gasoline and diesel combined

b: various socioeconomic explanatory variables

c: aggregated real gasoline price in foreign countries (weighted by the distance)

d: dummy for abolition of leaded gasoline, 1993 increase of mineral oil tax meta analysis also found long run elasticity being larger than short run elasticity, which also supports the explanation of variances of results presented in Table 1.

2.2.2 Tax elasticity estimation

Dieler et al. (2015) and Li et al. (2012) went further and they decomposed the final price to unit tax and net price. Thus, their models look as follows:

$$ln(\frac{y_{it}}{y_{it-1}}) = \beta_0 + \beta_1 ln(\frac{P_{it}}{P_{it-1}}) + \beta_2 ln(\frac{T_{it}}{T_{it-1}}) + Z_1 + \eta_{it} \tag{4}$$

and

$$ln(y_{it}) = \alpha_0 + \alpha_1 ln(P_{it}) + \alpha_2 ln(T_{it}) + Z_1 + \theta_{it} \tag{5}$$

respectively. Here P_{it} represents net price and T_{it} stands for unit tax in month t and state i. (Unit tax is used on purpose since ad valorem tax is not exogenous)

This allowed them to observe the elasticity for price change caused by taxation and net price change separately. Table 2 shows us OLS estimates of fuel demand elasticity on net prices and taxes from selected studies. As we see in this Table 2, the unit tax elasticity is substantially larger in both regressions. As mentioned above, consumers tend to respond to tax changes more, because changes are announced in advance and they expect them to last longer.

2.2.3 Anticipation and catch-up effect

As described in the previous section, Dieler et al. (2015) studied the so-called anticipation and catch-up effect. To filter out these effects, the following equation was utilized:

$$ln(\frac{y_{it}}{y_{it-1}}) = \gamma_0 + \gamma_1 ln(\frac{P_{it}}{P_{it-1}}) + \gamma_2 ln(\frac{T_{it}}{T_{it-1}}) + \gamma_3 ln(\frac{T_{it-1}}{T_{it-2}}) + \gamma_4 ln(\frac{T_{it+1}}{T_{it}}) + Z_1 + \iota_{it} \tag{6}$$

Estimator γ_3 is supposed to capture the anticipation effect and γ_4 should estimate the catch-up effect. Results are presented in the third column of Table 2. Both γ_3 and γ_4 are statistically significant at 5% level and not negligible. We can observe that the tax elasticity became larger when anticipation and catch-up effects were

Table 2: Fuel demand elasticity on net prices and taxes OLS

	Dieler, Jus, Zimmer (2015)	Li et al. (2012)	Dieler, Jus, Zimmer (2015)
Gasoline net price elasticity	-0.068 (0.028)	-0.113 (0.038)	-0.063 (0.028)
Gasoline unit tax elasticity	-0.635 (0.128)	-0.292 (0.084)	-0.837 (0.171)
Diesel net price elasticity	-0.074 (0.029)	-	-0.071 (0.029)
Diesel unit tax elasticity	-1.029 (0.211)	-	-1.044 (0.211)
# of countries/states	11 EU	50 US	11 EU
Data	1990-2012 monthly	1966-2008 annually	1990-2012 monthly
Equation	diff. in logs diff. in logs	log log	diff. in logs diff. in logs
Additional explanatory variables	month fix eff country fix eff year indicator working days unemployment	month fix eff country fix eff state spec. quad. trends covariates[a]	tax lag tax lead

a: various socioeconomic explanatory variables filtered out. The elasticity for diesel is even larger, which authors interpret as a result of larger fuel tanks used by diesel vehicles. Some commercial consumers might even have an extra storage capacity which allows them to shift the purchase in time.

2.2.4 Identification testing

Dieler et al. (2015) carried out feasible generalized least squares regression which allows autocorrelation and heteroskedasticity.

Results are shown in Table 3 in the first column. We can see that the estimates are very similar to those in the last column of the Table 2 with OLS estimates which according to authors confirms that OLS estimates are robust. However, chapter 3 Empirical work shows that the formal tests for heteroskedasticity and autocorrelation should have been executed.

Since the amount of demanded fuel influences the final price of the fuel, the price could be endogenous. Dieler et al. (2015), Li et al. (2012) and Davis and Kilian (2011) addressed this issue with two-stage least squares approach. In order to run 2SLS regression, we need to find instrumental variable which is not correlated with fuel demand in the country (after controlling for explanatory variables) and which is correlated with fuel price. Dieler et al. (2015) used exchange rate and world crude oil price as an instrument. Both definitely influence the fuel price and they are not correlated with oil consumption at the same time. Since changes in crude oil price and exchange rate do not project in fuel price immediately, their lags were used as well. The second stage regression looks the same as OLS regression:

$$ln(\frac{y_{it}}{y_{it-1}}) = \beta_0 + \beta_1 ln(\frac{\overline{P_{it}}}{P_{it-1}}) + \beta_2 ln(\frac{T_{it}}{T_{it-1}}) + Z_3 + \kappa_{it} \tag{7}$$

However, the instrumental variable, $\overline{P_{it}}$ here is obtained from following regression:

$$\begin{aligned} ln(\frac{\overline{P_{it}}}{P_{it-1}}) =& \sigma_0 + \sigma_1 oilpr_t + \sigma_2 oilpr_{t-1} + \sigma_3 oilpr_{t-2} + \sigma_4 exchr_{it} + \sigma_5 exchr_{it-1} + \\ & \sigma_6 exchr_{it-2} + \tau_{it} \end{aligned} \tag{8}$$

Here *oilpr* and *exchr* actually represent the % growth rate of respective variables. Thus, it would be more appropriate to write

$$ln(\frac{oilpr_t}{oilpr_{t-1}}) \tag{9}$$

Table 3: FGLS estimates and 2SLS (IV) estimates of net price and unit tax elasticity

	Dieler, Jus, Zimmer (2015)	Dieler, Jus, Zimmer (2015)	Li et al. (2012)	Davis and Kilian (2001)
Gasoline net price elasticity	-0.036 (0.018)	-0.040 (0.041)	-0.0697 (0.0240)	-0.46 (0.23)[a]
Gasoline unit tax elasticity	-0.699 (0.111)	-0,821 (0.143)	-0.323 (0.0828)	
Diesel net price elasticity	-0.071 (0.020)	-0.012 (0.048)	-	-
Diesel unit tax elasticity	-0.952 (0.107)	-1.004 (0.223)	-	
# of countries/states	11 EU	11 EU	51 US	51 US
Data	1990-2012 monthly	1990-2012 monthly	1968-2008 annually	1989-2008 monthly
Regression	FGLS	2SLS (IV)	2SLS (IV)	2SLS (IV)
Equation	diff. in logs diff. in logs	log log	log log	diff. in logs diff. in logs
Additional explanatory variables	tax lag tax lead	tax lag tax lead	month fix eff country fix eff state spec. quad. trends covariates[b]	time fix eff country fix eff unemployment population density

a: final price elasticity

b: various socioeconomic explanatory variables instead of $oilpr_t$. This simplification was used just in order to make the equation less clumsy. The results from 2SLS regression are shown in Table 3 in the second column. If we compare the estimates with those from OLS regression in Table 2 in the third column, we can see that 2SLS price estimators are smaller for both gasoline and diesel. If the fuel price was influenced by consumption in the dataset, we would expect the OLS estimators to be biased towards zero meaning to be smaller than 2SLS estimators. Since 2SLS estimators are smaller than OLS estimators, we can expect that there is no bias in OLS estimators meaning that the price is exogenous.

Li et al. (2012) used imported crude oil price as an instrument for 2SLS regression. Again, we see that the estimators from 2SLS regression in Table 3 in the third column are smaller than those from OLS regression in the second column of Table 2 meaning that fuel price is exogenous.

The study of David and Kilian (2011) did not use unit tax as a separate explanatory variable allowing them to utilize it as an instrument for the final fuel price. Taxation and final price are correlated and the taxation should not depend on consumption (at least not in a particular month). Thus, tax satisfies the assumption for being an instrumental variable due to being correlated with the price and not being correlated with consumption. The result of preferred 2SLS specification is presented in the fourth column of Table 3. In this case, the 2SLS estimator is more than twice as large as the OLS estimator and it is statistically significant at the 5% level. However, we can not simply replace the OLS estimator with the 2SLS estimator. The OLS estimator represents the change in consumption induced by the change of price while the 2SLS estimator captures the change in consumption induced by the change of price caused by the change of taxation. As found in papers of Dieler et al. (2015) and Li et al. (2012), the change of price induced by the change of tax has a much larger response causing the 2SLS estimator to be much larger. In this case the tax is not a proper instrument for the price.

Chapter 3

Empirical work

3.1 Data

The data was collected from 12 European countries for the period between years 1990 and 2012 on a monthly basis. The observed countries are Austria, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Portugal, Spain, Sweden, the United Kingdom and the Czech Republic. The observed types of fuel are 95 octane unleaded gasoline and diesel. The dependent variable in the presented model is the amount of fuel purchased in a given country in a given month expressed in tons of oil equivalent for all countries except for the Czech Republic where it is expressed in thousands of tons of respective fuel. The key explanatory variable is the national average of the nominal final price of the fuel for each month expressed in national currency. This price is then decomposed to the sum of all excise taxes and fees which are not price dependent and the net price excluding these taxes and fees. Other explanatory variables include the seasonally adjusted unemployment rate expressed in the percentage of unemployed people from the number of people in labor force and the number of working days in a given month and country. Consumption and prices are used in the first difference of their natural logarithms meaning that only the month to month change of these enters models. Therefore, we can use different units of measure such as different national currencies. Unemployment rate is used as the difference of rates between the observed month and the previous month and the number of working days as month-over-month change in the number of working days.

