Fill'er up! Anticipation and Inventory Effects on Fuel Demand

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Recent years have seen increased interest in the economic literature in assessing the effects of fuel prices and taxes on fuel demand. We contribute to this literature by including anticipation and inventory effects for the first time in the analysis of motor fuel tax elasticities. Recent studies have focused on US data and gasoline consumption. By constructing a new data set we provide a complementary study for European countries and extend the analysis to diesel fuel, essential for understanding the European market. Neglecting the reaction on anticipated tax increases leads to upward biased estimates for the tax elasticities. We also reveal a difference in the ability of gasoline and diesel consumers to react to announced tax changes. By including anticipation effects we are able to narrow down the band for the tax elasticity from 0 - 0.39. Lastly we show that using quarterly data in the presence of anticipation effects may also lead to upward biased results.

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KEYWORDS:

- C33 – Multiple or Simultaneous Equation Models; Multiple Variables - - - Panel data models
- C53 – Mathematical and Quantitative Methods - - Econometric Modeling - - - Forecasting and Prediction Models; Simulation Methods
- D12 - Microeconomics - - Household Behavior - - - Consumer Economics: Empirical Analysis
- L91 - Industrial Organization - - Industry Studies: Transportation and Utilities - - - Transportation: General
- Q31 - Agricultural and Natural Resource Economics; Environmental and Ecological Economics - - Nonrenewable Resources and Conservation - - - Demand and Supply
- Q41 - Agricultural and Natural Resource Economics; Environmental and Ecological Economics - - Energy - - - Demand and Supply
- Q48 - Agricultural and Natural Resource Economics; Environmental and Ecological Economics - - Energy - - - Government Policy
- R40 - Urban, Rural, Regional, Real Estate, and Transportation Economics - - Transportation Systems - - - General
- R41 - Urban, Rural, Regional, Real Estate, and Transportation Economics - - Transportation Systems - - - Transportation: Demand, Supply, and Congestion

1. Introduction

Fuel taxes have received increased attention in today's policy agendas as they are a hotly debated topic in the public and they are a seen as an important instrument to raise tax revenues on the one hand but also curb carbon emissions on the other hand. Consequently in recent years the economic literature has moved its focus from assessing price elasticities to assessing tax elasticities of fuel consumption.

We analyze the effectiveness of fuel taxes in Europe in the short-run by estimating how gasoline consumption responds to fuel price changes. More specifically, we derive the reactions to price and excise tax changes using a unique data set covering 11 European countries. Our data includes diesel consumption and prices in addition to gasoline, extending previous literature which has mainly focused on gasoline[1]. Considering diesel fuel consumption is important in our study, since diesel plays a more significant role in Europe than in the United States. Our panel covers the period between 1990 and 2012 on a monthly basis.

We make five contributions to the existing literature. Our main contribution is the disclosure and the quantification of an anticipation effect in the demand for motor fuel that results from an increase in fuel taxes[2]. Consumers fuel up their cars shortly before the tax increase is implemented. Consequently they refuel less in the month when the tax increase comes into force. Thus there are two reasons for less consumption in the tax month. Firstly, the retail price of motor fuel increases and secondly the fuel tank is fuller than in months without a tax increase. In terms of the effect of taxes on fuel consumption, only the reaction to the increased retail price represents an actual decline in fuel consumption. The fuller tank in the beginning of a tax month represents an *anticipation effect,* or an intertemporal shifting of fuel purchases with no change in overall fuel consumption. Disregarding the anticipation effect leads to an overestimation of the tax impact. Controlling for the anticipation effect we find tax elasticities in the range of 0 and -0.39. This is decisively smaller than the elasticities Davis and Kilian (2011) and Li et al. (2012) find in their studies for the USA without controlling for the anticipation effect. Their estimates

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[1] See e.g. Hughes et al. (2008), Davis and Kilian (2011) and Li et al. (2012)

[2] Ours is the first paper to present this idea and we apply it to the European context. Anticipation effects should be included in any empirical analysis of the effects of announced tax changes. This point is considerably strengthened by the fact a corresponding analysis from the American context is forthcoming by Coglianese, J. et al. as NBER Working Paper 20980.

for the tax elasticities lie between -0.46 and -0.765. When we don't control for the anticipation effect we find similar results for the European gasoline market.

In the literature of modeling crude oil markets anticipation effects are already acknowledged to have an impact on demand and thereby on the crude oil price. Studies like Kilian and Lee (2014) and Kilian and Murphy (2014) argue for the necessity of including the stock of above-ground oil inventories in modeling the oil price, as the stock of inventories is an indicator for the anticipation of future oil price movements.

A second contribution of our study lies in the fact that we construct a new European dataset on a monthly basis. The previous literature has either focused on US data (e.g. Hughes et al. (2008)) or on yearly data for the European countries (e.g. Pock (2010) and Liu (2004)) as monthly data was not centrally available for Europe before. We have collected data from many different national institutions and compiled them into a single data set of comparable fuel tax measures in 11 European countries.[3]

As a third contribution we analyze – in addition to the commonly studied gasoline consumption – the effects of fuel taxes on diesel consumption. Including diesel use in the analysis is crucial for Europe as the share of diesel cars in the EU fleet amounts to 36.8% and is increasing further.[4] In the United States, diesel-fueled cars are also becoming more and more important, but at the moment they make up only 3% of the entire market. In Europe the above mentioned 36.8% of diesel cars are mainly bought by frequent drivers. For frequent drivers it pays off to incur the

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[3] See table 11 in the appendix for detailed information on the data sources. The dataset is available on request.

[4] Newest figures from 2011 (ACEA 2014)

higher initial costs of acquiring a diesel car as the fuel costs are lower due to higher mileage and lower fuel prices. Additionally, most light and heavy duty trucks, typically used for commercial purposes, have diesel engines. Fuel costs account for a major share of total expenses for these commercial users. Assuming they react differently from people who only use their car to drive to the supermarket, we expect to find a difference between the consumption behavior of diesel and the consumption behavior of gasoline. In addition to being more sensitive to fuel costs, commercial fuel consumers also have better opportunities for intertemporal shifting due to bigger fuel tanks or even large central fuel reservoirs (e.g. in trucking companies or farms).

Fourthly, taking the anticipation effect into account we find no significant difference between the effect of a tax change on fuel consumption and the effect of a net of tax price change on fuel consumption. This is in line with a finding by Anderson et al. (2013) who analyze consumer beliefs about future gasoline prices in Michigan. They find that consumers' price forecasts do not respond differently to net of tax price changes and to tax changes. This means consumers do not view tax increases as a more important reason than pre-tax price changes to invest in more fuel efficient vehicles. Consequently a tax increase should lead to similar gasoline consumption effects as a net of tax price increase does. Using a similar approach to the one used in this paper, but without controlling for the anticipation effect, Davis and Kilian (2011) and Li et al. (2012), however, find indication for differential impacts of tax changes and pre-tax price changes. Analyzing the impact of the introduction of a carbon tax in British Columbia, Rivers and Schaufele (2013) also find evidence for differences between tax exclusive price effects and tax effects. The authors of these studies advance two arguments as possible explanations for their results. First, they argue that tax changes attract more media attention than pre-tax price changes, and that thereby tax changes are more salient and lead to larger responses of consumers. The second possible explanation is that of Anderson et al. (2013): namely, that tax changes are perceived to have a more persistent impact on the retail price than net of tax price changes and, thus, a stronger influence on the vehicle choice. In their survey of consumer beliefs, however, Anderson et al. do not find statistical evidence in support of this hypothesis.

Lastly, we make a further methodological contribution and show that using quarterly data, in a calendar quarterly sense and in the presence of anticipation effects, may also lead to upward biased results. When the anticipated event takes place in the first month of the calendar quarter, which is rather often the case for tax changes, it might impact the behavior in the quarter before through the anticipation effect, and that this effect should thus be controlled for.

The structure of our paper is as follows. We proceed in the next section by presenting a summary of the quantitative results and placing them in the conclusions of the previous literature. In section we 3 explain our data in detail and present some summary statistics before we address the different empirical methods applied and their respective results in section 4. In the remaining section we draw some conclusions.

