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Cross-border competition in the gasoline retail market: Impact of proximity at the German-Polish border

Mats Petter Kahl

Leuphana University Lueneburg, Institute of Economics, Universitaetsallee 1, 21335 Lueneburg, Germany

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A B S T R A C T

In this article, I analyze how persistently lower gasoline prices in Poland affect the prices set in the German border region. Based on a complete dataset of German gasoline prices and an assessment of driving distances between gasoline stations, I estimate the impact of one additional kilometer of distance to the nearest Polish competitor on the price charged by German gasoline stations. Following the fixed effects filtered estimator approach proposed by Pesaran and Zhou (2018) and controlling for various station characteristics, I find no evidence that German gasoline stations enter price competition with their Polish counterparts. My descriptive analysis of gasoline station infrastructure in the German border region reveals increasingly sparse gasoline station density when approaching the Polish border, along with an increasing share of premium brands. These results may reflect the effect of substantially lower taxes in Poland, discouraging German gasoline stations from locating near the border and effectively ruling out cross-border price competition. Although indirect, my findings suggest the presence of fuel tourism.

1. Introduction

Price competition and spatial competition are two aspects at the center of industrial organization. Competition in the market for gasoline retailing is characterized by two essential conditions: the fact that goods are homogeneous (Haucap et al., 2015) and are perfect substitutes and the fact that the market is spatially limited, e.g., residents of Hamburg would not fuel their vehicles in Warsaw just because it is cheaper there. Moreover, the German gasoline market is characterized by price transparency, resulting from recently introduced requirements of German competition authorities. Investigating the interplay between price competition and spatial market characteristics is a continuing concern within the gasoline retail literature and depends on the availability of such granular data.

This article investigates gasoline retail competition in the German border region to Poland. German gasoline taxes are much higher than Polish taxes (Organisation for Economic Co-operation and Development, 2018b, 2018b). Research in this field is highly relevant for individual cost considerations affecting consumer utility (Michaelis, 2003; Wlazlowski et al., 2009), for fiscal reasons, as well as externalities related to resource use and pollution (Banfi et al., 2005). If German consumers drive across the border to fuel their vehicles, then the German state will lose tax revenue. Consumers put effort in terms of time and money into saving on their fuel bill by fueling in Poland, and as traffic rises, the usage of roads and related costs increase. The additional kilometers traveled increase pollution and promote climate change. The research at hand shows that German gasoline retailers do not enter into price competition with their Polish opponents and describes that the German infrastructure of retail sides becomes less dense with increasing proximity to the Polish border.

Gasoline taxes and tax changes have a direct impact on the markets, and retail fuel markets are characterized by high pass-through rates in the European Union, as has recently been shown for numerous tax changes by corresponding empirical research (Besley and Rosen, 1999; Buettner and Madzharova, 2021; Dovern et al., 2023; Drolsbach et al., 2023; Fuest et al., 2022; Kahl, 2024; Seiler and Stöckmann, 2023). In fact, Rietveld and van Woudenberg (2005) argue “that the most important source of variation in fuel prices must be taxes.” Thus, the constantly lower gasoline prices in Poland apparently result from permanently lower taxes, in contrast to higher prices in Germany’s high-tax environment. On the one hand, permanent tax differences may lead German retailers to exit the market at the border to Poland. On the other hand, spatial segregation allows for niches (such as at the border) for which Polish competition could still be expected to have a negative effect on the price.

In this paper, I compare the pricing behavior of German gasoline

E-mail address: mats.kahl@leuphana.de.

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stations at the border with Poland to the pricing behavior further inland and describe the retailing infrastructure in the German border region. I use complete data on virtually all price changes at all German gasoline stations in the border region, covering three quarters from January to September 2019. Estimating the impact of distance to the nearest Polish competitor on the price charged by German gasoline stations in the border region, I find no economically relevant effect. The distance to Polish competitors does not seem to affect the prices set by German retailers in the border region, even though there is no cost to border crossing because there are no border controls in the European Union.

To reconcile this somewhat surprising finding from the price analysis, I next suppose that gasoline retailers in Germany account for the permanent competition disadvantage near Polish competitors when deciding on where to locate their gasoline stations. Here, I focus on long-run aspects such as station density and brand composition along the border with Poland. My description of the gasoline station infrastructure reveals considerable differences between the German border region and the German interior. Gasoline station density gets increasingly sparse when approaching the Polish border, along with an increasing share of premium brands. Due to a lack of data availability, it is not possible to carry out a corresponding empirical causal analysis, and I will, therefore, leave this to future research.

To the best of my knowledge, I am the first researcher to contribute to the gasoline retailing literature on price competition and retailing infrastructure in a German border region based on the comprehensive German dataset. The German gasoline retail market is interesting because, apart from perfect price transparency, it is completely unregulated. Moreover, there are no barriers to fueling across the border, which provides an ideal setting to investigate the effects of cross-border competition. Firstly, I tie onto the literature on local competition in gasoline markets by focusing on price competition effects in the extreme setting at the Polish border. The research question is: What is the effect of "closeness to Poland" on the retail gasoline prices set in the German border region? The inquiry aims not merely at finding *whether* there is a significant effect but also at *quantifying* this possible effect.

Secondly, I address another facet of local competition regarding the decision of where to locate a gasoline station in the German border region. Specifically, I ask: how do the gasoline station density and brand composition change towards the border with Poland? For this purpose, I define gasoline station density relative to population density and rely on accurate driving time estimations. Lastly, there may be implications for a country's fiscal policy, as noted by Banfi et al. (2005), who argue that a spatial graduation of gasoline taxes could prevent consumers from fuel-tanking trips abroad ("fuel tourism").

The remainder of this paper is structured as follows: Section 2 reviews the relevant literature. I introduce my data and econometric methodology in Section 3. Section 4 presents and discusses the results, and I conclude in Section 5.

2. Literature review

Starting in the 1950s, numerous publications on competition in fuel retailing appeared. One of the first spatial investigations by Livingston and Levitt (1959) investigated competition in the retail gasoline market in the Midwest of the USA. They found that lower prices are associated with disadvantages of service station type or location, where location means traffic intensity and station density. In line with these findings and based on data from a panel study in the US, Borenstein (1991) states that margin differences are best explained by gasoline stations exercising some local market power and stations engaging in price discrimination against customers who are less likely to switch. Similarly to Borenstein (1991), Shepard (1993) finds that prices decrease with the number of nearby rivals in her investigation of competition among gasoline retailers in eastern Massachusetts. She concludes that gasoline stations exercise some local market power. Lewis (2012) studies price cycles focusing on 280 cities in the US, finding the existence of cycles in local markets in which two dominant firms are present.