In the section 3.2.2 Price difference analysis we need the data on the difference in prices for each country and its neighboring countries. The data regarding prices was also collected for neighboring countries which are not in the panel, so that the differences could be calculated. (Excepting Norway, Luxembourg and Switzerland where the monthly data could not be collected.) Calculating the differences in the prices of fuel between neighboring countries gave us 35 new variables for gasoline and 33 for Diesel. Denmark had to be excluded from the regression focused on diesel price differences due to inconsistency in the data for Diesel. Unfortunately, Danish diesel prices data obtained from Julian Dieler is unrealistic and different from the data from Eurostat and UK Department of Energy & Climate Change which is consistent.

3.1.1 Data sources

Related studies used data sets for the US market or they utilized data for Europe collected on an annual basis. Dieler et al. (2015) made great contribution of constructing European data set on a monthly basis composed from the data collected from various national institutions. Julian Dieler was asked to provide key data on consumption, prices and excise taxes allowing to extend his study. His data covered key variables for all countries except the Czech Republic which is important in this work.

The Czech data on consumption and final prices was obtained from the Czech Statistical Office. The level of excise taxes in the Czech republic was collected from the Czech legislation (353/2003 Sb. and its previous versions).

Excise taxes were measured in CZK per ton of fuel before 1/7/1999 and in CZK per 1000 liters after 1/7/1999. To avoid any distortion of the tax change in 1/7/1999 the CZK/ton unit was converted to CZK/1000 l unit using the mean value of the density given in safety data sheets (ČEPRO a.s - 2/2015 and 3/2015) published by the Czech main state owned company operating in the oil industry.

Unemployment rates were downloaded from Eurostat public database for all countries.

The number of working days was obtained for a small fee from private website workingdays.org (Temime, 2016) for all countries except the Czech Republic. Data for the Czech Republic were downloaded from an online calendar (Kalendář Online, 2016).

The data on fuel prices for countries which are not in the panel was downloaded from the Weekly Oil Bulletin website provided by the European Commission. The data on monthly exchange rate used for converting price differences and as an instrumental variable for two stage least square regression was downloaded from Eurostat. Crude oil price was used as an instrumental variable in the 2SLS regression as well. Our 2SLS model works with the West Texas Intermediate (WTI) crude oil prices provided by the US Energy Information Administration. Dieler et al. (2015) claims it does not matter which specific type of crude oil (WTI, Brent, Dubai crude) price is used as an instrumental variable because they are highly correlated with a correlation coefficient larger than 0.95.

3.1.2 Data testing

The original study presented by Dieler at al. (2015) does not include formal tests for heteroskedasticity and autocorrelation. Instead, the authors compared OLS results with those from the feasible generalized least square approach. Since the results from the robust regression did not differ substantially, the OLS results were taken as robust as well. This work conducts formal tests for heteroskedasticity, autocorrelation and presents robust clustered sandwich estimates as well as OLS non-robust estimates in order to be able to compare them with the original study. Dieler et. al (2015) proved price exogenity in his data set. Thus, we prove the exogenity only for added Czech prices.

3.2 Models and results

This section presents the replication of Dieler et al.'s (2015) work and subsequent extension of the model

3.2.1 Czech data analysis

We begin with the basic OLS regression of the key variables to see if our results correspond with the original study.

3.2.1.1 Price elasticity

The specification presented as the dif-log model 2 in Chapter 2 Literature review stands as follows:

$$ln(\frac{y_{it}}{y_{it-1}}) = \beta_0 + \beta_1 ln(\frac{p_{it}}{p_{it-1}}) + Z_1 + \omega_{it} \tag{10}$$

where y_{it} represents the consumption in month t and country i, p_{it} denote the price of fuel in month t and country i and Z_1 contains month of the year fixed effect, country fixed effect and year fixed effect. The Breusch-Pagan test did not reject homoskedasticity in data on retail prices provided by Julian Dieler nor in the Czech retail prices. However, the Wooldridge test for autocorrelation in panel data rejected the no-first order autocorrelation null hypothesis in the original data and the Breusch-Godfrey LM test for autocorrelation rejected the null for Czech data as well. According to the article Robust standard errors for panel regressions with cross-sectional dependence published by Daniel Hoechle (2007) the serial correlation of any type in panel data can be treated by the model allowing to cluster standard errors. This is done by "cluster" option in Stata which allows errors to be correlated within observations for each country. Additionally, these errors are robust to heteroskedasticity as well. We run indicated regression and provide robust clustered sandwich errors in squared brackets along with the standard errors from the OLS regression for comparison. For the time-series regression of Czech data, the heteroskedasticity and serial correlation robust Newey-West standard errors are shown in square brackets.

Resulting price elasticity of demand for gasoline is -0.243 and -0.203 for diesel, both significant at 1% level. Dieler at al. (2015) published estimates -0.224 for gasoline and -0.198 for diesel which differs only marginally. When the data for the Czech Republic was added to the panel data set, following elasticities were obtained:

gasoline -0.271 and -0.238 for diesel. The estimate for diesel would be statistically significant at 1% level with nor-robust standard error, it is statistically significant at 5% level with clustered sandwich robust standard error. All estimates with their standard errors can be clearly seen in table 4 which summarizes estimates of fuel demand elasticity on retail price. Significance levels expressed by stars are calculated from clustered sandwich robust errors.

Table 4: Fuel demand elasticity on retail price

	Gasoline	Diesel
Dieler et al. (2015)	-0.224**	-0.198**
	(0.076)	(0.079)
Original data	-0.243**	-0.203**
	(0.064)	(0.063)
	[0.066]	[0.084]
Czech data added	-0.271**	-0.238*
	(0.065)	(0.064)
	[0.065]	[0.086]
Czech data only	-0.885*	-0,912*
	(0.348)	(0,403)
	[0.357]	[0.427]

clustered sandwich robust errors in squared brackets

Significance levels : $*$: 5% $**$: 1%

The increase in the magnitude of estimates is rather larger than expected, suggesting the regression for Czech data only should be executed. Equation 11 represents time-series model for Czech data only. Here y_t represents the consumption in month t, P_t represents fuel price in month t and Z_4 covers month of the year fixed effect and year fixed effect. The results from time series regression following equation 11 can be seen in the last line of table 4. We see that Czech customers are very responsive to price changes. These results are statistically significant even with Newey-West robust standard errors.

$$ln(\frac{y_t}{y_{t-1}}) = \beta_0 + \beta_1 ln(\frac{p_t}{p_{t-1}}) + Z_4 + \lambda_t \tag{11}$$

Dieler et al. suggested including month-to month change in unemployment and month to month change in working days as control variables in the model. The reasoning behind such decision is that the number of working days in a given month define the amount of commercial activity in this month and thus the fuel consumed in the commercial sector. In addition, many people who drive to work choose to stay at home on vacation. One could argue that due to vacation purposes, certain drivers drive more frequently. However, since roads are generally busier on working days, this effect is probably only marginal, as we will see in the following results. The rationale for including the change in unemployment in the model is very similar. Unemployed people simply do not have to drive to work every day, thus the unemployment drives the consumption down.

We run the clustered sandwich regression following already used model 11 but in this case, Z_4 additionally contains the month to month change in unemployment and month to month change in working days. Results of these regressions using unemployment and working days as explanatory variables can be seen in Table 5 (gasoline) and Table 6 (diesel).

Estimators are very similar to those found by Dieler et al. The authors found the estimator for change in unemployment significant for gasoline only. However, our unemployment estimators are not significant for diesel nor for gasoline even though different forms of the variable were used. Additionally, clustered sandwich robust errors for change in unemployment are smaller. This could be caused by many missing observations in the data from Eurostat. Authors probably used the data on unemployment collected from national statistical offices which ensured higher quality of the data. Clustered sandwich robust errors do not influence the level of statistical significance for gasoline. The diesel retail price elasticity estimator is not statistically significant anymore with clustered sandwich robust errors and the estimate for diesel retail price elasticity with the Czech data added is significant only at 5% level with

Table 5: Fuel demand elasticity on retail price with unemployment and working days

	Gasoline		
	ret price	change in working days	change in unemployment
Dieler et al. (2015)	-0.211** (0.071)	0.014** (0.001)	-0.015** (0.005)
Original data	-0.227** (0.062) [0.066]	0.014** (0.001) [0.002]	-0.006 (0.010) [0.007]
Czech data added	-0.253** (0.062) [0.064]	0.014** (0.001) [0.002]	-0.008 (0.010) [0.008]
Czech data only	-0.823* (0.334) [0.342]	0.021** (0.006) [0.006]	-0.109 (0.083) [0.071]

clustered sandwich robust errors in squared brackets

Significance levels : $*$: 5% $**$: 1%

Table 6: Fuel demand elasticity on retail price with unemployment and working days

	Diesel		
	ret price	change in working days	change in unemployment
Dieler et al. (2015)	-0.181**	0.027**	0.000
	(0.065)	(0.001)	(0.007)
Original data	-0.184	0.025**	-0.004
	(0.055)	(0.001)	(0.010)
	[0.092]	[0.002]	[0.010]
Czech data added	-0.213*	0.026**	-0.009
	(0.057)	(0.001)	(0.010)
	[0.091]	[0.002]	[0.011]
Czech data only	-0.789	0.028**	-0.132
	(0.370)	(0.006)	(0.083)
	[0.412]	[0.006]	[0.072]

clustered sandwich robust errors in squared brackets

Significance levels : $*$: 5% $**$: 1%

clustered sandwich robust errors. Czech data still gave us very high estimators proving the statement that the Czech customer is either extremely responsive to changes in price or there are other factors driving the elasticity upwards. Both will be examined later on in this work. Nevertheless, Czech retail price elasticity estimator is just insignificant (p-value 0.058) with clustered sandwich robust errors.