2. Data

For our empirical analysis of the effect of vehicle fuel taxes on gasoline and diesel consumption, we construct a new panel data set from a wide range of sources. These include national governments and ministries, national statistical offices, research institutes, private companies, and supranational organizations (cf. Table 11 in the Appendix). In total, our data set with monthly observations covers 11 countries (Austria, Belgium, Denmark, France, Germany, Ireland, the Netherlands, Portugal, Spain, Sweden, and the United Kingdom). The observation period is from 1990 until 2012. Unfortunately, the data are not available for all countries over the entire period. The key variables in our econometric analysis are the consumption of the two main vehicle fuel types ("Eurosuper", which is a 95 octane gasoline, which, for the sake of simplicity, we refer to as gasoline, and "diesel"), the respective consumer prices, and the taxes levied on these two products. The taxes consist of excise taxes, the value-added tax (VAT), and additional fees that act like excise taxes. In the remainder of the article tax stands for the sum of excise taxes, the VAT levied on excise taxes and additional fees that act like excise taxes. That means taxes according to our definition comprise only price exogenous elements and no elements which change automatically with pre-tax price like the VAT for example. See Figure 1 for the evolution of taxes and retail price in the analyzed countries. Figure 6 and 7 in the Appendix show exemplarily the composition of the gasoline and diesel retail price. Figure 2 shows the consumption of gasoline and diesel over time. The sales of diesel grew due to the increasing spread of turbo-charged engines in passenger vehicles since 1988. Comparing the evolution of the consumption of diesel with that of gasoline, we observe in all countries – but especially in France, Sweden and the United Kingdom – a trend away from gasoline fueled cars to more fuel efficient diesel fueled cars. In the case of gasoline, the increase stems from the fact that we use 95 octane gasoline, which was not used widely before the end of the 1980s. In the subsequent years, it steadily replaced 91 octane gasoline, previously the main type of gasoline. Therefore, the increase in gasoline consumption in Figure 2 does not imply an overall increase in consumption, but is the result of the substitution of 95 octane for 91 octane gasoline.

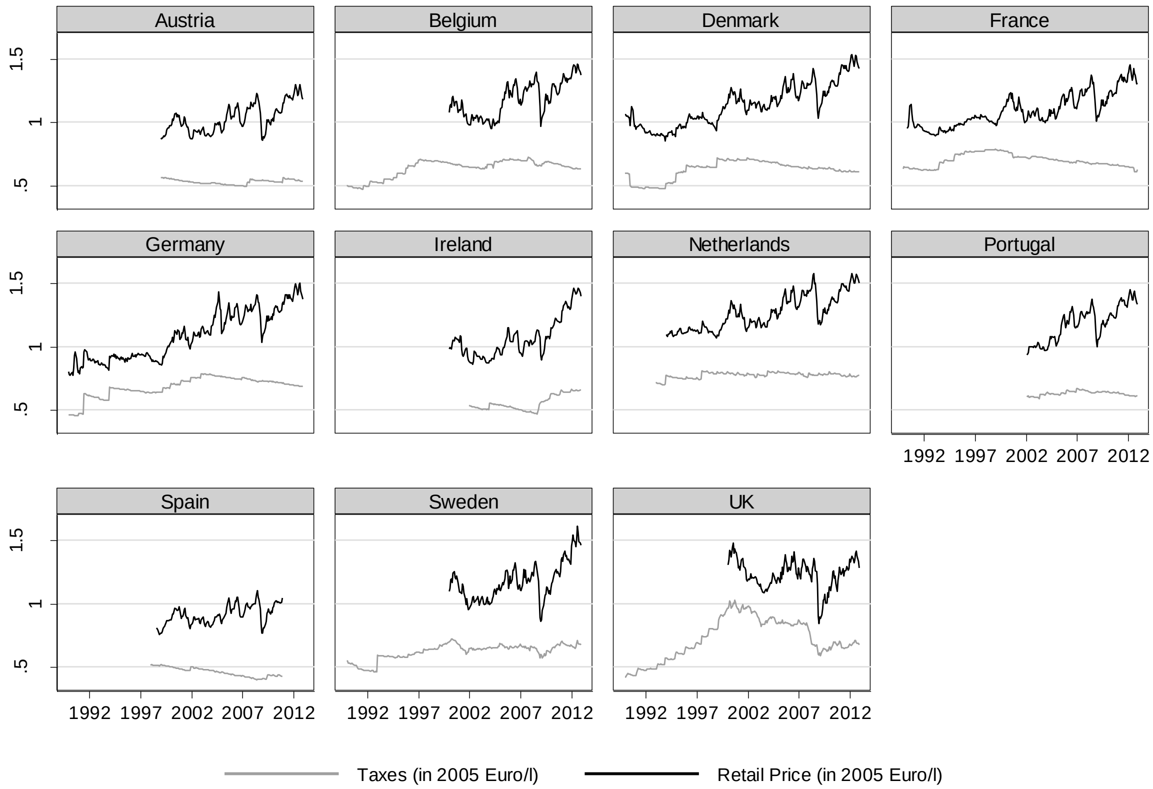

Figure 1: Taxes and prices per liter in 2005 Euros for gasoline

The consumption curves of those countries that were severely affected by the financial crisis (Ireland, Portugal, and Spain) exhibit a discontinuity in 2008. German consumption of gasoline has two discontinuities: one at the end of 2007 when 91 octane gasoline was taken "off the shelf" by most gas stations and a second one at the beginning of 2011 when a new type of gasoline with a higher degree of bioethanol was introduced. Another observation from Figure 2 is the high seasonality of the consumption data which implies the necessity to control for the month of the year.

Data on the other control variables, including the number of working days per month, the monthly oil price, and the monthly national currency to dollar exchange rate are taken from OECD and World Bank databases, respectively.

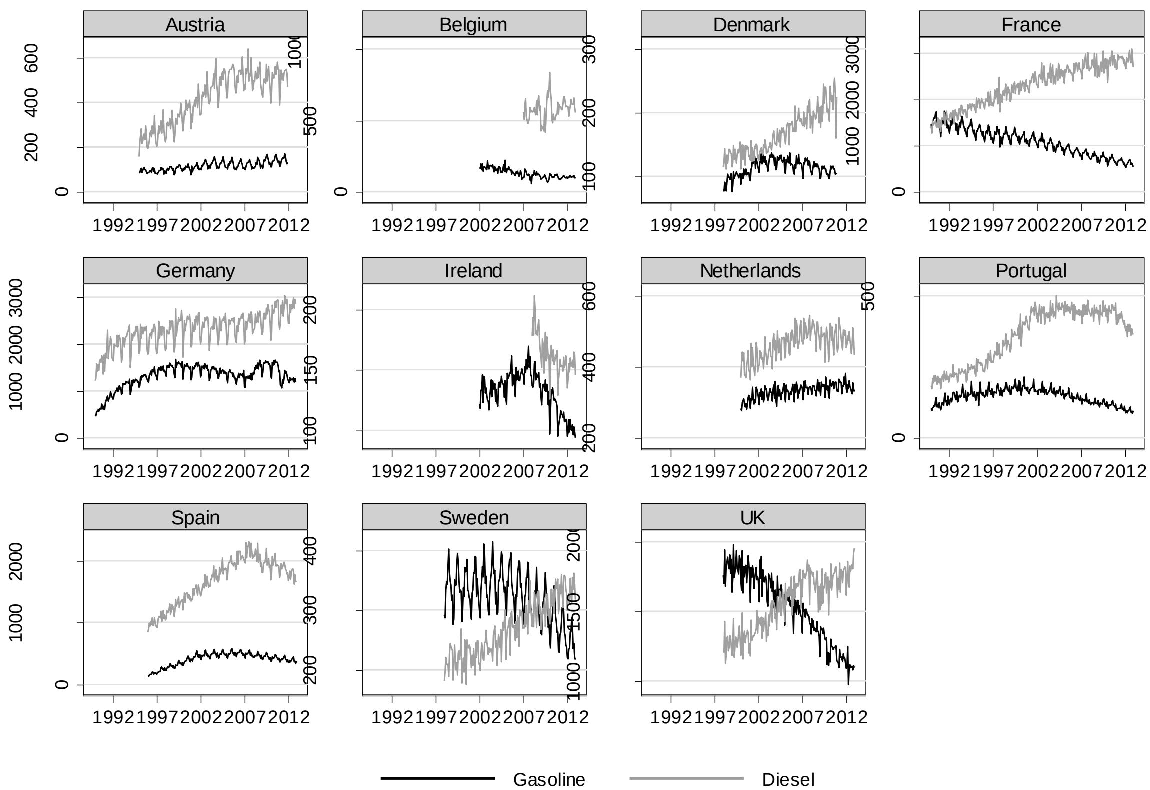

Figure 2: Gasoline and diesel consumption

Table 1 sets out summary statistics for the variables used in the regression analysis. Since the analysis is performed using log-differences of the variables (except for "working days"), the summary statistics are also provided in this format. The "working days" variable carries the absolute difference in the working days from one month to the next. Intuitively, all variables in log-differences have their mean close to zero, meaning that the month-over-month percentage change is on average about zero. Similarly, the month-over-month absolute change in the number of working days is on average nearly zero. However, all variables show fairly high variation.