Hosken et al. (2008) report substantial variation in retail margins in their analysis based on data from the US. This finding is confirmed for Germany three years later by the German Federal Cartel Office, Bundeskartellamt, arguing that "in relation to the margin, price increases in the high two-digit percent range are at stake" (Bundeskartellamt, 2011a, p. 4). This suggests that gas stations have some scope for reacting to competition.

Clemenz and Gugler (2006) analyze the local competition in Austria. They find that higher station density reduces the average gasoline price. They show that gasoline station density increases less than proportionally to population density because the implied rise in competition drives the price down, and they find that the equilibrium price and the price variation decrease with the distance to competitors. They argue that causality runs from station density to price and conclude that "spatial competition is an appropriate benchmark for judging the intensity (or lack thereof) of competition in the retail fuel market." (Clemenz and Gugler, 2006, p. 310). Another study of the Austrian market by Pennerstorfer et al. (2020) shows that a sequential search model – based on identifying the commuting share of customers – reveals an inverted U relationship between price dispersion and the share of informed (commuting) consumers. They include a variable capturing the number of competitors within a specific area around each station, showing that a station's price decreases as the number of nearby rivals increases. Although not always statistically significant, the effect points in the expected direction. They seem to be the first to use driving distance instead of the Euclidean distance, as done in the previous literature.

Triggered by the newly collected data from the German Market Transparency Unit for Fuels (MTUF), a growing number of recent papers have studied the German gasoline market. The data are made available by certain registered consumer information service providers (Bundeskartellamt, 2018). Since August 2013, fuel stations have been obliged to report price changes for the most common fuel types to the MTUF (Bundeskartellamt, 2018). This authority was created by the (Bundeskartellamt, 2018) in order to "intervene in the case of illegal predatory strategies and other forms of market power abuse."

Haucap et al. (2015) noted that extensive research on the German gasoline market was rare before 2013. Among these studies, Kihm et al. (2014) found a more substantial influence of the crude oil price on the retail price as local competition increases. They use variation in market concentration, gasoline station density, and spatial isolation from competitors to account for spatial competition. Haucap et al. (2015) provide a spatial investigation of the German gasoline market based on the novel German dataset to explain how and why retail prices differ across stations. The spatial component enters the regression in terms of driving distance to a station's single closest competitor and the number of competitors within a surrounding area defined by a critical value of either driving distance or driving time. Based on random-effects regression models, Haucap et al. (2015) find that the average retail price increases statistically significantly (at the 10 % level) with the distance to the closest competitor and decreases with the number of nearby competitors. However, the magnitude of the coefficients is minimal.

Another recent study of the German gasoline market by Neukirch and Wein (2016) focused on intraday fuel price cycles centers around the question of whether stations make use of their market power and whether there is internal and external competition between the branded chains Aral (PB), Esso (ExxonMobil), Shell, Total, and Jet (ConocoPhillips). They find that high intra-day price volatility likely reflects effective competition, while, in contrast, the uniform price setting indicates parallel behavior, hence ineffective competition. I also include variables for branded chain affiliation.[1]

Notably, the Bundeskartellamt (2018, 2011a, 2011b) analyzed the competition between retailers in the German gasoline market. The authority finalized its fuel sector inquiry by publishing a thorough report in May 2011 (Bundeskartellamt, 2011b). The objects of analysis were the four German cities of Hamburg, Leipzig, Cologne, and Munich. Three findings are of particular relevance to my study. Firstly, the highway and off-highway markets are fundamentally different since access to the highway market is restricted. License allocation was initially determined via quotas and is recently confined in part via quotas and distribution through auctions. Secondly, the diesel and the petrol retail markets are considered strictly separate markets. Together, these two findings imply that controlling for location on highways and separately analyzing petrol and diesel prices is necessary. Thirdly, a group of five branded chains jointly holds a dominating market position (Bundeskartellamt, 2011a), namely Aral, Shell, Esso, Total, and Jet.

Publications on the cross-border effects of price differentials in the gasoline market are rare. Rietveld et al. (2001) analyze the Netherlands' spatially graduated fuel tax system and conclude that such a system leads to considerable problems for gasoline station owners in this small country. Michaelis (2003) looks at the incentives of domestic car drivers to engage in fuel tourism, differentiating between limited and complete rationality. He concludes that in the case of limited rationality, even relatively small price differences induce sufficiently strong incentives for fuel tourism. Banfi et al. (2005) investigated gasoline station sales along the border of Switzerland and fuel tourism[2] from Italy, Germany, and France based on data from 1985 to 1997. They find that a decrease of 10 % in the ratio of the Swiss gasoline price to the price charged in the neighboring country yields an increase in fuel demand of 6.7 % to 7.7 %. Furthermore, fuel tourism declined from accounting for 15 % of overall gasoline sales in the three regions to about 7 % during that period. Based on these results, the authors conclude that consumers react very sensitively to price differentials in border regions and observe lower employment in gasoline retailing along with diminished fiscal revenues due to lower price differentials. The authors base their analysis on detailed quantity data, which allows them to draw specific fiscal policy conclusions. Rietveld and van Woudenberg (2005) focus on fuel tax differences across countries in Europe and find that small countries are more aggressive than large countries with respect to charging lower fuel taxes to attract neighboring countries' customers.

Based on weekly country price data from the Weekly Oil Bulletin of the European Commission, Wlazlowski et al. (2009) try to analyze the effect of unexpected changes in foreign market conditions on domestic aggregated prices. They argue that their findings may be interpreted as support for fuel tourism. Dreher and Krieger (2010) analyze European consumer and producer price convergence for diesel. They find that convergence for consumer prices is driven rather by producer price convergence than by tax convergence. Based on monthly diesel price data for a region in Spain, Romero-Jordán et al. (2013) argue that retailers in border regions with higher taxes adapt their pricing strategies to "minimize the effects of fuel tourism."

In contrast, my empirical results, which are based on very granular price data, show that German retail gasoline prices do not fall for retailers located closer to the Polish border but that the retail infrastructure is different at the border. These results are based in part on significantly more recent and more robust methodology than previous estimates, as outlined in the following section.