3.2.1.2 Net price and excise tax elasticity

Next stage is decomposing the price to net price and excise tax. Therefore, the simplest model looks as follows:

$$ln(\frac{y_{it}}{y_{it-1}}) = \beta_0 + \beta_1 ln(\frac{p_{it}^{net}}{p_{it-1}^{net}}) + \beta_2 ln\frac{tax_{it}}{tax_{it-1}} + Z_4 + \mu_{it} \quad (12)$$

presented as equation 4 in chapter 2 Literature review. y_{it} again represents respective consumption, p_{it}^{net} denotes the price of fuel without excise tax in month t and country i, tax_{it} stands for excise tax per liter of fuel in month t and country i and Z_4 captures the month of the year, year and country specific effects, month to month change in unemployment and month to month change in working days. It is necessarily to admit that the data needed to be changed due to the presence of an unexpected discrepancy in the Spanish data. The value of excise tax jumped from 42.5 to 2.4 for gasoline and from 33.2 to 2.4 for diesel in 1/2001 resulting in a very high value of difference in logarithm of this variable for both fuels. The excise tax is measured in national currencies and the time of this observation falls into the era of adopting euro in Spain. While the data for all other countries was adjusted for change in national currency, the Spanish data was not, which is why this artificial difference was deleted.

Breusch-Pagan test for heteroskedasticity in this model rejected the homoskedasticity in original data provided by Dieler with p-value 0.0213 for gasoline and 0.0004 for Diesel. The homoskedasticity was rejected when the Czech data was added as well. However, the formal test did not reject the homoskedasticity hypothesis with the Czech data only. The Wooldridge test for autocorrelation in panel data rejected the no-serial correlation hypothesis for both fuels for original data as well as when Czech data was added. Additionally Breusch-Godfrey LM test for autocorrelation rejected no-serial correlation for the time-series model with Czech data for both fuels. That is why we provide clustered sandwich robust errors in square brackets allowing for heteroskedasticity and serial correlation as in the results of previous models. Significance levels are calculated form clustered sandwich robust errors.

Results of the clustered sandwich regression employing net price and excise tax as key explanatory variables (equation 12) in Table 7 shows how customers respond differently to price changes caused by different reasons. Changes of the net price

Table 7: Fuel demand elasticity on net price and excise tax

	Gasoline		Diesel	
	net price	excise tax	net price	excise tax
Dieler et al. (2015)	-0.068*	-0.635**	-0.074*	-1.029**
	(0.028)	(0.182)	(0.029)	(0.211)
Original data	-0.067*	-0.436	-0.062	-1.079**
	(-0.025)	(0.103)	(0.027)	(0.128)
	[0.030]	[0.256]	[0.035]	[0.328]
Czech data added	-0.082*	-0.702	-0.070	-1.244**
	(0.026)	(0.106)	(0.028)	(0.127)
	[0.035]	[0.354]	[0.035]	[0.311]
Czech data only	-0.275	-3.786**	-0.200	-2.352**
	(0.189)	(0.767)	(0.247)	(0.573)
	[0.158]	[0.400]	[0.192]	[0.282]

clustered sandwich robust errors in squared brackets

Significance levels : $*$: 5% $**$: 1%

stemming from market fluctuations have much smaller impact on the purchaser's behavior than changes induced by the tax change. The Czech data even shows insignificance of the net price changes, whereas the estimator for elasticity of the demand on excise tax is very large in magnitude and strongly significant for both fuels even with Newey-West robust errors. Original gasoline OLS estimators were strongly statistically significant for original data as well as when the Czech data was added. However, after the correction for serial correlation and heteroskedasticity, the gasoline excise tax estimators are not significant at all and the net price estimators are significant at 5% level only. Clustered sandwich robust errors affected significance of the diesel net price estimators, but diesel excise tax estimators remained strongly significant.

The last step is to include lag and lead. Therefore, the model follows the equation 13 analogical to the equation 6 in chapter 2 Literature review

$$ln(\frac{y_{it}}{y_{it-1}}) = \beta_0 + \beta_1 ln(\frac{p_{it}^{net}}{p_{it-1}^{net}}) + \beta_2 ln\frac{tax_{it}}{tax_{it-1}} + \beta_3 ln\frac{tax_{it+1}}{tax_{it}} + \beta_4 ln\frac{tax_{it-1}}{tax_{it-2}} + Z_4 + \nu_{it} \quad (13)$$

where Z_4 again contains all control variables - month of the year, year and country specific effects, month to month change in unemployment and month to month change in working days.

Table 8: Anticipation and catch-up effect: Gasoline

	net price	tax	tax lag	tax lead
Dieler et al. (2015)	-0.063*	-0.837**	0.250*	0.373**
	(0.028)	(0.171)	(0.121)	(0.145)
Original data	-0.067*	-0.500	0.244	0.140
	(0.025)	(0.106)	(0.102)	(0.103)
	[0.030]	[0.256]	[0.142]	[0.125]
Czech data added	-0.082*	-0.703	0.340	0.268
	(-0.026)	(0.110)	(0.106)	(0.106)
	[0.034]	[0.354]	[0.178]	[0.198]
Czech data only	-0.267	-3.610**	1.620**	1.927**
	(0.184)	(0.747)	(0.725)	(0.730)
	[0.158]	[0.395]	[0.345]	[0.244]

clustered sandwich robust errors in squared brackets

Significance levels : $*$: 5% $**$: 1%

Tables 8 and 9 present the results from clustered sandwich regression capturing the anticipation and catch-up effect (equation 13) for gasoline and diesel. Before

Table 9: Anticipation and catch-up effect: Diesel

	net price	tax	tax lag	tax lead
Dieler et al. (2015)	-0.071*	-1.044**	0.371**	0.323**
	(0.029)	(0.211)	(0.131)	(0.152)
Original data	-0.062	-1.096**	0.403	0.356
	(0.027)	(0.128)	(0.125)	(0.127)
	[0.035]	[0.328]	[0.251]	[0.210]
Czech data added	-0.071	-1.260**	0.518*	0.366
	(-0.028)	(0.127)	(0.125)	(0.126)
	[0.035]	[0.311]	[0.233]	[0.194]
Czech data only	-0.181	-2.234**	1.508**	0.798*
	(0.241)	(0.560)	(0.547)	(0.551)
	[0.192]	[0.281]	[0.348]	[0.336]

clustered sandwich robust errors in squared brackets

Significance levels : $*$: 5% $**$: 1%

correcting for heteroskedasticity and autocorrelation, almost all estimators in Tables 8 and 9 were statistically significant. However, using clustered sandwich robust errors, only net price remained significant for gasoline and excise tax for diesel as in previous models. Even though clustered sandwich robust estimates for lag and lead are not significant, they should be included in the model in order to filter so-called anticipation and catch-up effect for the reasons already discussed in Literature review 2. Czech customers tend to use their fuel tanks as storage when tax change is anticipated to a larger extent than their counterparts across the panel.

In order to compare the results for the Czech Republic to results for individual countries in the data set, we run Newey-West time series regressions for each country individually, which can be expressed by common specification 14 which uses the same variables as equation 13. We do not use indicators for countries here since each regression utilizes the data for one country only.

$$ln(\frac{y_t}{y_{t-1}}) = \beta_0 + \beta_1 ln(\frac{p_t^{net}}{p_{t-1}^{net}}) + \beta_2 ln\frac{tax_t}{tax_{t-1}} + \beta_3 ln\frac{tax_{t+1}}{tax_t} + \beta_4 ln\frac{tax_{t-1}}{tax_{t-2}} + Z_5 + \xi_t \quad (14)$$

Table 10 presents results for each Newey-West time series regression using the data for each country individually. All standard errors are Newey-West robust standard errors. Allowing for heteroskedasticity and autocorrelation did not influence significance levels except for gasoline tax estimator which was significant at 5% level with OLS estimator and which is not statistically significant with Newey-West standard error. Also, the gasoline net price estimator for the Netherlands dropped from 1% level to 5% level and gasoline tax estimator increased from a 5% level to a 1% level.

Although the estimators for net price and tax elasticity are statistically significant for the whole panel with 12 countries and 1933 observations, the estimators in time series regressions are less significant. France, the Netherlands and Portugal have statistically significant estimators for net price elasticity for gasoline. There are four countries with significant estimators for net price elasticity for diesel (Austria, Belgium, France and Portugal). The estimator of tax elasticity is significant for more countries. The tax elasticity estimator for gasoline is significant for 6 countries and it is 5 countries for diesel. Netherlands have both net price and tax elasticity estimators significant for gasoline and Austria for diesel. No country has all estimators statistically significant. Portuguese drivers seem to be very responsive to price changes, but least responsive to tax changes. Least responsive to net price changes are French drivers and the most responsive for tax changes are Czech drivers with elasticities of -3.61 for gasoline and -2.234 for diesel, both robustly significant at 1% level meaning that one percent change in taxes induce $2.2 - 3.6\%$ reduction in demand in the Czech Republic.

It seems that there is no pattern in regards to which country has significant estimators and which does not, suggesting that there are not any economic rationale behind this phenomena. Countries with significant estimators have generally not anything in common leading to conclusion that large standard errors are caused by small number of observations in time series data. That is why we should work with

Table 10: Time series regressions with Newey-West robust standard errors

	Gasoline		Diesel	
	net price	tax	net price	tax
Austria	-0.166	-1.532*	-0.254**	-2.184**
	(0.125)	(0.694)	(0.087)	(0.227)
Belgium	-0.106	-1.140	0.678*	1.082
	(0.256)	(2.303)	(0.300)	(1.383)
Czech Republic	-0.267	-3.610**	-0.181	-2.234**
	(0.158)	(0.395)	(0.192)	(0.281)
Denmark	-0.057	-1.169**	0.029	0.718
	(0.063)	(0.292)	(0.067)	(0.715)
France	-0.087*	-0.197	-0.079*	-0.426
	(0.036)	(0.267)	(0.036)	(0.260)
Germany	0.053	-0.766**	-0.037	-2.033**
	(0.053)	(0.154)	(0.049)	(0.207)
Ireland	-0.109	-0.367	-0.090	-1.018
	(0.116)	(0.619)	(0.168)	(0.573)
Netherlands	-0.147*	-1.765*	-0.035	-0.472
	(0.061)	(0.700)	(0.060)	(0.402)
Portugal	-0.300**	-0.280	-0.410**	-0.582**
	(0.078)	(0.187)	(0.087)	(0.176)
Spain	-0.085	-0.653	-0.051	-0.366
	(0.063)	(0.506)	(0.039)	(0.316)
Sweden	-0.032	-1.261**	0.067	-1.863**
	(0.033)	(0.236)	(0.066)	(0.416)
United Kingdom	0.016	-0.720	-0.078	0.259
	(0.058)	(0.572)	(0.087)	(0.556)

Significance levels : $*$: 5% $**$: 1%

the panel data as a whole in the following section.