Gasoline

Variable	Obs	Mean	Std.Dev.	Min	Max
consumption	1,582	-0.000478	0.0934	-0.647	0.755[5]
tax	1,582	0.000198	0.0132	-0.0715	0.298
working days	1,582	-0.00316	1.927	-6	5
net of tax price	1,582	0.00406	0.0721	-0.448	0.325
oil price	1,582	0.00976	0.0923	-0.311	0.459

Diesel

Variable	Obs	Mean	Std.Dev.	Min	Max
consumption	1,454	0.00272	0.0984	-0.477	0.354
tax	1,454	0.000597	0.0143	-0.131	0.189
working days	1,454	-0.00481	1.933	-6	5
net of tax price	1,454	0.00347	0.0639	-0.322	0.281
oil price	1,454	0.00866	0.0931	-0.311	0.459

Table 1: Summary statistics

Especially with regard to taxes one could be concerned about sufficient variation. These concerns can be met by the fact that we observe about 1.8 nominal tax changes per country and fuel type

[5] The minimum and maximum value of the change in consumption are outliers from Belgian data. Unfortunately the monthly consumption data in Belgium is based on estimations, meaning that these two values result from statistical issues. As we do not want to manipulate the data more than necessary, we keep the observations in the dataset. In a robustness check we excluded them to check that these extreme values do not drive our results, which they do not. The next smaller minimum and maximum values of consumption change are around 0.40 and thereby seem to be more realistic.

per year. That totals to 262 changes for gasoline and 230 for diesel over the entire panel. For gasoline as well as for diesel the bulk of the changes are increases: 75% for gasoline and 79% for diesel.

3. Models of Fuel Consumption

We extend the analytic structure used by Davis and Kilian (2011) by controlling for forward looking consumption behavior, in order to study changes in purchasing behavior *before* the tax is implemented. Estimating this tax anticipation effect leads us to the conclusion that taxes are less effective in the short run than previously stated.

3.1 Least Squares Estimates of Fuel Consumption

To establish a common benchmark with similar studies, we start with the analysis of the impact of price changes on monthly fuel consumption (cf. e.g., Hughes et al., 2008; Davis and Kilian, 2011).

A frequently employed specification in the literature links y_t, the logarithm of fuel consumption in month *t*, linearly to p_t, the logarithm of the average price of the respective fuel in the same month, along with a vector Z of control variables and an unobserved idiosyncratic time-varying factor ε_t.

$$y_t = \alpha_0 + \alpha_1 p_t + Z_1 + \varepsilon_t$$

In the basic specification, Z_1 contains month-of-the-year fixed effects that are intended to control for the strong seasonality of the consumption data.

However, since y_t and p_t are likely to follow a long-run trend, we estimate the equation in differences in logs, i.e., in growth rates ($\Delta x_t = \ln \frac{x_t}{x_{t-1}} = \ln x_t - \ln x_{t-1}$):

$$\Delta y_t = \alpha_0 + \alpha_1 \Delta p_t + Z_1 + \varepsilon_t \quad (1)$$

This equation uses the pooled data set, meaning that country-specific effects are ignored. In the second step, we make use of the panel structure for the 11 countries in our data set:

$$\Delta y_{it} = \alpha_0 + \alpha_1 \Delta p_{it} + Z_2 + \omega_{it} \quad (2)$$

In this specification, Δy_{it} is the monthly growth rate of fuel consumption in month *t* in country *i*. Accordingly, Δp_{it} is the monthly growth rate of the price of the respective fuel in the same month *t* and in the same country *i*. In addition to the month-of-the-year fixed effects included in Z_1, Z_2 contains country and year fixed effects and other controls, such as the change in the unemployment rate and the month-over-month change in working days. Their relevance will be explained below. Thereby, the unobserved idiosyncratic error term varies across countries and over time on a monthly basis.[6]

Table 2 (gasoline) and Table 3 (diesel) show the results of the estimation equation. Column (1) gives the results of the basic model, i.e., the relationship between the change in fuel consumption and change in its price using a pooled OLS regression (cf. Equation (1)). The explanatory power of this model is rather poor, mainly due to the strong seasonality of consumption (cf. Figure 2) which explains much of the variation. We address this issue by using the panel structure of the

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[6] When we discuss a variable in the remainder of this article we refer to its growth rate, month-to-month growth concerning working days, or change in growth rate concerning the unemployment rate, unless otherwise stated.

data in column (2). Column (2) depicts the results of Equation (2) without controlling for changes in working days and changes in the unemployment rate. The model's explanatory power increases and the price coefficient becomes highly significant. In Column (3) we add changes in working days and changes in the unemployment rate. The number of working days in a month has a decisive impact on gasoline and diesel consumption. As described in Section 2, the number of working days sometimes varies quite substantially (up to a 6-day difference from the previous month). The positive impact of working days on fuel consumption may be attributed to commercial activity that requires fuel or simply because many individuals are commuting to work by car. Similar reasoning drives the observed effect of including changes in the unemployment rate. When the unemployment rate increases, fewer individuals commute to work. And, indeed, for gasoline consumption, we find empirical evidence in support of this argument.

Gasoline

% change in consumption	(1)	(2)	(3)
% change in retail price	-0.008	-0.224***	-0.211***
	(0.083)	(0.076)	(0.071)
change in working days			0.014***
			(0.001)
change in unemployment			-0.015***
			(0.005)
month of the year indicators	No	Yes	Yes
country indicators	No	Yes	Yes
year indicators	No	Yes	Yes
R^2	0.00	0.35	0.42
N	1861	1861	1861

* p<0.1; ** p<0.05; *** p<0.01

Table 2: OLS estimates—gasoline

Diesel

% change in consumption	(1)	(2)	(3)
% change in retail price	-0.101	-0.198**	-0.181***
	(0.084)	(0.079)	(0.065)
change in working days			0.027***
			(0.001)
change in unemployment			0.000
			(0.007)
Month of the year indicators	No	Yes	Yes
Country indicators	No	Yes	Yes
Year indicators	No	Yes	Yes
R^2	0.00	0.23	0.46
N	1829	1829	1829

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Table 3: OLS estimates—diesel

Our short-run price elasticity estimates of around –0.2 (for both gasoline and diesel) are very similar to those found in the literature (cf. the review study by Dahl and Sterner (1991)).[7] While the analysis of price elasticities may serve as a proxy on how consumption is affected by tax changes (which naturally translate into price changes), Davis and Kilian (2011) and Li et al. (2012) propose a different approach. They point out that decomposing the effects of taxes and net prices, respectively, instead of looking at the overall effect of a changing gross price, provides further insight into consumer behavior. Such a disentanglement enables discovering the difference between the reaction to difficult-to-predict and highly volatile net price changes and the reaction to more easily foreseeable and persistent tax changes (cf. Figure 3). Li et al. (2012) find evidence for a stronger reaction to salient retail price changes due to tax changes (elasticity of –0.77) than to net price changes (–0.37). Their explanation for this is that tax changes are announced before their introduction and consumers perceive them to be more persistent. Net

[7] Dahl and Sterner (1991) reveal a short-run price elasticity of -0.26.

price changes, on the other hand, are always difficult for consumers to predict in advance and they fluctuate strongly. Therefore, at least in the short run, consumption behavior changes should be larger with respect to tax changes.