3. Data and econometric methodology

Of all German borders, I focus on the border with Poland for three major reasons. Firstly, the border to Poland is mainly formed by rivers (Oder and Neisse), which reduces distortion of the data through unaccounted border crossings via unofficial roads. Secondly, data on gasoline prices in neighboring countries is rare, but weekly price estimates exist for Poland. Thirdly, and arguably most importantly, I focus on Poland, among all German neighboring countries, because Polish weekly price estimates indicate systematically lower prices for petrol and diesel. Hence, if there is any cross-border competition effect on the German gasoline market, it should be found here (most extreme case); see Appendix Fig. 1.

The price difference results from differences in fuel taxes (Rietveld and van Woudenberg, 2005), illustrated in Appendix Fig. 2. Taxes are about 65 Eurocents per liter (cpl) for petrol and about 47 cpl for diesel in Germany (European Commission, 2022) and remained constant over time (Bundesministerium der Finanzen, 2018). Additionally, a value-added tax of 19 % is charged (since the beginning of the year 2007 and 16 % beforehand).[3] In contrast, taxes are about 40 cpl for petrol and about 36 cpl for diesel in Poland (OECD, 2018c).[4] Moreover, no changes in taxation occurred in Poland during the period investigated here (OECD, 2020). Other neighboring countries have higher prices for both fuel types than Poland, Appendix Fig. 3. The differences in taxes of about 14 cpl for diesel and about 28 cpl for petrol exceed the profit margins of gasoline stations by far (Haucap and Müller, 2012; Pollak, 2017).

The data collected by the MTUF are provided, among others, by tankerkoenig.de (2019) and infoRoad GmbH (2019). Information on fuel station characteristics is partly contained in the price dataset from tankerkoenig.de (2019) and supplemented manually via the websites of infoRoad GmbH (2019) and single brands, such as Aral and Shell. Mine are panel data for Germany, containing all price changes effectuated by each German gasoline station. There are numerous further variables, such as different brand categories, various measures for local competition, an approximation for input costs, some demand-side controls, and station characteristics, as illustrated in Appendix Table 1. The underlying database comprises 211 German gasoline stations observed for nine months, from January to September 2019. The number of stations per postcode area is illustrated in Fig. 1.[5]

The distances to Polish competitors and between German gasoline stations are calculated based on OpenStreetMap data. The variable of interest, "Dist. nearest Polish competitor," measures the driving distance to the closest Polish competitor. According to theory, I expect this impact on fuel prices to be positive because the competition a German retailer faces increases the closer it is to the nearest Polish competitor.

Further, local competition variables enter the regression. I estimate all driving distances between all German gasoline stations in order to identify the nearest German competitor and the number of German competitors in a predefined surrounding area. Similar to Haucap et al. (2015, p. 21), I experimented with different critical values (10 km, 5 km, 2 km, and 1 km) to define this surrounding area and found that the variable of interest is not affected by much. Due to the readily available calculation capacity, all distances are estimated driving distances based on OpenStreetMap data.

[1] Haucap et al. (2015) and Noel (2015) provide a thorough outline of distantly related literature, also covering the price cycle literature that is essentially based on the work on Edgeworth cycle theory by Maskin and Tirole (1988). This is also reviewed by the Bundeskartellamt (2011a, 2011b). However, I abstain from analyzing intra-day price-setting behavior and focus on the daily average, minimum, and maximum prices.

[2] Fuel tourism describes the phenomenon of people crossing borders in order to fuel their cars.

[3] An overview of road fuel taxes in several countries is provided by the OECD (2018a).

[4] Taxes per gigajoule (GJ) were transformed into taxes per liter using conversion factors from the webpage of the University of California Berkeley (2018).

[5] The brand composition and categorization are illustrated in Appendix Table 2.

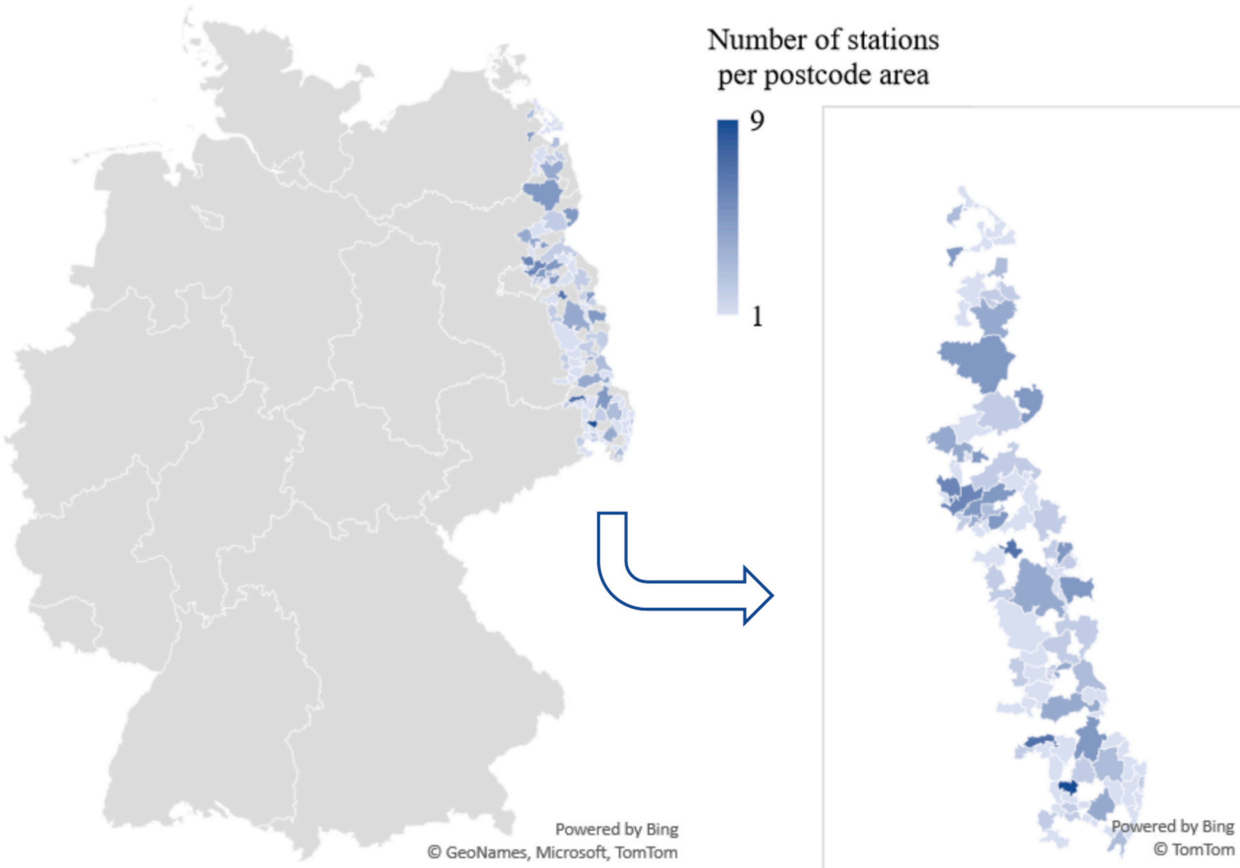

Fig. 1. Overview of the number of German gasoline stations per postcode area along the German-Polish border.