3.2.2 Price differences analysis

This subsection will develop the model 13 utilizing net price, excise tax and its lag and lead as it was announced before. This model tries to capture consumption of fuel, but our data contains the amounts of fuel purchased. Since drivers can use their tanks as storage, they can shift their consumption in time and space. While crossing the border, drivers are encouraged to buy fuel in the country where it is cheaper and consume it in the country where it is more expensive. Thus, we should filter this effect out in order to clarify resulting elasticities. It is not possible to track how much of foreign-bought fuel is spent in each country. However, we can include new variables which indicate the difference between the price levels of each fuel between two countries assuming the size of this difference is the incentive for drivers to shift the purchase and consumption between those countries.

The following section is divided into two subsections. In the first subsection, we add price difference variables to the final model provided by Dieler et. al. (2015) in order to clarify the net price and tax elasticity estimates. In the second subsection, we focus on price differences. The second subsection presents an adjusted model which allows us to capture and interpret the estimates for each price difference individually.

3.2.2.1 Price differences default model

First we take our final model from the last section and add price differences variables. Resulting regression is denoted by the following equation:

$$\begin{aligned} ln(\frac{y_{it}}{y_{it-1}}) =& \beta_0 + \beta_1 ln(\frac{p^{net}_{it}}{p^{net}_{it-1}}) + \beta_2 ln\frac{tax_{it}}{tax_{it-1}} + \beta_3 ln\frac{tax_{it+1}}{tax_{it}} + \beta_4 ln\frac{tax_{it-1}}{tax_{it-2}} + \\ & + \beta_k D_{kt} + Z_4 + \phi_{it} \end{aligned} \tag{15}$$

This equation differs from equations 13 and 6 in the presence of D_{kt} which represents all variables for differences in fuel prices for all neighboring countries so that β_k represents corresponding effect on demand for certain fuel in specific country. Other variables remains the same as in equation 13 and 6 meaning that

Table 11: Anticipation and catch-up effect including price differences

	Gasoline		Diesel	
	Differences not included	Differences included	Differences not included	Differences included
net price	-0.077^{*} $p = 0.006$ $[p = 0.020]$	-0.079^{*} $p = 0.007$ $[p = 0.024]$	-0.056 $p = 0.077$ $[p = 0.246]$	-0.065 $p = 0.057$ $[p = 0.236]$
excise tax	-0.349 $p = 0.010$ $[p = 0.224]$	-0.355 $p = 0.010$ $[p = 0.275]$	-0.853^{*} $p = 0.000$ $[p = 0.018]$	-0.849^{*} $p = 0.000$ $[p = 0.019]$

P-values calculated from clustered sandwich robust errors in square brackets

Significance levels : $*$: 5% $**$: 1%

y_{it} represents the amount of fuel purchased in country i in month t
p_{it}^{net} represents net price without excise tax in country i in month t so β_1 captures net price elasticity of demand
tax_{it} represents the sum of excise taxes levied for certain type of fuel in country i in month t so that β_2 captures excise tax elasticity of demand, β_3 captures the so-called catch-up effect and β_4 captures so-called anticipation effect. Both effects were already explained in chapter 2 Literature review.

Table 11 compares the results from clustered sandwich regressions following equations 13 and 15 showing how coefficients changed when all price differences between neighboring countries were added to the regression. Robust clustered sandwich p-values are in square brackets. We can see the change in estimators after all differences in prices for neighboring countries were added to the model. The net price elasticity slightly increased for gasoline. The excise tax elasticity slightly decreased for the diesel. Adding differences to the model did not influence the significance levels. However, adding differences slightly increased the p-values except for the diesel net price elasticity estimator which became little more significant. The first and third column show results for clustered sandwich regression denoted by equation 13. These results of the clustered sandwich regression which does not utilize price differences (first and third column of table 11) are different from the results of the same regression presented before (Table 8 and 9) because slightly different data set was used. In order to compare results from the model which does not utilize price differences 13 with the results from the model utilizing the price differences 15, we dropped the observations which could not be used in the second model 15 also for the first regression denoted by model 13. The data on prices was not available for the whole time period for some countries and that is why the differences in prices between neighboring countries could be calculated for the period for which the data was available for both countries only. We could work with 2073 observations for gasoline and 1933 observations for diesel before the variables for differences in prices were generated. The model using price differences 15 can work with 1648 observations for gasoline and 1380 observations for diesel only, meaning that we lost 425 and 553 observations. The estimates from the model which does not cover price differences (third row of table 8) show gasoline demand elasticities as -0.082 (clustered sandwich robust P-value 0.037) for net price and -0.703 (clustered sandwich robust P-value 0.073) for excise tax. The same regression with less observations gave us results presented in the first column of table 11 as -0.077 (clustered sandwich robust P-value 0.020) for net price and -0.349 (clustered sandwich robust P-value 0.224) for excise tax. The original clustered sandwich results for diesel are shown in the third row of the table 9 as -0.071 (clustered sandwich robust P-value 0.067) for net price and -1.260 (clustered sandwich robust P-value 0.002) for excise tax. The clustered sandwich results from regression with less observations can be seen in the third column of the table 11 as -0.056 (clustered sandwich robust P-value 0.246) for net price and -0.853 (clustered sandwich robust P-value 0.018) for excise tax. Unfortunately, the results from the regression using less observation differ from the original one. However, we need to work with those results in order to compare them with the results of the clustered sandwich regression capturing the price differences between neighboring countries. Clustered sandwich robust standard errors again moved the p-values beyond conventional level of significance for gasoline excise tax estimators and diesel net price estimators even though these variables had strongly significant OLS estimators before correction.

Table 12: OLS estimates for price differences : Gasoline

Variable	**Coefficient**	**(Rob. Std. Err.)**
A_CZ	0.000	(0.000)
B_F	-0.001	(0.000)
CZ_D	-0.001	(0.001)
DK_D	0.000	(0.000)
F_ES	-0.001	(0.001)
D_CZ	0.000	(0.001)
IR_UK	0.000	(0.000)
NL_D	-0.001^{**}	(0.000)
PT_ES	0.000	(0.000)
ES_PT	0.001^{*}	(0.000)
S_DK	$0.000^{\dagger}$	(0.000)
A_SR	0.001	(0.000)
B_D	-0.003^{**}	(0.000)
CZ_PL	$0.002^{\dagger}$	(0.001)
DK_S	0.000	(0.000)
F_B	0.000	(0.000)
NL_B	$-0.001^{\dagger}$	(0.000)
S_FIN	0.000^{**}	(0.000)
A_SLO	0.000	(0.000)
B_NL	0.004^{**}	(0.001)
CZ_A	$-0.003^{\dagger}$	(0.002)
F_D	0.000	(0.000)
D_F	0.001	(0.001)
A_I	-0.002^{**}	(0.000)
CZ_SK	0.002^{*}	(0.001)
F_I	0.000	(0.000)
D_B	0.003^{**}	(0.000)
A_D	0.001^{*}	(0.000)
D_NL	0.000	(0.001)
A_HUN	-0.002^{**}	(0.000)
D_DK	-0.002^{*}	(0.001)
D_PL	-0.002^{**}	(0.000)
UK_IR	0.000	(0.000)
D_A	$-0.002^{\dagger}$	(0.001)
ES_F	0.000	(0.001)

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

Table 13: OLS estimates for price differences : Diesel

Variable	**Coefficient**	**(Rob. Std. Err.)**
A_CZ	-0.001**	(0.000)
B_F	-0.005**	(0.001)
CZ_D	0.003**	(0.001)
F_ES	0.000	(0.000)
D_CZ	-0.001**	(0.000)
IR_UK	0.000	(0.000)
NL_D	0.000	(0.000)
PT_ES	0.000	(0.000)
ES_PT	0.000	(0.000)
S_DK	0.000**	(0.000)
A_SR	0.001**	(0.000)
B_D	0.002†	(0.001)
CZ_PL	-0.003*	(0.001)
F_B	0.000	(0.000)
NL_B	0.000	(0.000)
S_FIN	0.000†	(0.000)
A_SK	-0.001**	(0.000)
B_NL	0.002**	(0.001)
CZ_A	-0.002	(0.002)
F_D	0.000	(0.000)
D_F	-0.003**	(0.001)
A_I	0.000	(0.000)
CZ_SLO	0.002†	(0.001)
F_I	0.000	(0.000)
D_B	0.000	(0.000)
A_D	-0.001	(0.000)
D_NL	0.002**	(0.000)
A_HUN	-0.001*	(0.000)
D_DK	-0.002*	(0.001)
D_PL	0.000	(0.000)
UK_IR	0.000	(0.000)
D_A	0.003**	(0.000)
ES_F	-0.001*	(0.000)

Significance levels : † : 10% $*$: 5% $**$: 1%

Table 14: OLS and FGLS estimation

	Gasoline		Diesel	
	OLS	FGLS	OLS	FGLS
net price	-0.079^{**}	-0.065^{**}	-0.065	-0.074**
	(0.029)	(0.021)	(0.034)	(0.021)
excise tax	-0.355^{**}	-0.257*	-0.849**	-0.600**
	(0.137)	(0.128)	(0.151)	(0.121)

Significance levels : $*$: 5% $**$: 1%

Tables 12 and 13 show us the clustered sandwich estimators for each variable representing the difference in prices. The name of each variable contains two country abbreviations determining for which two countries the difference is calculated. The difference in prices is always calculated in hundredths (cents, öre, øre) of local currency of the first country. (except for the Czech Republic where it is expressed in whole Czech crowns) Thus, the currency of the second country is converted to the currency of the first country using the Eurostat and World Bank exchange rates. All the standard errors are robust. Since the specification of the model covers consumption in month to month difference of its logarithm, the results for price differences are difficult to describe. The section 3.2.2.2 Price differences model adjustment focuses especially on price differences with model which is more suitable. Estimators for all variables used in the final model 15 are shown in Appendix A 4

Throughout the whole chapter 3, we needed to adjust our standard errors because of heteroskedasticity and autocorrelation in our data. As mentioned before, the paper presented by Dieler et al. (2015) did not present a formal test for heteroskedasticity and autocorrelation. The authors ran a FGLS regression and based on similarity of FGLS results to OLS results, they declared their OLS results to be robust. We replicate the same procedure with our final regression 15 to see if our FGLS results differ from the OLS.