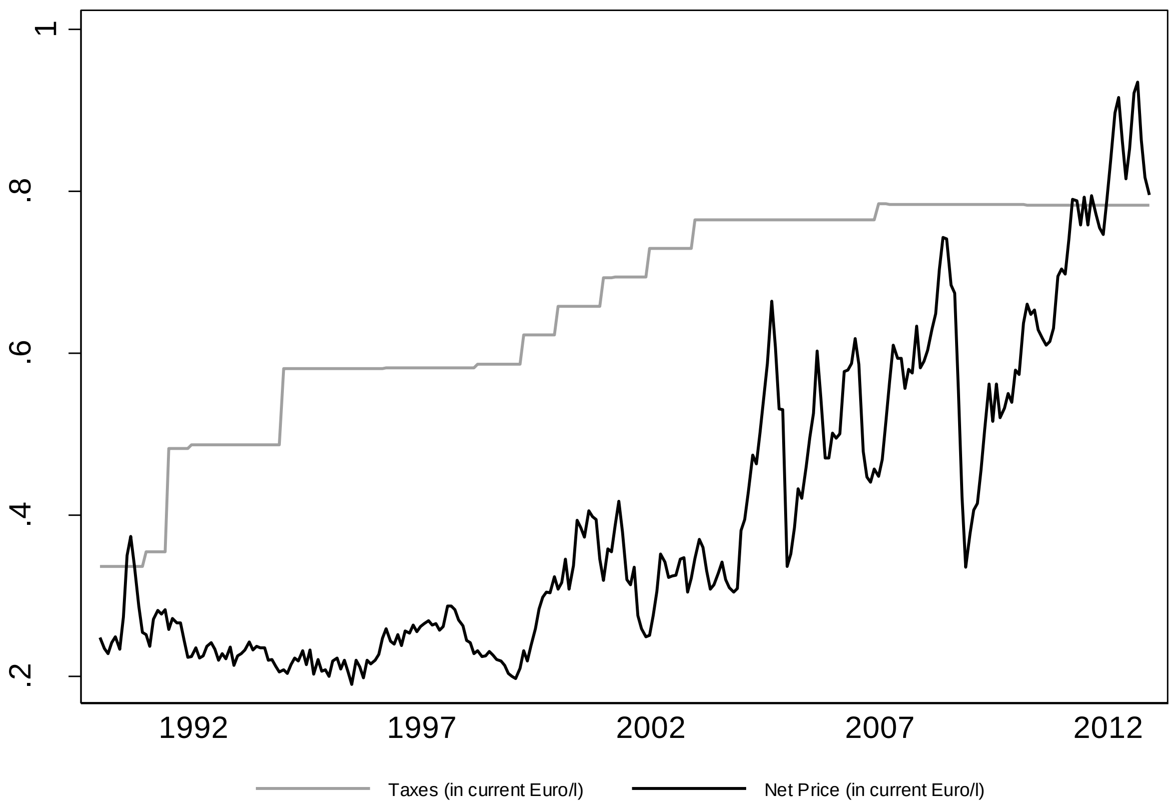

Figure 3: Taxes and net price in current values (Germany)

Differentiating between individuals' reactions to tax changes and to changes in the net price also raises another question: do individuals form expectations about the retail price and, if so, what this implies for their purchasing decisions? We interpreted our variable y_{it} as *consumption* of gasoline and diesel, but what we are actually observing is the *purchase* of fuel, not its consumption. That means the demand for motor fuel possesses features of stock demand. Such features are not as pronounced as for crude oil (Kilian and Murphy (2014), Kilian and Lee

(2014)), but up to a certain degree, car drivers can use their fuel tank for storage. Therefore the observed reduction of purchases in the month the tax increases can be either the consequence of a reduction in consumption or of a depletion of fuel stocks. Figure 4 and Figure 5 – which will be discussed in depth later –shed light on this issue. They show a significant increase in purchases in the month before and after the tax increase, which can be an indication of the accumulation and restocking of fuel stocks, subsequently depleted in the month of the tax increase. Thus it seems unlikely that individuals really consume less fuel by e.g. not using their cars to go to work or to take their children to school. Especially towards the end of the month, before an announced tax increase is implemented, individuals could choose to increase their purchase volume in anticipation of the tax increase. We control for this by including the first lead of tax in our estimation equation. To analyze consumption or, rather, purchase behavior after the month of the tax increase, we also include the lag of tax in our regression, as do Blundell and Bond (1998). These considerations lead to the following estimation equation:

$$\Delta y_{it} = \beta_0 + \beta_1 \Delta \overline{p_{it}} + \beta_2 \Delta tax_{it} + \beta_3 \Delta tax_{it-1} + \beta_4 \Delta tax_{it+1} + Z_2 + \omega_{i\tau} \quad (3)$$

As in Equations (1) and (2), Δ stands for the first differences of the logs. The tax exclusive fuel price is denoted by $\overline{p_{it}}$ and the tax of the current, previous, and next month are denoted by Δtax_{it}, Δtax_{it-1}, and Δtax_{it+1}, respectively. Z_2 again contains the unemployment growth rate and the difference in working days of the current month compared to the previous one.

Table 4 and Table 5 summarize the results of our disentangled analysis of the tax exclusive price and the tax. The first column is provided merely for purposes of comparing these results with those of the previous approach. Column (2) shows that we observe even larger differences between consumption reactions to net price changes and consumption reactions to tax changes in the European data (cf. Table 4, Column (2)) than Li et al. (2012) found in the U.S. data. The short-run tax elasticity of –0.64 is decisively larger than the price elasticity of –0.07.

A tax elasticity of –0.64 translates into a 5% consumption reduction in the month of a 5 cent tax increase, which is a large effect. These large values confirm the results Davis and Kilian (2011) and Li et al. (2012) found for the United States. Next we check for intertemporal shifting of fuel purchases around the month of a tax change. The tax change next month and the tax change in the previous month are statistically significant and non-negligible in magnitude (cf. Column (3)). The coefficient of the tax lead depicts the anticipation effect (cf. β_4 in Equation (3)) and the lag of tax stands for the catch-up effect after a tax change (cf. β_3 in Equation (3)).

Gasoline

% change in consumption	(1)	(2)	(3)
% change in retail price	-0.211***		
	(0.071)		
% change in net price		-0.068**	-0.063**
		(0.028)	(0.028)
% change in unit tax		-0.635***	-0.837***
		(0.182)	(0.171)
% change in unit tax (lag1)			0.250**
			(0.121)
% change in unit tax (lead1)			0.373**
			(0.145)
change in working days	0.014***	0.014***	0.014***
	(0.001)	(0.001)	(0.001)
change in unemployment	-0.015***	-0.014***	-0.014***
	(0.005)	(0.005)	(0.005)
month of the year indicators	Yes	Yes	Yes
country indicators	Yes	Yes	Yes
year indicators	Yes	Yes	Yes
R^2	0.42	0.42	0.43
N	1861	1861	1849

* p<0.1; ** p<0.05; *** p<0.01

Table 4: OLS estimates for decomposed retail price—gasoline

It seems plausible that at least some consumers refuel their cars during the last few days before a tax increase comes into force. Consequently, these consumers need to buy less fuel in the month of the tax increase, independent of any changes in their consumption behavior. This means that the effect we measure in the tax-change month is a combination of less fuel purchased due to having refueled at the end of the previous month and less fuel purchased due to a change in consumption behavior. According to these results, a 1% tax increase in the next month leads to a 0.38% consumption increase in the current month. In the month of the tax change, consumption decreases by 0.84% before increasing again in the following month by 0.25%.