The Polish average price variable shows a weekly snapshot price based on a sample of the entire country drawn once per week. This snapshot price is applied to all days of the week.

The crude oil price is approximated by the Brent price, as is commonly done in the relevant literature, where the prices are obtained from Quandl (2019). I take the population density data from the German Federal Statistical Office, Statistisches Bundesamt (2019). These data are available at the county level (German *Kreisebene*). Average weekly prices for Germany and weekly price estimates for Poland are taken from globalpetrolprices.com (2019). The Polish weekly price estimates are entered into the regression analysis to approximate the Polish average price. The dependent variable is the German daily average price of a station based on price observations reported on the second. I refer to the weekly price estimate as the "Polish average price" for readability. Appendix Table 1 provides an overview of all variables.

Various panel data unit-root tests reveal that the average daily prices have a unit root (non-stationary). I present the results of the Maddala-Wu unit-root test (Maddala and Wu, 1999), the Im-Pesaran-Shin unit-root test (Im et al., 2003), Choi's Logit unit-root test, and Choi's modified P unit-root test (Choi, 2001) in Appendix Table 3.[6]

Since the time series likely has a unit root (is non-stationary), a first-differencing regression methodology is appropriate. Fig. 2 visualizes the average daily market price series and its first-differenced version. Panel unit-root test results reveal that the first-differenced series is stationary (Appendix Table 3).

Moreover, the price series may suffer from structural breaks. I search for breakpoints on the individual panel level following the approach of Bai and Perron (2003). For most series, the optimal number of breaks (according to the Basian Information Criterion, BIC) appears to be four. Fig. 3 visualizes the aggregated results and the breakpoints for the average daily market price.

After identifying structural breaks, one has to conduct unit-root tests for the single segments. For this, I use the structural breaks identified for the average daily market price and, therefore, implicitly assume that they are driven by common factors (such as structural breaks stemming from the crude oil price series). Maddala and Wu (1999) unit-root test results reveal (Appendix Table 4) that the average prices are non-stationary, while the first-differenced prices are stationary in all segments. Thus, accounting for structural breaks and transforming the data to deal with non-stationarity appears to be the best strategy for regression analysis. The model can be formalized as:

$$p_{it} = \beta_0 + \beta_1 DIS_i + \beta_2 PAP_t + \beta_3 CO_t + \beta_4 x_i + \beta_5 WEH_t + \beta_6 S_t + \varepsilon_{it} \quad (1)$$

where p_{it} represents station i's average (minimum or maximum) daily retail price (for petrol or diesel) at time t, DIS_i is station i's distance to the closest Polish competitor, and PAP_t represents the Polish average weekly price at time t. The CO_t gives the crude oil price at time t, x_i represents a vector of all time-invariant, station-specific control variables as well as population density. WEH_t is a vector of dummy variables to control for particular days of the week, public holidays etc. The βs are the coefficients to be estimated, where β_0 is the constant. The ε_{it} is the error term, expressed as $\varepsilon_{it} = \mu_i + u_{it}$, which consists of an individual-specific time-invariant part, μ_i, and an idiosyncratic error that changes both over time and across space, u_{it}. A segment indicator S_t is added to most specifications.

The first difference approach can be formalized as:

$$\Delta p_{it} = \beta_1 \Delta PAP_t + \beta_2 \Delta CO_t + \beta_3 \Delta WEH_t + \beta_4 \Delta S_t + \Delta u_{it} \quad (2)$$

[6] The unit-root tests proposed by Levin et al. (2002) and Hadri (2000) require balanced panels and are therefore not included.

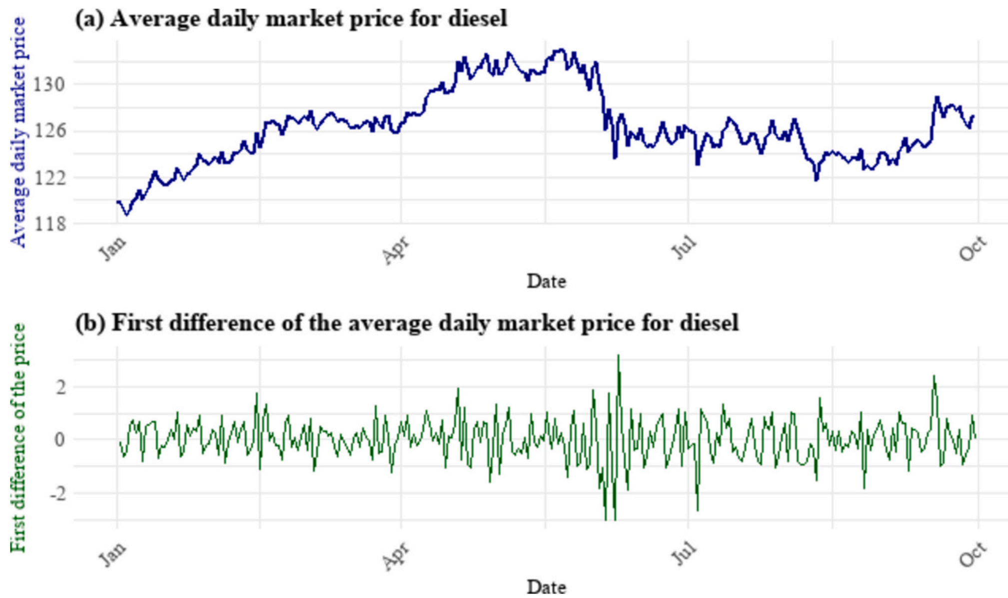

Fig. 2. The German average daily market price for diesel in panel (a) and its first differenced version in panel (b) from January to September 2019.