Table 14 compares the OLS and FGLS results and we can see that estimators slightly changed. Gasoline net price elasticity estimators remained almost unchanged, but the elasticity estimator for diesel net price became significant. Excise tax estimators slightly decreased their magnitude and remained statistically significant at a 5% level. The FGLS estimators for price differences remained insignificant. Dieler et. al (2015) presented a comparison with larger differences between OLS and FGLS estimators. However, the authors claim that their data does not suffer from heteroskedasticity and autocorrelation. Previously presented formal tests prove the opposite.

Finally, we execute two-stage least squares (2SLS) regression with our final model in order to prove or disprove possible endogeneity of the price. Since we are using the data provided by Julian Dieler for 11 out of 12 countries and the data for price was proven to be not endogenous by the author (Dieler et al. 2015), we will test the Czech data only. In chapter 2 Literature review, we showed that the best instrument for price is the US dollar exchange rate and the world price of oil. The world price of oil as the main input for gasoline and diesel production influences the final price of these products. Similarly, the US dollar exchange rate influences the final price in the Czech Republic because oil is traded in US dollars, but the final product is sold in Czech crowns. Both the US dollar exchange rate and the world price of oil are not defined by consumption of fuel which makes these variables suitable instruments for the price. Our first stage regression looks as follows:

$$\begin{aligned} ln(\frac{\overline{P_t}}{\overline{P_{t-1}}}) =& \sigma_0 + \sigma_1 ln(\frac{oilpr_t}{oilpr_{t-1}}) + \sigma_2 ln(\frac{oilpr_{t-1}}{oilpr_{t-2}}) + \sigma_3 ln(\frac{oilpr_{t-2}}{oilpr_{t-3}}) + \sigma_4 ln(\frac{exchr_t}{exchr_{t-1}}) + \\ & \sigma_5 ln(\frac{exchr_{t-1}}{exchr_{t-2}}) + \sigma_6 ln(\frac{exchr_{t-2}}{exchr_{t-3}}) + \upsilon_t \end{aligned} \tag{16}$$

It differs from equation 8 presented in chapter 2 Literature review in the absence of country indicators because we are working with time-series data for the Czech Republic only. The first and second lags are included due to the fact that fuel producers typically respond to the crude oil price and exchange rates with delay. The results from the first stage regression are present in the table 15 (gasoline) and 16 (diesel).

We can see that for gasoline, the price of oil and its first lag have statistically significant estimators. First stage regression with data for diesel have all estimators

Table 15: Estimation results : First stage gasoline

Variable	Coefficient	(Std. Err.)
dlOILPRICE	0.215**	(0.033)
dlUSEXRATE	0.138†	(0.083)
lag1dlOILPRICE	0.326**	(0.034)
lag2dlOILPRICE	0.029	(0.034)
lag1dlUSEXRATE	0.259**	(0.085)
lag2dlUSEXRATE	0.092	(0.083)
Intercept	-0.001	(0.003)

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Table 16: Estimation results : First stage diesel

Variable	Coefficient	(Std. Err.)
dlOILPRICE	0.168**	(0.024)
dlUSEXRATE	0.149*	(0.059)
lag1dlOILPRICE	0.268**	(0.024)
lag2dlOILPRICE	0.049*	(0.024)
lag1dlUSEXRATE	0.221**	(0.061)
lag2dlUSEXRATE	0.042	(0.059)
Intercept	0.002	(0.002)

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

statistically significant except for the second lag of exchange rate. Results prove that we chose instrumental variables well. Lagged exchange rate is significant as right. The third lags of both instruments were also tried in the first stage regression, but their estimates were not statistically significant. Therefore, they are not used as instrumental variables. The second stage regression looks as the OLS regression except that the net price growth rate is replaced by the result from the first stage regression. The second stage regression is denoted below:

$$ln(\frac{y_t}{y_{t-1}}) = \beta_0 + \beta_1 ln(\frac{\overline{P_t}}{\overline{P_{t-1}}}) + \beta_2 ln\frac{tax_t}{tax_{t-1}} + \beta_3 ln\frac{tax_{t+1}}{tax_t} + \beta_4 ln\frac{tax_{t-1}}{tax_{t-2}} + Z_5 + \pi_t \tag{17}$$

Here Z_5 contains controls for change in unemployment, change in the number of working days in a month and month and year specific effects. The coefficient for instrumented gasoline net price is equal to -0.062 (0.244). In the standard OLS model, the coefficient is equal to -0.267 (0.184). If the gasoline price was endogenous, we would expect the OLS coefficient to be smaller than 2SLS coefficient due to the bias towards zero. Since the 2SLS estimator is smaller, we can assume the gasoline price to be exogenous. The coefficient for instrumented diesel price is equal to -0.237 (0.286). In a standard OLS model, the coefficient is equal to -0.181 (0.241). In this case, the 2SLS coefficient is slightly larger. However, nor OLS neither 2SLS estimators are statistically significant, which is why we execute a formal test for endogeneity. For gasoline prices, both the Durbin and the Wu-Hausman test could not reject the null hypothesis that variables are exogenous with p-values of 0.248 and 0.299, respectively. For diesel, the p-values for above mentioned tests are 0.767 and 0.792. The results from formal tests are satisfying proofs of Czech price exogeneity.

3.2.2.2 Price differences model adjustment

Since the interstate price differences do not have any long-run trends and consumers respond to price differences between states immediately, the consumption could be expressed in its natural logarithm instead of differences in logs (growth rates). The adjusted model looks as follows:

$$ln(y_{it}) = \beta_0 + \beta_1 ln(\frac{p_{it}^{net}}{p_{it-1}^{net}}) + \beta_2 ln\frac{tax_{it}}{tax_{it-1}} + \beta_3 ln\frac{tax_{it+1}}{tax_{it}} + \beta_4 ln\frac{tax_{it-1}}{tax_{it-2}} + \beta_i D_j + Z_4 + \phi_{it} \tag{18}$$

This model allows us to estimate and interpret the influence of different fuel price levels on behavior of consumers.

Again, we should test for heteroskedasticity and serial correlation. The Breusch-Pagan test strongly rejected the constant variance hypothesis for both gasoline and diesel. Furthermore, the Wooldridge test for autocorrelation in panel data rejected no first-order autocorreltaion hypothesis for the model working with the data for gasoline. No first order autocorrelation hypothesis could be rejected at 10% level for the model working with the data for Diesel, but it could be rejected at 15% level (P-value 0.112). The presented standard errors in this section are therefore all automatically clustered sandwich robust errors.

The results for price differences from the adjusted model 18 are presented in tables 17 and 18. Estimates for all variables used in the adjusted final regression are shown in Appendix B 4

The price differences became statistically significant for more countries. For example, the sixth variable in table 17 labeled as D_CZ shows us how the difference between the price of gasoline in Germany and the Czech Republic influence the demand for gasoline in Germany and it claims that if the price of gasoline in Germany is more expensive by one euro cent, the demand for gasoline in Germany decreases by 1.5% As concern of gasoline statistically significant negative correlation is also present in Belgium, Denmark, the Netherlands, Portugal, Spain and Austria. The largest negative response was found for the difference between Austrian and Slovenian prices. When the gasoline in Austria is more expensive by one euro cent than the gasoline in Slovenia, the demand for gasoline in Austria decreases by 2.6%. In the first part of the observed period, the gasoline was quite considerably more expensive in Austria. In the second part of the period, the prices vary widely with the average difference of 7.57 euro cents. Both countries are rather small and many drivers driving from northwest Europe to southeast Europe choose these two countries as

Table 17: Adjusted model OLS estimates for price differences : Gasoline

Variable	**Coefficient**	**(Rob. Std. Err.)**
A_CZ	0.016**	(0.001)
B_F	-0.010**	(0.003)
CZ_D	-0.006	(0.005)
DK_D	-0.001	(0.000)
F_ES	-0.006†	(0.003)
D_CZ	-0.015**	(0.002)
IR_UK	0.003	(0.002)
NL_D	-0.010*	(0.003)
PT_ES	-0.003	(0.002)
ES_PT	-0.012*	(0.004)
S_DK	0.000	(0.001)
A_SR	-0.013**	(0.002)
B_D	0.001	(0.002)
CZ_PL	0.005	(0.008)
DK_S	0.001	(0.001)
F_B	0.013**	(0.004)
NL_B	-0.018**	(0.003)
S_FIN	0.000	(0.000)
A_SLO	-0.026**	(0.001)
B_NL	-0.001	(0.003)
CZ_A	0.026**	(0.006)
F_D	0.009**	(0.003)
D_F	-0.012**	(0.004)
A_I	0.079**	(0.004)
CZ_SK	-0.013	(0.008)
F_I	-0.002	(0.002)
D_B	-0.005**	(0.001)
A_D	0.030**	(0.001)
D_NL	0.014**	(0.002)
A_HUN	-0.010**	(0.002)
D_DK	0.003	(0.003)
D_PL	0.003†	(0.001)
UK_IR	0.007	(0.005)
D_A	0.017**	(0.002)
ES_F	0.016*	(0.007)