Diesel

% change in consumption	(1)	(2)	(3)
% change in retail price	-0.181***		
	(0.065)		
% change in net price		-0.074**	-0.071**
		(0.029)	(0.029)
% change in unit tax		-1.029***	-1.044***
		(0.211)	(0.211)
% change in unit tax (lag1)			0.371***
			(0.131)
% change in unit tax (lead1)			0.323**
			(0.152)
change in working days	0.027***	0.026***	0.026***
	(0.001)	(0.001)	(0.001)
change in unemployment	0.000	0.002	0.002
	(0.007)	(0.007)	(0.007)
month of the year indicators	Yes	Yes	Yes
country indicators	Yes	Yes	Yes
year indicators	Yes	Yes	Yes
R^2	0.46	0.47	0.47
N	1829	1781	1769

* p<0.1; ** p<0.05; *** p<0.01

Table 5: OLS estimates for decomposed retail price—diesel

Table 5 shows similar results for diesel. The tax and net price elasticities tend to be slightly higher for diesel than for gasoline. A possible explanation for this finding is that diesel is to a large extent used commercially and commercial fuel customers, such as freight carriers, might be better positioned to shift fuel purchases across time (e.g. due to having more storage capacity). However, the differences in the elasticities are not statistically significant. Based on the arguments above, we should observe smaller tax effects after aggregating the monthly data to calendar quarterly data (Jan-Mar, Apr-Jun, etc.). That is, some of the intertemporal shifts should vanish over the course of a quarter. We use the same methodology as we did for the monthly data analysis above (see Equation (3)), but omit the lag and the lead of the tax variable and replace month of the year indicators with quarter of the year indicators. As expected, the tax elasticity of consumption decreases from –0.84 (cf. Table 4: OLS estimates for decomposed retail price—gasoline) to –0.31 for gasoline and from –1.04 (cf. Table 5) to –0.50 for diesel (see column 1 and 2 in Table 6). Although aggregating to calendar quarters diminishes the anticipation effect, the tax effect is still overestimated, as more than 60% of the tax changes occur at the beginning of a quarter. Thereby the anticipation and the tax effect act in two different quarters and using quarterly data still exhibits a large tax effect driven by anticipation. Moving the calendar quarter one month forward so that the first quarter starts in December instead of January leads to a decisive reduction of the tax effect (see column 3 and 4 in Table 6). The tax effect is statistically not different from zero any more. An even more precise way of identifying the tax effect net of the intertemporal shifting is to pretend that the pre-fueling in the month before the tax change, the reduced purchases in the tax month, and the return to the pre-tax behavior in the month after the tax change all happen in one month. We implement this test aggregating over these three months[8] by averaging the consumption, tax, and net price data. We call this period the tax period. [9] By leaving the estimation methodology unchanged compared to Equation (3), except for excluding the lead and the lag of tax, we again obtain a smaller coefficient for the tax elasticity than without aggregating (cf. Table 4 and Table 5). Thus, we find that the tax elasticity is overestimated without controlling for the anticipation effect.

	Quarterly		Quarterly (shifted)		Tax period	
% change in consumption	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel
% change in net price	-0.015	0.009	-0.090*	-0.043	-0.114***	-0.044
	(0.035)	(0.028)	(0.049)	(0.035)	(0.029)	(0.033)
% change in unit tax	-0.308**	-0.503***	-0.195	-0.200	-0.296*	-0.356**
	(0.121)	(0.133)	(0.149)	(0.166)	(0.162)	(0.170)
R^2	0.52	0.45	0.71	0.74	0.37	0.23
N	614	587	623	596	1537	1476

* $p<0.1$; ** $p<0.05$; *** $p<0.01$

Table 6: OLS estimates of aggregated data.

As a robustness check we compare the OLS results with those of a feasible generalized least squares (FGLS) approach (see Table 7). Allowing for autocorrelation of the AR(1) type and heteroskedasticity across panels, we obtain similar results. The net price elasticity decreases for

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[8] In reality, this is often a period of four months since in countries such as Austria, for example, an increase in the mineral oil tax occurs in two steps over two consecutive months.

[9] The “tax period” includes the month before the tax change, the month of the tax change, and the month after the tax change.

gasoline and stays the same for diesel. For both fuel types, the net effect of the tax over the three months decreases as the purchase-reducing effect of the tax in the tax month shrinks and the anticipation and catch-up effects increase. As the results of the two methods do not differ substantially, we are confident that our results are robust.

	Gasoline		Diesel	
% change in consumption	OLS	FGLS	OLS	FGLS
% change in net price	-0.063**	-0.036**	-0.071**	-0.071***
	(0.028)	(0.018)	(0.029)	(0.020)
% change in unit tax	-0.837***	-0.699***	-1.044***	-0.952***
	(0.171)	(0.111)	(0.211)	(0.107)
% change in unit tax (lag1)	0.250**	0.277***	0.371***	0.379***
	(0.121)	(0.091)	(0.131)	(0.099)
% change in unit tax (lead1)	0.373**	0.428***	0.323**	0.402***
	(0.145)	(0.106)	(0.152)	(0.101)

* p<0.1; ** p<0.05; *** p<0.01

Table 7: Favored OLS estimates compared to heteroskedastic- and autocorrelation-robust FGLS estimates

As Davis and Kilian (2011) point out, fuel demand elasticity analyses should take into account the possible endogeneity of the price. Endogeneity could be caused by reverse causality of price and demand. If it is true that the amount of fuel consumed has an influence on its price, the price elasticity would be underestimated by a simple least squares approach. To take the possible endogeneity of the price into account we apply a two-stage least squares (2SLS) approach in the next section.

3.2 IV Estimates of Fuel Consumption

This section addresses the problem of endogeneity of the price by introducing an IV approach. The price is instrumented by a variable (or a set of variables) that is not correlated with consumption, but that is an explanatory variable for the price development. In a first step we use the unit tax on each fuel in each country as an instrument for the average monthly price of the respective fuel in the respective country. Since the tax and the retail price are strongly correlated, and given – based on Li et al. (2012) – that tax changes occur independent of changes in consumption, this could be a valid instrument. A second possible and common instrument for the fuel price and one with the same characteristics is the world price of oil. We use the spot price of Brent, but this choice is arbitrary and of no special importance as the spot prices of all reference oil grades (WTI, Brent, and Dubai crude) are highly correlated with a correlation coefficient larger than 0.95 (World Bank, 2013). For the oil price to be a valid instrument for the fuel price in the estimation of the consumption equation, consumption of gasoline and diesel should have no impact on the crude oil price, which is an assumption our data appear to support. On average, each of the observed countries account for 0.9% of the world crude oil consumption. Out of our sample countries, Ireland consumes the smallest fraction (0.07% of world consumption) and Germany the largest (2.3%) (IEA, 2013).[10] Moreover, the amount of crude oil used to produce car fuels is even less important. Considering only the use of crude oil for light- and heavy-duty vehicle fuels, Germany's fraction of 2.3% of world consumption shrinks to 1.7%.[11] Thus, from the perspective of a single country, the oil price seems to be exogenous.

Another possible instrument in the European market is the dollar exchange rate as it is an important determinant of gasoline and diesel prices in European countries since oil, as the main

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[10] The figures are for 2012 but appear represenative of the observation period. Germany consumed the biggest fraction of world consumption in the observation period in 1994 with 3.4%.

[11] These figures are from December 2012.

input for producing gasoline and diesel, is traded in U.S. dollars, but the final products are sold in national currencies. Hence, the first-stage equation is:

$$\Delta p_{it} = \gamma_0 + \gamma_1 \Delta tax_{it} + \gamma_2 \Delta oilpr_t + \gamma_3 \Delta oilpr_{t-1} + \gamma_4 \Delta oilpr_{t-2} + \gamma_5 \Delta exch\_r_{it} + \gamma_6 \Delta exch\_r_{it-1} + Z_2 + u_{i\tau} \quad (4)$$

Note that tax_{it} comprises only the exogenous tax part, that is, the excise tax and the ad valorem tax levied on the excise tax. It is independent of the level of the price. The VAT on the net price is deliberately not taken into account as it is not exogenous. For the oil price ($oilpr$) we use a monthly average of Brent since Brent is the relevant oil grade for Europe. $exch\_r$ stands for the exchange rate of each country's currency relative to the U.S. dollar.