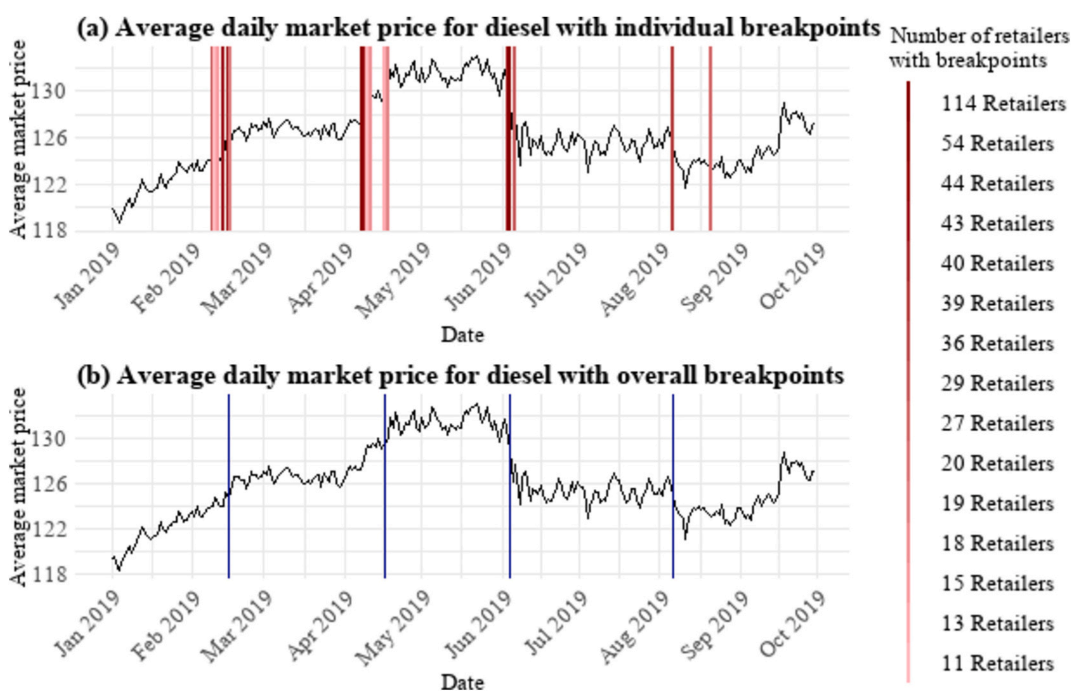

Fig. 3. Aggregated breakpoints of the price series of individual retailers in panel (a) and the structural breakpoints of the average daily market price for diesel in panel (b). The German diesel price data covers the period from January to September 2019.

where the variables are defined as above. The first differences are formalized with a capital delta, hence, $\Delta p_{it} = p_{it} - p_{it-1}$. First differencing removes entity-specific time-invariant variables and unobserved heterogeneity. Thus, the error term is simply u_{it}.

Moreover, it might be necessary to include lags because responses to changes in the crude oil price or the Polish average price may occur with some time lag. Then, including lags into eq. (2) yields:

$$\Delta p_{it} = \beta_1 \Delta PAP_t + \beta_2 \Delta PAP_{t-k} + \beta_3 \Delta CO_t + \beta_4 \Delta CO_{t-k} + \beta_5 \Delta WEH_t + \beta_6 \Delta S_t + \Delta u_{it} \tag{3}$$

with k denoting the lag number. I include specifications up to the fourth lag because the fifth lag is usually statistically insignificant. As known from previous research, lag selection based on information criteria results in"extremely long - and seemingly implausible – lag orders" (Frondel et al., 2016).

The structural breaks in the average daily price series might partly be driven by structural breaks in the crude oil price that I present in Fig. 4. Indeed, taking the average daily price minus the crude oil price mitigates the structural break issue of the series, as test results following Bai and Perron (2003) show (Appendix Table 5). However, other factors seem to contribute to the structural breaks because the crude-oil-transformed average daily market price also has relevant structural breaks, as visualized in Fig. 5.

First-difference regression accounts for unobserved heterogeneity on the entity level. However, this approach cannot be used to estimate the

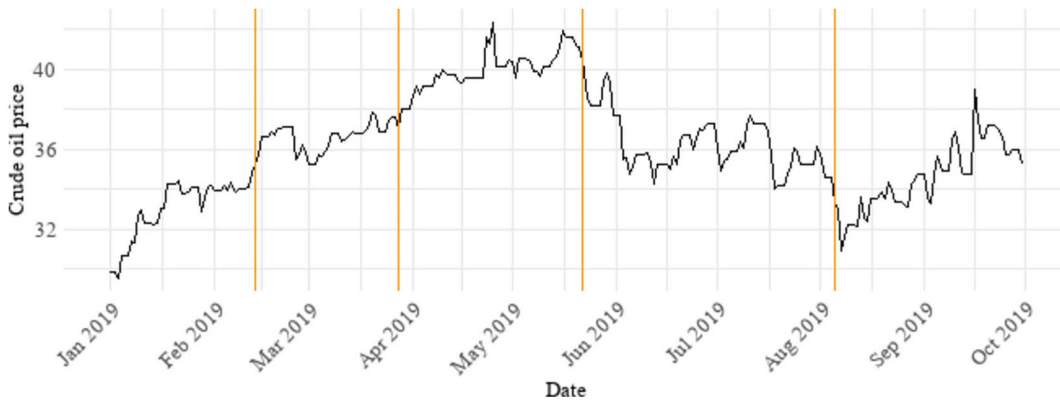

Fig. 4. The Crude oil price and its structural breakpoints from January to September 2019.

coefficients of entity-specific time-invariant factors, such as the distance to the nearest Polish competitor.

In accordance with the panel data and the objective of identifying the effect that distance to Poland has on the price set by a German gasoline station, I implement the two-stage approach proposed by Pesaran and Zhou (2018). In the first stage of this "fixed effects filtered estimator" (FEF), fixed effects estimates are computed for the coefficients of time-varying regressors to filter out the time-varying effects. In the second stage, the time-averaged residuals from the first stage are used in a cross-section OLS regression that includes an intercept and the vector of time-invariant independent variables. Pesaran and Zhou (2018) argue that this approach performs well in the presence of residual serial correlation and is consistent in the presence of individual-effect heteroskedasticity. Formalizing my panel data model with time-invariant effects following the notation of Pesaran and Zhou (2018) yields:

$$p_{it} = \alpha_i + z'_i\gamma + x'_{it}\beta + \varepsilon_{it}, i = 1,2,\ldots,N; t = 1,2,\ldots,T \tag{4}$$

where:

$$\alpha_i = \alpha + \eta_i \tag{5}$$

and where x_{it} is a $k \times 1$ vector of time-varying variables, and z_i is a $m \times 1$ vector of observed entity-specific variables (such as the distance to the nearest Polish competitor). The price of German gasoline retailers, p_{it}, is governed by the observed (z_i), and the unobserved entity-specific effects, α_i. The entity-specific effects may consist of a common part, α, and an entity-varying part, η_i. My research question aims at estimation and inference on an entity-specific variable that is contained in z_i, hence, at estimating γ.