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Table 18: Adjusted model OLS estimates for price differences : Diesel

Variable	**Coefficient**	**(Rob. Std. Err.)**
A_CZ	0.037**	(0.006)
B_F	0.005**	(0.001)
CZ_D	0.012**	(0.003)
F_ES	-0.006**	(0.001)
D_CZ	-0.001	(0.001)
IR_UK	0.000	(0.001)
NL_D	0.005*	(0.002)
PT_ES	-0.011**	(0.002)
ES_PT	-0.003	(0.002)
S_DK	0.001**	(0.000)
A_SR	0.017**	(0.002)
B_D	-0.003	(0.002)
CZ_PL	0.004	(0.005)
F_B	0.001	(0.002)
NL_B	0.002	(0.002)
S_FIN	0.000†	(0.000)
A_SLO	-0.009**	(0.001)
B_NL	0.004	(0.003)
CZ_A	-0.012*	(0.005)
F_D	0.005**	(0.002)
D_F	0.008†	(0.003)
A_I	0.042**	(0.007)
CZ_SK	0.005	(0.005)
F_I	0.000	(0.001)
D_B	-0.003*	(0.001)
A_D	0.027**	(0.004)
D_NL	0.007**	(0.001)
A_HUN	-0.020**	(0.003)
D_DK	-0.005*	(0.002)
D_PL	0.002†	(0.001)
UK_IR	0.005	(0.007)
D_A	-0.004*	(0.001)
ES_F	-0.006*	(0.002)

Significance levels : † : 10% $*$: 5% $**$: 1%

transit countries, which might be the reason for such a large response. Austria also has a negative response for the difference with Slovakia (1.3%) and Hungary (1%). A remarkable negative response was also found for the difference between Germany and the Czech Republic (1.5%), Spain and Portugal (1.2%), Germany and France (1.2%), Belgium and France (1%) and the Netherlands and Germany (1%). Surprisingly, the demand in large countries can be influenced by the prices in much smaller neighbors. According to these results, the German demand for gasoline is influenced by the Czech price, but not vice versa. Similarly, the Spanish demand is influenced by Portuguese prices by 1.2% per euro cent, but the Portuguese demand does not respond to Spanish prices. What is even more surprising is that there are countries with positive correlation between the price difference and demand. This could be explained by economic argument. If we compare two countries when one of them is experiencing economic growth and the other is rather stagnating, we can assume that the growth can increase the demand and drive the fuel prices up compared to a stagnating country. Thus, especially when the observed country is large and the amount of cross border traffic is negligible, it can be a reason for positive correlation. Notable positive correlation was found for the differences between France and Belgium (1.3%), Germany and the Netherlands (1.4%), Austria and the Czech Republic (1.6%), Spain and France (1.6%), Germany and Austria (1.7%) and the Netherlands and Belgium (1.8%). We can see that these findings mostly suit the proposed theory. However, estimates for differences between Austria and Germany (3%) and Austria and Italy (7.9%) are rather unexpected with no obvious reason. It is necessary to stress that the differences between Austria and Germany and Austria and Italy are always negative and they are increasing over time, suggesting there might be some underlying trend which drives the correlation up. However, our estimates are robust so they should account for this problem.

Diesel price differences are negatively correlated with demand for the Czech Republic and Austria (3.2%) (the table indicates 1.2% response in Czech crowns which is equivalent to 3.2% response in euros), Austria and Hungary (2%), Portugal and Spain (1.1%), Austria and Slovenia (0.9%) and France and Spain and vice versa with the same coefficient (0.6%). There is a small negative response in Germany for the differences with Denmark (0.5%), Austria (0.4%) and Belgium (0.3%) These results are similar to gasoline estimates. The largest response is present in rather small countries, Austria and Portugal, suggesting the international traffic plays an important role. Freight transport uses almost exclusively diesel and according to Eurostat, the ratio of international freight transport and domestic freight transport is 6.1% in Austria and 10.39% in Portugal which is above the average in observed countries 5.8% being in accordance with the theory that negative correlation is caused by international traffic. (The numbers are valid for the period of 2011-2014).

The number of countries with positive correlation between diesel demand and diesel price difference is slightly larger than the number of countries with negative correlation. This can be explained by the nature of diesel fuel. Diesel powered vehicles are used more for commercial purposes than gasoline powered vehicles. Thus, the economic argument suggesting economic cycles drive both price differences and consumption seems to be more valid here. Additionally, many large international transport companies have contracts with oil companies in their home countries and the volume of the tank of trucks allow them to drive through Europe without the necessity to refuel in another country. Thus, international transport probably plays a smaller role here than with gasoline and that is the opposite to what we expected due to larger tanks of diesel powered vehicles. Positive correlation was found for differences between Belgium and France (0.5%) the Netherlands and Germany (0.5%), France and Germany (0.5%), Germany and the Netherlands (0.7%), Sweden and Denmark (1%) - (the table indicates 0.1% response in Swedish krona which is equivalent to 1% response in euros). Largest positive response was found again in Austria. Austria gave us 1.7% response for the difference with Slovakia, 2.7% with Germany, 3.7% with the Czech Republic and the highest magnitude was found again for the price difference between Austria and Italy (4.2%). The difference between the Czech Republic price and German price gives us response equal to roughly 4% increase of demand in the Czech republic for each euro cent of the difference.

Chapter 4

Conclusion

This thesis enhances the analysis of fuel demand elasticities on price and specifically on excise duty. The results confirm that customers react much stronger to fuel price changes induced by changes in taxation than to price changes caused by market fluctuations. Czech customers were found to be much more responsive to both price and tax changes than their European counterparts. One percent increase in fuel excise duties induced a 3.6% reduction in gasoline demand and a 2.2% reduction in diesel demand in the Czech Republic, which is the highest response from the 12 analyzed EU countries. Czech drivers were also proven to react to future tax changes by intertemporal shifting of fuel purchases around the month of the tax change. They use their fuel tanks as a storage of cheaper fuel to a larger extent than drivers in other countries from our data set. Unlike the original study by Dieler et al. (2015), the aforementioned so-called anticipation and catch-up effect was even found to be statistically insignificant in the original data set for other countries when robust clustered sandwich estimators were used, as the formal tests did not exclude violation of OLS assumptions. The model presented by Dieler et al. (2015) was subsequently extended by implementing fuel price differences for neighboring countries in order to filter the purchases made by interstate travelers induced by different fuel price levels. Resulting gasoline net price elasticity slightly increased and the diesel tax elasticity slightly decreased compared to the original model. However, the estimates for price differences were statistically significant only for some countries. We introduced an adjusted model, which employs consumption in its natural logarithm instead of the month to month difference in natural logarithm in order to capture and interpret the effect of different price levels on demand for fuel. This move was based on the fact that drivers react to price differences immediately and their decisions regarding the place of purchasing fuel affect the consumption directly rather than affecting the consumption growth rate. Surprisingly, we found a statistically significant positive as well as negative response to price differences. Both were explained by economic theory confirmed by our results. The largest response was found in smaller countries which have higher ratio of international traffic to domestic traffic as was anticipated. The elasticity of fuel demand on fuel price and tax is comparatively higher than in the remaining 11 selected countries. The Czech Republic is also the only country from our selected sample which has experience with planned economy during 1948-1989, as a member of the communist Eastern Bloc. In future research, the study could be extended with the data for the rest of Eastern Europe because our findings suggest the fuel demand elasticity in those countries is different to the elasticity in the western part of Europe. Furthermore, allowing the model for price difference analysis to capture the effect of economic cycles on price differences could enhance the estimate of the effect of prices on demand.

Bibliography

[1] Lorna A. Greening, David L. Greene, and Carmen Difiglio. "Energy efficiency and consumption — the rebound effect — a survey". In: *Energy Policy* 28.6 (June 2000), pp. 389–401. ISSN: 03014215. DOI: 10.1016/S0301-4215(00)00021-5. URL: http://linkinghub.elsevier.com/retrieve/pii/S0301421500000215 (visited on 03/26/2016).

[2] Andrea Baranzini and Sylvain Weber. "Elasticities of Gasoline Demand in Switzerland". In: Haute école de gestion de Genève, 2012, p. 15. URL: http://hesso.tind.io/record/358/files/CR˙1˙12˙2˙Baranzini.pdf (visited on 01/09/2016).

[3] Martijn Brons et al. "A meta-analysis of the price elasticity of gasoline demand. A SUR approach". In: *Energy Economics* 30.5 (Sept. 2008), pp. 2105–2122. ISSN: 01409883. DOI: 10.1016/j.eneco.2007.08.004. URL: http://linkinghub.elsevier.com/retrieve/pii/S0140988307001144 (visited on 03/19/2016).

[4] a.s. ČEPRO. *Safety Data Sheet*. Mar. 3, 2015. URL: https://www.ceproas.cz/public/data/pdf/bezpecnost/listy/BA˙%C4%8CEPRO˙REACH˙CLP˙3˙3˙2015.pdf (visited on 12/03/2016).

[5] a.s. ČEPRO. *Safety Data Sheet*. Feb. 20, 2015. URL: https://www.ceproas.cz/public/data/pdf/bezpecnost/listy/BA˙%C4%8CEPRO˙REACH˙CLP˙3˙3˙2015.pdf (visited on 03/12/2016).