% change in retail price	Gasoline	Diesel
% change in unit tax	0.385***	0.176***
	(0.046)	(0.049)
% change in oil price	0.148***	0.137***
	(0.007)	(0.009)
% change in oil price (lag1)	0.096***	0.097***
	(0.007)	(0.009)
% change in oil price (lag2)	0.014*	0.046***
	(0.007)	(0.008)
% change in exchange rate	0.081***	0.073**
	(0.021)	(0.033)
% change in exchange rate (lag1)	0.088***	0.115***
	(0.027)	(0.031)
month of the year indicators	Yes	Yes
country indicators	Yes	Yes
year indicators	Yes	Yes
R^2	0.45	0.29
N	2071	2122

* p<0.1; ** p<0.05; *** p<0.01

Table 8: First-stage estimates I (retail price instrumented)

In the case of the oil price and the exchange rate, we include the first lags to account for potential timing issues related to the price setting of mineral oil firms. Table 8 shows the estimates of the first stage for both fuels[12]. The second stage estimation is identical to Equation (2), except for p_{it} being instrumented as explained above. The results are shown in Table 10, in the first column of the particular fuel type results. The coefficients are similar to those of the OLS approach (compare first columns of Table 4 and 5). Before proceeding with the comparison between the OLS and the IV approach, we take a closer look at the composition of the retail price. Again we divide the retail price effect into a tax exclusive price effect and a tax effect, in order to disentangle which effect arises from a volatile and unexpected price change, and which from a persistent and expected tax change. This slightly changes the first stage. Instead of instrumenting the retail price, we instrument the pre-tax price by the oil price and the dollar exchange rate. The tax and its lag and lead are now used as explanatory variables in the second stage. Thus, our first stage finally takes the following form:

$$\Delta\overline{p_{it}} = \delta_0 + \delta_1 \Delta oilpr_t + \delta_2 \Delta oilpr_{t-1} + \delta_3 \Delta oilpr_{t-2} + \delta_4 \Delta exch\_r_{it} + \delta_5 \Delta exch\_r_{it-1} + Z_2 + u_{i\tau} \qquad (5)$$

Table 9 shows the results of our preferred specification of the first stage regression for both fuel types (see columns (1)). The respective column 2 shows the impact of tax changes on the net price for gasoline or diesel. The underlying estimation equation for the coefficients in both columns (2) is identical to equation (4) except that we replace the retail price by the net of tax price as dependent variable. The two left columns – our first stage – hint at the fact that the chosen instruments seem to be valid. Concerning the insights into the fuel oil market the two

[12] We use robust standard errors since we reject the null hypothesis that errors are homoscedastic.

right columns appear to be more interesting. As already mentioned these two columns plot the results of an extension of Equation (5).

	Gasoline		Diesel	
% change in net price	(1)	(2)	(1)	(2)
% change in oil price	0.345***	0.341***	0.260***	0.257***
	(0.016)	(0.016)	(0.019)	(0.019)
% change in oil price (lag1)	0.230***	0.228***	0.184***	0.182***
	(0.019)	(0.019)	(0.018)	(0.018)
% change in oil price (lag2)	0.036*	0.035*	0.089***	0.087***
	(0.019)	(0.019)	(0.017)	(0.017)
% change in exchange rate	0.253***	0.255***	0.164**	0.161**
	(0.052)	(0.052)	(0.066)	(0.066)
% change in exchange rate (lag1)	0.219***	0.226***	0.221***	0.233***
	(0.069)	(0.069)	(0.065)	(0.063)
% change in unit tax		-0.533***		-0.654***
		(0.108)		(0.096)
% change in unit tax (lag1)		0.078		0.003
		(0.090)		(0.097)
% change in unit tax (lead1)		0.071		-0.065
		(0.080)		(0.086)
month of the year indicators	Yes	Yes	Yes	Yes
country indicators	Yes	Yes	Yes	Yes
year indicators	Yes	Yes	Yes	Yes
R^2	0.43	0.44	0.26	0.28
N	2084	2071	2136	2122

* p<0.1; ** p<0.05; *** p<0.01

Table 9: First stage estimates II (net price instrumented)

Besides the change in tax, its lead and lag are also included as explaining variables of the fuel net of tax price. The coefficient of *% change in unit tax* indicates that mineral oil companies tend to decrease the net of tax fuel price in months of tax increases. This indicates that, at least in the very short run, mineral oil companies carry part of the tax burden.

The second stage of our 2SLS approach is:

$$\Delta y_{it} = \mu_0 + \mu_1 \Delta\widehat{p_{it}} + \mu_2 \Delta tax_{it} + \mu_3 \Delta tax_{it-1} + \mu_4 \Delta tax_{it+1} + Z_2 + \omega_{i\tau} \qquad (6)$$

The $\widehat{p_{it}}$ stands for the instrumented pre-tax price based on Equation (5).

	Gasoline		Diesel	
% change in consumption	(1)	(2)	(1)	(2)
% change in retail price	-0.222**		-0.152	
	(0.109)		(0.106)	
% change in net price		-0.040		-0.012
		(0.041)		(0.048)
% change in unit tax		-0.821***		-1.004***
		(0.173)		(0.223)
% change in unit tax (lag1)		0.371**		0.370***
		(0.144)		(0.126)
% change in unit tax (lead1)		0.380***		0.332**
		(0.145)		(0.147)
change in working days	0.014***	0.014***	0.026***	0.026***
	(0.001)	(0.001)	(0.001)	(0.001)
change in unemployment	-0.016***	-0.014***	0.000	0.002
	(0.005)	(0.005)	(0.007)	(0.006)
month of the year indicators	Yes	Yes	Yes	Yes
country indicators	Yes	Yes	Yes	Yes
year indicators	Yes	Yes	Yes	Yes
R^2	0.41	0.43	0.44	0.47
N	1847	1847	1767	1767

* p<0.1; ** p<0.05; *** p<0.01

Table 10: IV estimates

Our findings for this sample of European countries differ only slightly from previous studies, e.g. those of Davis and Kilian (2011) and Li et al. (2012) for the United States. Our tax elasticity for gasoline consumption, at –0.82, lies in the range of the results of Davis and Kilian (–0.46) and those of Li et al. (–0.77). What distinguishes our results from previous works is that we also quantify the anticipation and the catch-up effect. Li et al. (2012) and Davis and Kilian (2011) only hint at intertemporal effects.[13] By not considering the effects in the previous and the following month of a tax change, the consumption reaction to a tax change is overestimated. Therefore quantification of the anticipation effect is necessary.

[13] Li et al. (2012, p. 11).

Again, the results (see Columns 2 and 4 in Table 10) from the IV approach do not substantially differ from those of the OLS estimation (see Column (3) in Table 4 and 5). If the net price was endogenous due to a reverse causality with the consumption we would expect our price coefficient be biased towards zero in the OLS estimation. But as the price coefficient becomes even smaller in the IV estimation it is questionable whether reverse causality is an issue in our consumption and price data. As OLS is the most efficient estimator given no endogeneity problems we regard the OLS approach as our preferred model.

3.3 Anticipation Effect and Temporary Persistency of a Motor Fuel Tax

Figure 4 and 5 illustrate the change in consumption behavior prior to and after a tax change for gasoline and diesel, respectively. This graph was generated by including additional lags and leads in the OLS model (Equation (3)) and then plotting the point estimates (solid line) and the 95% confidence interval around it (dashed lines). The time of the tax change is indicated by month 0. In the observed period around a tax change, we find significant tax effects only in the month before a tax change, in the month after a tax change, and in the month of a tax change. The grey shaded area marks the period for which we do not find statistical significant coefficients for the percentage change in tax. Making more long-run-oriented statements about tax elasticities is difficult, especially with monthly macro data.