Under the assumption that the ε_{it} and the x_{it} are uncorrelated over entities and time, β can be consistently estimated under fairly general assumptions on the distribution of the fixed effects α_i and the temporal dependence and cross-sectional heteroskedasticity of ε_{it} (Pesaran and Zhou, 2018). Let $\widehat{\beta}$ denote the fixed effects estimator of β, and let $\overline{p}_i$ result from averaging across t; then, the γ can be estimated by the regression of $\overline{p}_i - \widehat{\beta}\overline{x}_i$ on z_i and an intercept. The resulting estimator is denoted $\widehat{\gamma}_{FEF}$ and called the fixed effects filtered (FEF) estimator of γ. It can be estimated using the following two-step procedure.

The first step of the FEF approach proposed by Pesaran and Zhou (2018) is as follows[7]:

$$p_{it} = \widehat{\beta}' x_{it} + \widehat{u}_{it} \tag{6}$$

where $\widehat{\beta}$ denotes the fixed-effects estimator of β and the associated residuals $\widehat{u}_{it}$ are defined by:

$$\widehat{u}_{it} = p_{it} - \widehat{\beta}' x_{it}. \tag{7}$$

In the second step, the time averages of these residuals are computed:

$$\overline{\widehat{u}}_i = \frac{1}{T}\sum_{t=1}^{T}\widehat{u}_{it}. \tag{8}$$

And these averaged residuals $\overline{\widehat{u}}_i$ are regressed on z_i with an intercept to obtain estimates of the desired coefficients, $\widehat{\gamma}_{FEF}$:

$$\widehat{\gamma}_{FEF} = \left[\sum_{i=1}^{N}(z_i - \overline{z})(z_i - \overline{z})'\right]^{-1}\sum_{i=1}^{N}(z_i - \overline{z})(\overline{\widehat{u}}_i - \overline{\widehat{u}}), \tag{9}$$

and

$$\widehat{\alpha}_{FEF} = \overline{\widehat{u}} - \widehat{\gamma}'_{FEF}\overline{z}, \tag{10}$$

where:

$$\overline{\widehat{u}} = \frac{1}{N}\sum_{i=1}^{N}\overline{\widehat{u}}_i. \tag{11}$$

Pesaran and Zhou (2018) attribute the idea of using fixed-effects residuals for consistent estimation of coefficients of entity-specific time-invariant variables to an established literature pioneered by Hausman and Taylor (1981).

Desired coefficients include those of single brand effects, local competition, services offered, and further retailer-specific characteristics. To answer my research question, I pay special attention to the distance to the nearest Polish competitor coefficient. To explore and capture potential nonlinear effects of distance to competitors, I employ polynomial regression techniques. Specifically, I include quadratic and cubic versions of distance measures as commonly done in research related to spatial economics (Agrawal (2015), Brinkman and Mok-Lamme (2019), Kolay and Tyagi (2018)).[8]

I also introduce an interaction term between distance to the nearest Polish competitor and the Polish average weekly price (hereafter simply "interaction term"). Further robustness checks include changing the dependent variable from daily average prices to maximum or minimum daily prices. Furthermore, I consider a 13-h day, from 7 a.m. to 8 p.m., because more than 90 % of the gasoline stations are open during this period. This alternative specification of the day prevents distortion caused by different market constellations in the late evening and early

[7] The notation is widely adopted from Pesaran and Zhou (2018), and since there is no R package, I implemented the FEF myself in R.

[8] I pay careful attention to the adjusted R^2 when adding polynomials.

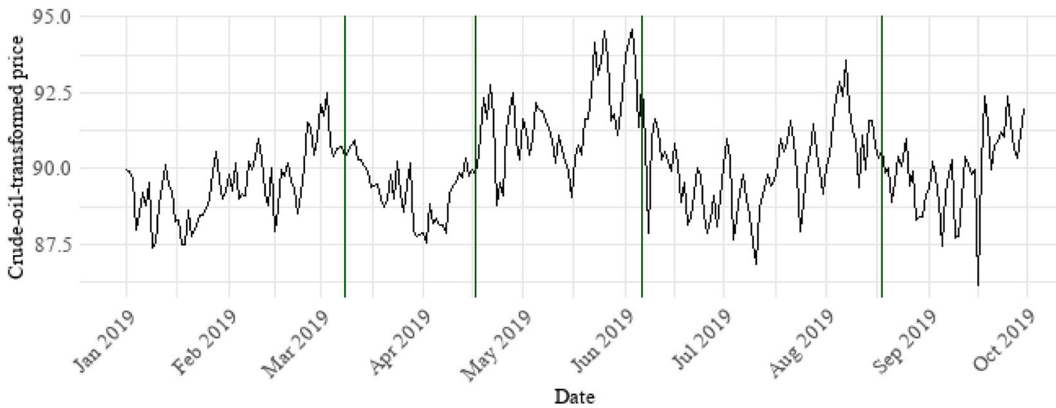

Fig. 5. The average daily market price for diesel, adjusted based on the crude oil price ("crude-oil-transformed"), from January to September 2019.

morning hours. I focus solely on the two most common fuel types, namely diesel and 95 octane unleaded petrol, called "*Bleifrei Super E5*" in Germany (hereafter referred to as petrol).

Robust standard errors á la Driscoll and Kraay's SCC (Driscoll and Kraay, 1998) that account for heteroskedasticity, autocorrelation, and cross-sectional dependence are used for inference.[9] SCC standard errors are estimated for first-difference approaches because the FEF approach is consistent with respect to autocorrelation and heteroskedasticity.

The distance is modeled as being independent of time. Hence, the driving distance variable is used instead of the driving time variable. The driving time may vary substantially, e.g., late evening compared to rush hour or weekday compared to Sunday; however, the data are unavailable for different daytimes.