[6] Carol Dahl and Thomas Sterner. "Analysing gasoline demand elasticities: a survey". In: *Energy Economics* 13.3 (July 1991), pp. 203–210. ISSN: 01409883. DOI: 10.1016/0140-9883(91)90021-Q. URL: http://linkinghub.elsevier.com/retrieve/pii/014098839190021Q (visited on 03/26/2016).

[7] Lucas W. Davis and Lutz Kilian. “Estimating the effect of a gasoline tax on carbon emissions”. In: *Journal of Applied Econometrics* 26.7 (Nov. 2011), pp. 1187–1214. ISSN: 08837252. DOI: 10.1002/jae.1156. URL: http://doi.wiley.com/10.1002/jae.1156 (visited on 03/19/2016).

[8] Stacy C Davis, Susan W. Diegel, and Robert G. Boundy. “Transportation Energy Data Book: Edition 33”. In: U.S. Department of Energy, 2014, p. 440. URL: http://cta.ornl.gov/data/tedb34/Edition34˙Full˙Doc.pdf (visited on 03/26/2016).

[9] Julian Dieler, Darko Jus, and Markus Zimmer. “Fill’er up! Anticipation and Inventory Effects on Fuel Demand”. In: 37th Annual International Conference of the International Association for Energy Economics. New York: Institute for Economic Research at the University of Munich, June 2014, p. 35. URL: https://www.cesifo-group.de/ifoHome/publications/docbase/details.html?docId=19157506 (visited on 03/16/2016).

[10] Molly Espey. “Gasoline demand revisited: an international meta-analysis of elasticities”. In: *Energy Economics* 20.1998 (), pp. 273–295.

[11] European Comission. *SDĚLENÍ KOMISE EVROPSKÉMU PARLAMENTU, RADĚ, EVROPSKÉMU HOSPODÁŘSKÉMU A SOCIÁLNÍMU VÝBORU A VÝBORU REGIONŮ Plán přechodu na konkurenceschopné nízkouhlíkové hospodářství do roku 2050*. Aug. 3, 2011. URL: http://eur-lex.europa.eu/legal-content/CS/TXT/PDF/?uri=CELEX:52011DC0112&from=EN (visited on 02/27/2016).

[12] Daniel J. Graham * and Stephen Glaister. “Decomposing the determinants of road traffic demand”. In: *Applied Economics* 37.1 (Jan. 20, 2005), pp. 19–28. ISSN: 0003-6846, 1466-4283. DOI: 10.1080/0003684042000291263. URL: http://www.tandfonline.com/doi/abs/10.1080/0003684042000291263 (visited on 03/27/2016).

[13] Daniel J. Graham and Stephen Glaister. “Road Traffic Demand Elasticity Estimates: A Review”. In: *Transport Reviews* 24.3 (May 2004), pp. 261–274. ISSN: 0144-1647, 1464-5327. DOI: 10.1080/0144164032000101193. URL: http:

//www.tandfonline.com/doi/abs/10.1080/0144164032000101193 (visited on 03/27/2016).

[14] Tomas Havranek and Ondrej Kokes. "Income elasticity of gasoline demand: A meta-analysis". In: *Energy Economics* 47 (Jan. 2015), pp. 77–86. ISSN: 01409883. DOI: 10.1016/j.eneco.2014.11.004. URL: http://linkinghub.elsevier.com/retrieve/pii/S0140988314002734 (visited on 03/26/2016).

[15] Daniel Hoechle. "Robust standard errors for panel regressions with cross-sectional dependence". In: *The Stata Journal* 7.3 (2007), pp. 281–312. URL: http://www.stata-journal.com/sjpdf.html?articlenum=st0128 (visited on 06/15/2016).

[16] Shanjun Li, Joshua Linn, and Erich Muehlegger. "Gasoline Taxes and Consumer Behavior". In: *Working Paper 17891*. National Bureau of Economic Research. URL: http://www.nber.org/papers/w17891 (visited on 02/11/2015).

[17] Brantley Liddle. "The systemic, long-run relation among gasoline demand, gasoline price, income, and vehicle ownership in OECD countries: Evidence from panel cointegration and causality modeling". In: *Transportation Research Part D: Transport and Environment* 17.4 (June 2012), pp. 327–331. ISSN: 13619209. DOI: 10.1016/j.trd.2012.01.007. URL: http://linkinghub.elsevier.com/retrieve/pii/S1361920912000156 (visited on 03/25/2016).

[18] C.-Y. Cynthia Lin and Jieyin (Jean) Zeng. "The elasticity of demand for gasoline in China". In: *Energy Policy* 59 (Aug. 2013), pp. 189–197. ISSN: 03014215. DOI: 10.1016/j.enpol.2013.03.020. URL: http://linkinghub.elsevier.com/retrieve/pii/S0301421513001742 (visited on 03/24/2016).

[19] James Odeck and Kjell Johansen. "Elasticities of fuel and traffic demand and the direct rebound effects: An econometric estimation in the case of Norway". In: *Transportation Research Part A: Policy and Practice* 83 (Jan. 2016), pp. 1–13. ISSN: 09658564. DOI: 10.1016/j.tra.2015.10.003. URL: http://linkinghub.elsevier.com/retrieve/pii/S0965856415002530 (visited on 03/24/2016).

[20] Kalendář Online. *Online Calendar*. 2016. URL: http://www.kalendar-online.cz/planovaci-kalendar-1990 (visited on 05/17/2016).

[21] Desiderio Romero-Jordán et al. “Price and income elasticities of demand for passenger transport fuels in Spain. Implications for public policies”. In: *Energy Policy* 38.8 (Aug. 2010), pp. 3898–3909. ISSN: 03014215. DOI: 10.1016/j.enpol.2010.03.010. URL: http://linkinghub.elsevier.com/retrieve/pii/S0301421510001734 (visited on 03/24/2016).

[22] Ilan Salmon. “Telecommunications and Travel: Substitution or Modified Mobility?” In: *Journal of Transport Economics and Policy* 19.3 (1985), pp. 219–235. URL: http://www.jstor.org/stable/20052753 (visited on 03/26/2016).

[23] Liliane Temime. *workingdays.org*. 2016. URL: http://www.arbeitstage.at˙http://www.joursouvres.be˙http://denmark.workingdays.org˙http://www.joursouvres.fr˙http://www.arbeitstage.de˙http://www.work-day.co.uk˙http://netherlands.workingdays.org˙http://www.dias-uteis.pt˙http://www.dias-laborables.es˙http://www.workingdays.se (visited on 05/17/2016).

[24] *Zákon o spotřebních daních, 353/2003 Sb., Sbírka zákonů ČR*. 2003.

Appendix A

Table 19: OLS estimates of final regression : Gasoline

Variable	Coefficient	(Rob. Std. Err.)
dlnetprice	-0.079*	(0.030)
dlexcise	-0.355	(0.276)
lagdlexcise	0.162	(0.159)
leaddlexcise	0.091	(0.169)
dworkingdays	0.012**	(0.002)
dunempadj	-0.004	(0.008)
m2	0.083**	(0.014)
m3	0.197**	(0.015)
m4	0.127**	(0.016)
m5	0.124**	(0.013)
m6	0.079**	(0.021)
m7	0.128**	(0.020)
m8	0.102**	(0.020)
m9	0.034†	(0.016)
m10	0.089**	(0.015)
m11	0.042*	(0.015)
m12	0.131**	(0.024)
c2	0.043**	(0.006)
c3	-0.001	(0.003)
c4	0.008	(0.005)
c5	0.014	(0.016)

c6	0.078**	(0.022)
c7	0.002	(0.002)
c8	0.033**	(0.006)
c9	0.003	(0.005)
c10	0.024†	(0.012)
c11	0.008	(0.005)
o.y2	0.000	(0.000)
o.y3	0.000	(0.000)
o.y4	0.000	(0.000)
o.y5	0.000	(0.000)
o.y6	0.000	(0.000)
o.y7	0.000	(0.000)
o.y8	0.000	(0.000)
y9	-0.005	(0.010)
o.y10	0.000	(0.000)
y11	-0.009*	(0.003)
y12	-0.012**	(0.004)
y13	-0.010*	(0.004)
y14	-0.014*	(0.006)
y15	-0.017**	(0.005)
y16	-0.017**	(0.004)
y17	-0.011**	(0.003)
y18	-0.015**	(0.003)
y19	-0.005	(0.008)
y20	-0.011†	(0.005)
y21	-0.016*	(0.006)
y22	-0.012†	(0.005)
y23	-0.014*	(0.006)
A_CZ	0.000	(0.000)
B_F	-0.001	(0.000)
CZ_D	-0.001	(0.001)

DK_D	0.000	(0.000)
F_ES	-0.001	(0.001)
D_CZ	0.000	(0.001)
IR_UK	0.000	(0.000)
NL_D	-0.001**	(0.000)
PT_ES	0.000	(0.000)
ES_PT	0.001*	(0.000)
S_DK	0.000†	(0.000)
A_SR	0.001	(0.000)
B_D	-0.003**	(0.000)
CZ_PL	0.002†	(0.001)
DK_S	0.000	(0.000)
F_B	0.000	(0.000)
NL_B	-0.001†	(0.000)
S_FIN	0.000**	(0.000)
A_SLO	0.000	(0.000)
B_NL	0.004**	(0.001)
CZ_A	-0.003†	(0.002)
F_D	0.000	(0.000)
D_F	0.001	(0.001)
A_I	-0.002**	(0.000)
CZ_SK	0.002*	(0.001)
F_I	0.000	(0.000)
D_B	0.003**	(0.000)
A_D	0.001*	(0.000)
D_NL	0.000	(0.001)
A_HUN	-0.002**	(0.000)
D_DK	-0.002*	(0.001)
D_PL	-0.002**	(0.000)
UK_IR	0.000	(0.000)
D_A	-0.002†	(0.001)

ES_F	0.000	(0.001)
Intercept	-0.089**	(0.013)

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Table 20: OLS estimates of final regression : Diesel