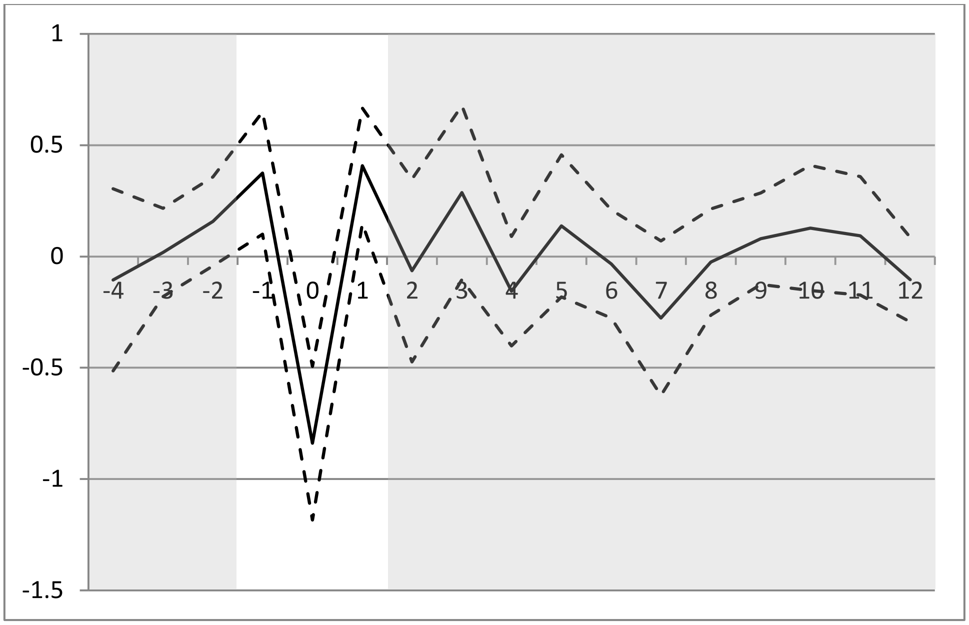

Figure 4: Development of gasoline purchases four months before and twelve months after a tax change

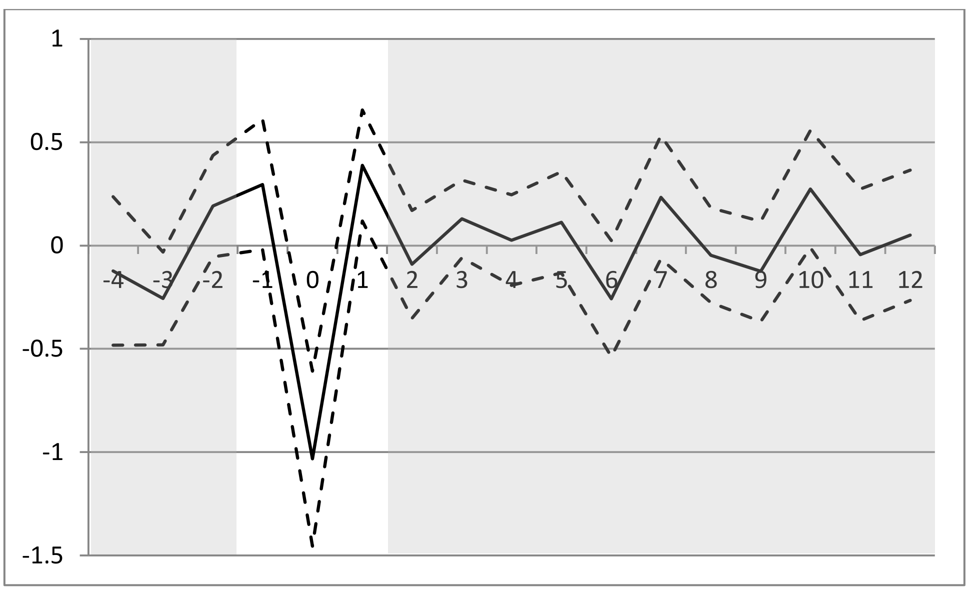

Figure 5: Development of diesel purchases four months before and twelve months after a tax change

3.4 Policy Implications

Comparing our results e.g. with those of the studies for the USA by Davis and Kilian (2011) and Li, Linn and Muehlegger (2012) we find similar elasticities. The point estimate of the gasoline demand's tax elasticity lies with −0.84 in the ballpark of the results of Davis and Kilian (−0.46) and Li, Linn and Muehlegger (−0.77). But considering a concrete absolute tax change of 10 US-cents per gallon, however, discloses the fundamental differences between the EU and the USA. A 10 US-cents increase of the gasoline tax per gallon leads according to Davis and Kilian's results for the USA to a consumption reduction of 1.4%. Imposing a 10 US-cents tax increase per gallon which equates a 1.9 Euro cents tax increase per liter in the EU would lead to 2.5% decrease of gasoline consumption and to a 4.5% decrease of diesel consumption. Although the tax elasticities look rather similar at first glance, the impact of the same absolute tax change differs a lot: on one hand between the USA and the EU, and on the other hand between gasoline and diesel consumption in the EU. These differences are due to discrepancies in the tax levels. Whereas the average gasoline tax in the USA amounts to 4.5 Euro-cents per liter the same tax in Europe averaged over the countries in our sample is more than ten times larger. The gasoline tax in Europe totals 52.5 Euro-cents and the diesel tax 37.3 Euro-cents.[14]

4. Conclusions

From our analysis of 11 European countries we draw three main conclusions. First, in analyzing short run tax elasticities of fuel demand, it is important to control for the anticipation and the catch-up effect since neglecting these two effects leads to overestimation of the tax effect. Second, the intertemporal shifting of fuel consumption only occurs in connection with tax

[14] These figures refer to the excise taxes only without VAT.

changes and not with net of tax price changes. Third, there seems to be a difference between gasoline and diesel consumption regarding the ability to shift fuel purchases over time.

The main contribution of our analysis to the existing literature in the area of fuel demand estimation is the identification of an anticipation effect. We show that vehicle drivers who expect a fuel price increase induced by a tax increase in the following month bring forward part of their fuel purchases of the next month to the extent their storage capacities allow them to do so. Consumers facing a tax increase in the next month go to the gas station one more time at the end of the current month, even if their tank is not completely empty yet. They simply want to make use of the still low retail price once more. Thereby we find an increase in the consumption or more precisely in the amount of fuel purchased by 0.37% (0.32%)[15] in the month before a 1% tax increase is implemented. In the month of the tax increase these consumers naturally have to fuel less as they have brought forward part of their usual monthly fuel purchase and this reaction has only little to do with a change in the consumption behavior. Another sign for the tax effect mainly being an intertemporal shifting effect is the result that the amount of fuel purchased rises again in the month after the tax increase. That means drivers return to their pre-tax-increase purchase behavior. The after-tax-increase effect of a 1% tax increase amounts to a 0.25% (0.37%) consumption increase. Aggregating over the entire "tax period" we do not find a statistically significant effect of the tax, leading us to conclude that considering only the consumption effect of the tax in the month of the tax increase leads to an overestimation of the tax impact. Regarding

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[15] Figures in brackets refer to diesel consumption.

net of tax price changes we do not find an anticipation effect which stands to a reason as pre-tax price changes can hardly be foreseen.

This result provides at the same time the basis for the following insight. As the large demand reducing effect of a tax increase in the month in which the legislative amendment comes into force is mainly induced by consumers shifting fuel purchases to the month before, and as we do not observe such shifting prior to net of tax price changes, we find different demand reactions to retail price changes dependent on whether they are caused by tax changes or by pre-tax price changes. This agrees with the findings of Davis and Kilian (2011), Li et al. (2012) and Rivers and Schaufele (2013). According to them, the rationale behind larger tax elasticities is that tax changes usually are announced and that they are perceived as more persistent than net of tax price changes. The price elasticities of our preferred specification are -0.06% for gasoline and to -0.07% for diesel, whereas the estimated tax elasticities are -0.84% for gasoline and -1.04% for diesel. Our interpretation of these results, however is somewhat different. We find that the announcement plays the biggest role in the difference between price and tax elasticities, and that controlling for the anticipation effect makes the estimates of tax changes and tax exclusive price changes statistically undistinguishable from each other.

The third major finding of this analysis is that diesel consumers seem to react more strongly to a tax change than gasoline consumers do. We explain this finding by the large fraction of commercial users among the diesel consumers. Firms like freight carriers might have more possibilities to shift fuel purchases over time, for example due to onsite storage capacities, whereas private users only have their car tank as storage capacity.