Regarding distance from the border, I divided all gasoline stations into four zones. Zone A contains all gasoline stations with a driving distance of no more than 15 km to the nearest Polish competitor; zone B includes all stations with a driving distance of more than 15 km but no more than 30 km to the closest Polish competitor. Analogously, zone C contains the stations with a 30-45 km distance, and zone D includes the remaining stations with a distance of up to 60 km from the nearest Polish competitor. I conduct regression analysis to estimate the pricing behavior by zone and continue analyzing the different zones' gasoline station infrastructure and brand composition.

When analyzing the gasoline station infrastructure, I calculate the population density for all postcode areas and assign it to each German gasoline station. I then calculate each zone's average population density and other local competition variables. Subsequently, I put the population density in relation to the number of gasoline stations in the different zones, obtaining a measure for the number of people per square kilometer and gasoline station.

Clemenz and Gugler (2006) show that gasoline station density increases less than proportionally to population density. They argue that competition drives the price down. This means that the number of gasoline stations increases less than proportionately with the population density. Therefore, I compare the number of stations relative to population density for various distances to Poland. Moreover, I describe how premium brand dominance changes with the distance to Poland using the zones defined above. For that, I consider the brand chains (namely Aral, Shell, Esso, and Total). However, I use the usual brand controls for regression analysis. In addition, I compare the average number of price changes per day in order to provide another estimate for competition activity in the different zones.

[9] Clustering yields less restrictive significance requirements and is less robust, as discussed by Driscoll and Kraay (1998).

4. Results and discussion

For the sake of simplicity and since the results for petrol are almost identical, I will discuss mostly the results obtained for diesel data in the text and move the regression results for petrol to the Appendix.[10] Table 1 displays the FEF regression results obtained for the diesel data.[11] The dependent variable is the average residuals from the fixed effects regression of the average daily price reported by German gasoline stations in the border region, considering the average of the prices reported over the whole 24-h day cycle.

The overall results are presented in the first column, followed by zone-specific results in the columns to the right. Zone A contains all gasoline stations no more than 15 km away from their nearest Polish competitor; zone B includes all stations more than 15 km and up to 30 km away; zone C consists of all stations more than 30 km and up to 45 km away; and zone D all stations between 45 km and 60 km away.

The FEF results for all zones indicate that there is no economically relevant effect of "distance to the nearest Polish competitor," though statistically significant at the 5 % confidence level. According to the coefficients, the price is, on average, about 0.05 cpl lower for retailers located one kilometer further away from the nearest Polish competitor, while the non-linear coefficients are negligible.

For zone A, there is a small economic effect of 1 cpl higher prices for retailers located 1 km further inland that is statistically significant at the 10 % confidence level. The quadratic coefficient, which is statistically significant at the 5 % confidence level, indicates that this effect is decreasing in the distance to Poland. Though statistically significant, the cubic coefficient is economically negligible. Overall, the zone A specification is sensible to changes in the functional form, has a low adjusted R^2, and is statistically insignificant. For petrol prices, estimation of the more complex model was achievable and led to insignificant "distance to the nearest Polish competitor" coefficients. Thus, the distance to Polish competitors does not significantly impact the residuals and, hence, the price of German retailers in the border region. In short, based on the analysis so far, distance to the nearest Polish competitor has no economically relevant impact on prices in the German border region.[12]

In line with previous research (e.g. Kleineberg (2020), Haucap et al. (2015)), the highway coefficient is positive. It is statistically significant at the 10 % confidence level overall and of a low magnitude, which is likely due to the small number of highway retailers in the sample

[10] Average daily petrol prices over the whole period of nine months are illustrated in Appendix Figure 4.

[11] Descriptive statistics for the data underlying Tables 1 to 3 are presented in Appendix Table 6. Descriptive statistics for the single zones are moved to Appendix Tables 7–10.

[12] The results are robust to changing the first-stage model to a first-difference approach rather than fixed effects.

Table 1
FEF regression for diesel.

Dependent variable: *Residuals of the FE Stage*					
	FEF - All Zones	FEF – Zone A	Zone B	Zone C	Zone D
Dist. Nearest Polish competitor (DNPC)	−0.0535** (0.0232)	0.9684* (0.5092)	6.7051 (7.8126)	4.3274 (2.9132)	0.3428 (7.6916)
$DNPC^2$	0.0021** (0.0009)	−0.1420** (0.0683)	−0.2815 (0.3205)	−0.1138 (0.0778)	−0.0134 (0.1479)
$DNPC^3$	−0.00002** (0.00001)	0.0062** (0.0028)	0.0039 (0.0043)	0.0010 (0.0007)	0.0001 (0.0009)
Dist. nearest Ger. Competitor (DNGC)	−0.0909** (0.0424)	0.3132 (0.2633)	0.6649 (0.3895)	−0.0814 (0.0833)	0.0097 (0.0935)
$DNGC^2$	0.0105* (0.0056)	−0.0757 (0.0528)	−0.0928* (0.0514)	−0.0012 (0.0146)	0.0023 (0.0147)
$DNGC^3$	−0.0004** (0.0002)	0.0042 (0.0027)	0.0031* (0.0016)	0.0003 (0.0007)	−0.0001 (0.0006)
No. German comp. in 10 km	0.0028 (0.0165)	0.0483 (0.0885)	0.1415 (0.1034)	−0.0010 (0.0258)	0.0296 (0.0302)
Highway	0.3251* (0.1830)		1.2810* (0.7018)		0.9272*** (0.2359)
National road	0.2769* (0.1438)		−1.0763 (0.6779)		0.1011 (0.2250)
Population density	−0.0001 (0.0002)	−0.0006 (0.0007)	−0.0011 (0.0015)	−0.0006 (0.0004)	−0.0002 (0.0004)
Agip	0.4530** (0.1847)		−0.7237 (0.7465)		0.0777 (0.3553)
Aral	0.0138 (0.1279)	0.2043 (0.3500)	0.0657 (0.5097)	0.0794 (0.1344)	0.2307 (0.1795)
AVIA	0.2619 (0.2370)		−1.4431 (0.8710)		0.5481 (0.4888)
Esso	0.2799* (0.1683)	−0.0490 (0.4147)	−0.9954 (0.7858)	−0.0910 (0.2184)	−0.0376 (0.2532)
SB	−0.0773 (0.1563)		0.0268 (0.5708)		−0.1863 (0.2887)
GO	0.1469 (0.2265)				−0.0242 (0.4454)
GULF	0.2717 (0.2387)		−1.1804 (0.7448)		
HEM	0.1116 (0.2117)				0.1488 (0.3294)
JET	−0.0045 (0.2153)		0.8805 (0.8506)		0.5811* (0.3327)
Supermarket	−0.1209 (0.1742)		−0.1880 (0.5768)		0.0908 (0.5106)
OIL	0.7321*** (0.2101)		−0.9916 (0.9085)		−0.8939** (0.3360)
Shell	0.1946 (0.1510)	0.5883 (0.5310)	−0.8572 (0.7526)	−0.0277 (0.1232)	−0.2644 (0.2509)
Sprint	0.1809 (0.2132)				0.1147 (0.2902)
STAR	0.1266 (0.1627)		−0.3598 (0.7521)		−0.2035 (0.2219)
Total	0.1288 (0.1496)	−0.0898 (0.3831)	−0.3616 (0.5670)	0.0434 (0.1506)	0.0706 (0.1954)
Shop	−0.1262 (0.1333)				
Truck	−0.1278* (0.0751)				
Bistro	0.0979 (0.1075)				
Baking station	−0.0878 (0.1176)				
Shower	−0.1387 (0.1790)				
Vacuum cleaner	−0.0302 (0.1045)				
ATM	0.1095 (0.0857)				
Pressure washer	−0.0536 (0.1247)				
Car wash	−0.0835 (0.0803)				
Tire pump	−0.1591 (0.1171)				
Restaurant	−0.1854 (0.2174)				
Service station	0.1623 (0.1103)				
Credit card	0.1059 (0.1388)				
Service index		0.0174 (0.0733)	0.0993 (0.1118)	−0.0470* (0.0233)	0.0552 (0.0345)
Constant	0.3447 (0.2160)	−2.4049* (1.3634)	−53.6015 (63.0972)	−53.7722 (36.0580)	−0.2442 (132.9485)
Observations	202	37	35	52	71
R^2	0.2527	0.3672	0.7440	0.3707	0.5102
Adjusted R2	0.0785	0.0096	0.2088	0.1555	0.2381
Residual Std. Error	0.3929 (df = 163)	0.6805 (df = 23)	0.4765 (df = 11)	0.2874 (df = 38)	0.4127 (df = 45)