Variable	**Coefficient**	**(Rob. Std. Err.)**
dlnetprice	-0.065	(0.051)
dlexcise	-0.849*	(0.301)
lagdlexcise	0.210	(0.198)
leaddlexcise	0.265	(0.221)
dworkingdays	0.022**	(0.002)
dunempadj	-0.003	(0.010)
m2	0.111**	(0.009)
m3	0.131**	(0.013)
m4	0.095**	(0.008)
m5	0.080**	(0.012)
m6	0.071**	(0.008)
m7	0.056*	(0.024)
m8	0.067†	(0.032)
m9	0.107**	(0.013)
m10	0.102**	(0.010)
m11	0.051**	(0.010)
m12	0.049*	(0.021)
c2	0.024	(0.016)
c3	0.022*	(0.009)
o.c4	0.000	(0.000)
c5	0.000	(0.011)
c6	-0.011	(0.009)
c7	-0.006	(0.010)
c8	-0.004	(0.010)
c9	-0.003	(0.011)
c10	-0.008	(0.011)
c11	-0.004	(0.010)

o.y2	0.000	(0.000)
o.y3	0.000	(0.000)
o.y4	0.000	(0.000)
o.y5	0.000	(0.000)
o.y6	0.000	(0.000)
o.y7	0.000	(0.000)
o.y8	0.000	(0.000)
y9	-0.004	(0.013)
o.y10	0.000	(0.000)
y11	-0.005	(0.003)
y12	-0.009*	(0.004)
y13	-0.008*	(0.003)
y14	-0.004	(0.004)
y15	-0.007†	(0.003)
y16	-0.007	(0.005)
y17	-0.008*	(0.004)
y18	-0.009*	(0.004)
y19	-0.014**	(0.004)
y20	-0.006	(0.005)
y21	-0.014**	(0.004)
y22	-0.008	(0.006)
y23	-0.011†	(0.005)
A_CZ	-0.001**	(0.000)
B_F	-0.005**	(0.001)
CZ_D	0.003**	(0.001)
F_ES	0.000	(0.000)
D_CZ	-0.001**	(0.000)
IR_UK	0.000	(0.000)
NL_D	0.000	(0.000)
PT_ES	0.000	(0.000)
ES_PT	0.000	(0.000)

S_DK	0.000**	(0.000)
A_SR	0.001**	(0.000)
B_D	0.002†	(0.001)
CZ_PL	-0.003*	(0.001)
F_B	0.000	(0.000)
NL_B	0.000	(0.000)
S_FIN	0.000†	(0.000)
A_SK	-0.001**	(0.000)
B_NL	0.002**	(0.001)
CZ_A	-0.002	(0.002)
F_D	0.000	(0.000)
D_F	-0.003**	(0.001)
A_I	0.000	(0.000)
CZ_SLO	0.002†	(0.001)
F_I	0.000	(0.000)
D_B	0.000	(0.000)
A_D	-0.001	(0.000)
D_NL	0.002**	(0.000)
A_HUN	-0.001*	(0.000)
D_DK	-0.002*	(0.001)
D_PL	0.000	(0.000)
UK_IR	0.000	(0.000)
D_A	0.003**	(0.000)
ES_F	-0.001*	(0.000)
Intercept	-0.064**	(0.013)

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Appendix B

Table 21: OLS estimates of final adjusted regression : Gasoline

Variable	Coefficient	(Rob. Std. Err.)
dlnetprice	0.025	(0.076)
dlexcise	-0.260	(0.240)
lagdlexcise	-0.328	(0.220)
leaddlexcise	-0.126	(0.170)
dworkingdays	0.006**	(0.001)
dunempadj	0.022	(0.023)
m2	-0.017	(0.011)
m3	0.093**	(0.010)
m4	0.119**	(0.017)
m5	0.132**	(0.017)
m6	0.121**	(0.022)
m7	0.162**	(0.031)
m8	0.159**	(0.029)
m9	0.096**	(0.022)
m10	0.094**	(0.019)
m11	0.034†	(0.016)
m12	0.068**	(0.014)
c2	-2.310**	(0.076)
c3	-8.991**	(0.099)
c4	-2.516**	(0.113)
c5	-0.238*	(0.096)

c6	0.237*	(0.083)
c7	-2.252**	(0.068)
c8	-1.058**	(0.065)
c9	-2.176**	(0.103)
c10	-1.008**	(0.120)
c11	-1.446**	(0.107)
o.y2	0.000	(0.000)
o.y3	0.000	(0.000)
o.y4	0.000	(0.000)
o.y5	0.000	(0.000)
o.y6	0.000	(0.000)
o.y7	0.000	(0.000)
o.y8	0.000	(0.000)
o.y9	0.000	(0.000)
y10	-0.119	(0.086)
y11	-0.056	(0.224)
y12	-0.028	(0.226)
y13	-0.010	(0.229)
y14	-0.022	(0.228)
y15	-0.018	(0.229)
y16	-0.063	(0.232)
y17	-0.106	(0.232)
y18	-0.131	(0.232)
y19	-0.149	(0.234)
y20	-0.224	(0.240)
y21	-0.260	(0.240)
y22	-0.318	(0.245)
y23	-0.371	(0.248)
A_CZ	0.016**	(0.001)
B_F	-0.010**	(0.003)
CZ_D	-0.006	(0.005)

DK_D	-0.001	(0.000)
F_ES	-0.006†	(0.003)
D_CZ	-0.015**	(0.002)
IR_UK	0.003	(0.002)
NL_D	-0.010*	(0.003)
PT_ES	-0.003	(0.002)
ES_PT	-0.012*	(0.004)
S_DK	0.000	(0.001)
A_SR	-0.013**	(0.002)
B_D	0.001	(0.002)
CZ_PL	0.005	(0.008)
DK_S	0.001	(0.001)
F_B	0.013**	(0.004)
NL_B	-0.018**	(0.003)
S_FIN	0.000	(0.000)
A_SK	-0.026**	(0.001)
B_NL	-0.001	(0.003)
CZ_A	0.026**	(0.006)
F_D	0.009**	(0.003)
D_F	-0.012**	(0.004)
A_I	0.079**	(0.004)
CZ_SLO	-0.013	(0.008)
F_I	-0.002	(0.002)
D_B	-0.005**	(0.001)
A_D	0.030**	(0.001)
D_NL	0.014**	(0.002)
A_HUN	-0.010**	(0.002)
D_DK	0.003	(0.003)
D_PL	0.003†	(0.001)
UK_IR	0.007	(0.005)
D_A	0.017**	(0.002)

ES_F	0.016*	(0.007)
Intercept	14.140**	(0.258)

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

Table 22: OLS estimates of final adjusted regression : Diesel

Variable	**Coefficient**	**(Rob. Std. Err.)**
dlnetprice	0.007	(0.077)
dlexcise	-0.678†	(0.324)
lagdlexcise	-0.576*	(0.238)
leaddlexcise	0.503	(0.316)
dworkingdays	0.010**	(0.001)
dunempadj	0.003	(0.019)
m2	0.032**	(0.008)
m3	0.097**	(0.015)
m4	0.103**	(0.017)
m5	0.094**	(0.017)
m6	0.107**	(0.018)
m7	0.095*	(0.031)
m8	0.095**	(0.026)
m9	0.124**	(0.022)
m10	0.153**	(0.023)
m11	0.114**	(0.017)
m12	0.080**	(0.010)
c2	-1.004**	(0.162)
c3	-8.347**	(0.175)
o.c4	0.000	(0.000)
c5	0.700**	(0.184)
c6	0.478*	(0.172)
c7	-2.240**	(0.162)
c8	-1.106**	(0.177)
c9	-1.136**	(0.173)
c10	0.172	(0.174)
c11	-1.686**	(0.173)

o.y2	0.000	(0.000)
o.y3	0.000	(0.000)
o.y4	0.000	(0.000)
o.y5	0.000	(0.000)
o.y6	0.000	(0.000)
o.y7	0.000	(0.000)
o.y8	0.000	(0.000)
o.y9	0.000	(0.000)
y10	0.057**	(0.012)
y11	0.144**	(0.037)
y12	0.206**	(0.031)
y13	0.255**	(0.037)
y14	0.304**	(0.034)
y15	0.371**	(0.035)
y16	0.359**	(0.039)
y17	0.407**	(0.042)
y18	0.442**	(0.041)
y19	0.458**	(0.043)
y20	0.417**	(0.043)
y21	0.426**	(0.051)
y22	0.422**	(0.053)
y23	0.403**	(0.065)
A_CZ	0.037**	(0.006)
B_F	0.005**	(0.001)
CZ_D	0.012**	(0.003)
F_ES	-0.006**	(0.001)
D_CZ	-0.001	(0.001)
IR_UK	0.000	(0.001)
NL_D	0.005*	(0.002)
PT_ES	-0.011**	(0.002)
ES_PT	-0.003	(0.002)

S_DK	0.001**	(0.000)
A_SR	0.017**	(0.002)
B_D	-0.003	(0.002)
CZ_PL	0.004	(0.005)
F_B	0.001	(0.002)
NL_B	0.002	(0.002)
S_FIN	0.000†	(0.000)
A_SK	-0.009**	(0.001)
B_NL	0.004	(0.003)
CZ_A	-0.012*	(0.005)
F_D	0.005**	(0.002)
D_F	0.008†	(0.003)
A_I	0.042**	(0.007)
CZ_SLO	0.005	(0.005)
F_I	0.000	(0.001)
D_B	-0.003*	(0.001)
A_D	0.027**	(0.004)
D_NL	0.007**	(0.001)
A_HUN	-0.020**	(0.003)
D_DK	-0.005*	(0.002)
D_PL	0.002†	(0.001)
UK_IR	0.005	(0.007)
D_A	-0.004*	(0.001)
ES_F	-0.006*	(0.002)
Intercept	13.720**	(0.185)

Significance levels : † : 10% * : 5% ** : 1%