Another interesting finding which comes out of this study is that price and tax elasticities of fuel demand seem to be rather constant as the results for our European dataset are in the same ballpark as those from Davis and Kilian (2011) for an American dataset. Although the price and tax levels differ tremendously between the EU countries and the USA the elasticities do not vary a lot.

In our study we show the importance of taking intertemporal purchase shifting into account in estimating tax elasticities of fuel demand. Neglecting the forward-looking purchase decisions of fuel consumers leads to an overestimation of the tax impact on consumption behavior. It remains to be shown whether this finding is also valid in the US data, or whether it is merely a European phenomenon.

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6. Appendix

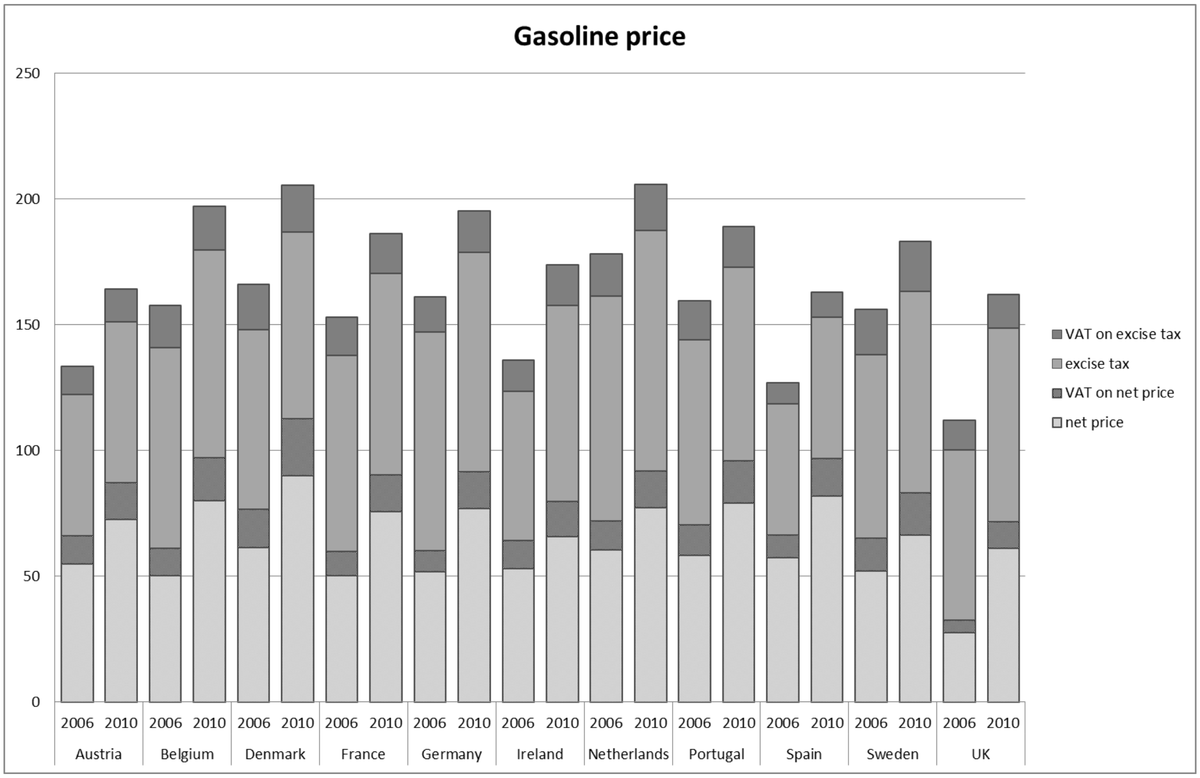

Figure 6: Gasoline retail price composition in December 2006 and 2010 (nominal values in € cents)

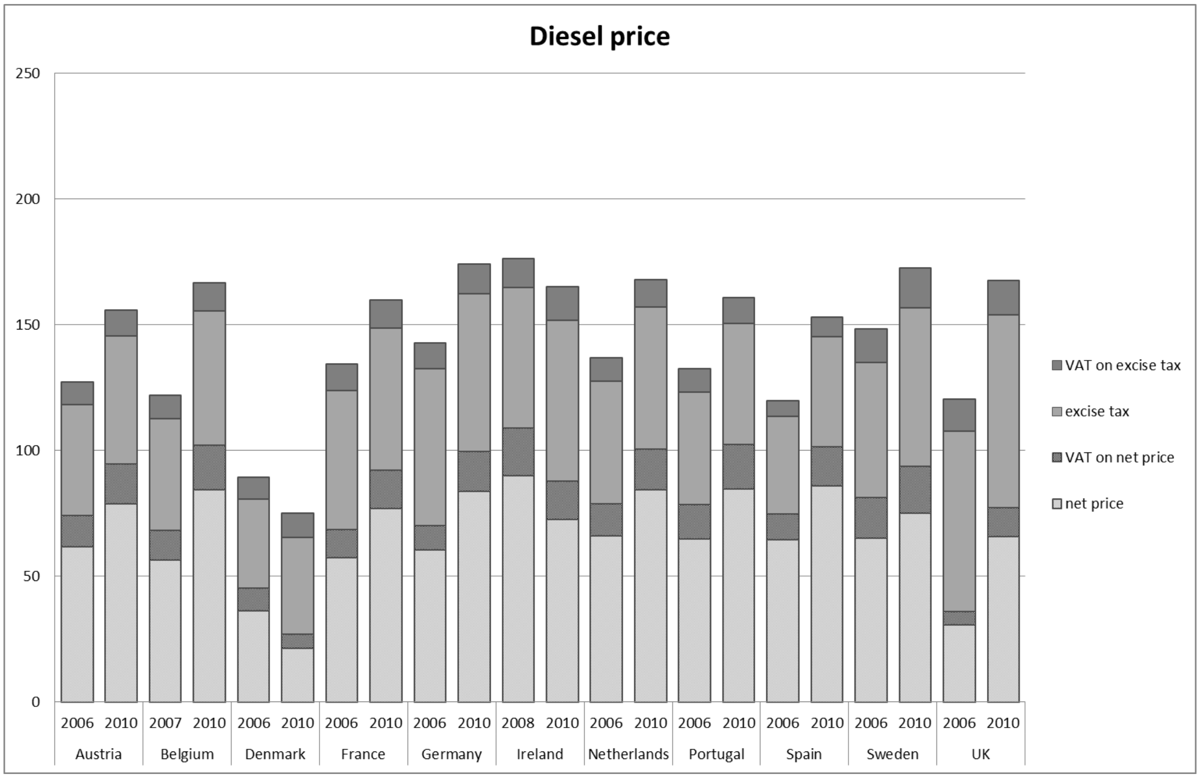

Figure 7: Diesel retail price composition in December 2006[16] and 2010 (nominal values in € cents)

[16] As the time series in Belgium and Denmark starts later, the first observation is used, which is February 2007 and February 2008, respectively.

	Time period	Consumption	Taxes	Prices
Austria	1999–2012	Federal Ministry of Economics		
Belgium	2002–2012	Federal Public Service Economy	Belgian Federation of Petrol	Europe's Energy Portal
Denmark	1990-2012	Danish Oil Industry Association		
France	1990–2012	Federal Ministry of Ecology, Durable Development and Energy	French Association of the Petrol Industry	Federal Ministry of Ecology, Durable Development and Energy
Germany	1990–2012	Federal Office of Economics and Export Control	Association of the German Petroleum Industry	ARAL, ADAC
Ireland	2002–2012	National Oil Reserves Agency	Irish Tax and Customs	Europe's Energy Portal
Netherlands	2000–2012	Statistics Netherlands		Thomson-Reuters
Portugal	1998–2012	Thomson-Reuters	Ministry of Economy	Thomson-Reuters
Spain	1990-2010	National Oil Reserves Agency	Spanish Tax Agency	Spanish Ministry of Industry, Agriculture and Tourism
Sweden	2000–2012	Swedish Petroleum and Biofuel Institute	Federal Tax Agency	Europe's Energy Portal
UK	2000–2012	Government Department of Energy & Climate Change	Government Department of Revenue & Customs	Europe's Energy Portal

Table 11: Data sources