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. In some subsample model specifications, some coefficients likely cannot be estimated due to collinearity issues.

($n_{highway} = 8$). I find a statistically significant (at the 1 % confidence level) highway coefficient of about 0.93 cpl for zone D. The results for petrol are very similar.

The entity-specific time-invariant variables regarding local competition in Germany and population density play a negligible role (over all zones). Only the coefficient of the distance to the nearest German competitor is statistically significant at the 5 % confidence level. In line with economic intuition, it indicates that a competitor that is 1 km closer is associated with a price that is, on average, 0.09 cpl lower. The coefficient of the number of German competitors is insignificant.[13]

Single brands and services offered play a role in some geographically defined areas for some fuel types. However, accounting for non-stationarity and structural breaks leads many brand coefficients to be insignificant. The explicitly modeled brands are compared to all other retailers, which are the independent gasoline stations for a specification that contains all single brand dummies.[14]

The first-stage results of the fixed effects regressions underlying Table 1 are presented in Appendix Table 11. The R^2 and adjusted R^2 values of about 0.68 indicate a good model fit in the first stage (the fixed effects regression), which is highly statistically significant overall. However, the adjusted R^2 value of the "all zones specification" of the second stage (ordinary least squares regression), where the dependent variable is the average residuals from the first stage, indicates that the model explains only a modest proportion of the variance in these average residuals. Moreover, the adjusted R^2 value of the zone A specification for the diesel market is tiny, suggesting that the model does not capture much meaningful variance in the dependent variable. This can be due to the small sample size or overfitting. Results for the petrol market are very similar to those for the diesel market overall.

[13] Changing the critical value of the perimeter from 10 km to 5 km, or 2 km, leaves the coefficient small and insignificant. When lowering the perimeter value to 1 km, it is +0.1773 and statistically significant at the 5 % confidence level (p-value = 0.03), and the distance to the nearest German competitor coefficients is insignificant.

[14] The term "independent gasoline stations" refers to all gasoline stations not named explicitly. This group consists mainly of very small groups of retailers with only one or two gasoline stations. They are named *Others* in the descriptive statistics and omitted in the regression analysis to avoid the dummy variable trap.

I present the regression results of the first difference approach in Table 2. The first column with coefficients contains the results of the specification with all zones. To the right is the according version with the interaction term and accounting for the structural breaks. Further to the right are the results of the single-zone specifications. The Polish average price has no significant effect on the prices set by German gasoline stations in the border region; neither do the lags. According to the Wald test, the Polish average price and its lags are not jointly significant.[15]

The first, second, and third lags of the crude oil price are all individually significant at a 5 % or 1 % confidence level and show that retail prices increase following a crude oil price increase. The Wald test indicates that the crude oil price and its lags have a statistically significant joint effect on the average daily prices set in the German border region.[16] The joint effect of a 1 cpl crude oil price increase on the average daily diesel price in the German border region is about 0.79 cpl, when restricting the analysis to include up to four lags (four days). This corresponds to findings from previous studies with slightly higher retail price adaption to changes in the crude oil price in the long run (e.g. Asane-Otoo and Dannemann (2022), Gurgur and Kilinc (2016), Haucap et al. (2017)).

From Tuesdays to Saturdays, diesel prices are, on average, 0.20 to 0.27 cpl lower than on Mondays. This effect is statistically significant at the 5 % confidence level and the 10 % confidence level for Wednesdays. There are, on average, 0.31 cpl and 0.58 cpl higher prices on Sundays and Holidays, respectively. The day-of-the-week coefficients are similar over the various specifications, although not statistically significant in some subsample analyses.

The interaction term between the Polish average price and the distance to the nearest Polish competitor is insignificant. The interaction term is statistically significant at the 10 % confidence level for zone A, indicating that the effect of the Polish average price on the price of a German retailer decreases by 0.013 cpl for every kilometer by which the distance to the nearest Polish competitor is greater. Overall, the results are very similar for the petrol market, as shown in Appendix Table 17.

In Table 3, I present first-difference regression results for single structural segments as well as controlling for segments. The Polish average price still has no statistically significant effect overall. However, there seem to be periods (specifically in segments 3 and 4) in which there was a statistically and economically significant positive relation.[17] Thus, a higher Polish average price implied a higher German average price. In contrast, this relationship was negative in other periods but economically weaker. The crude oil price coefficients remain statistically significant and economically relevant for all specifications and, as expected, are positive.

The day-of-the-week coefficients vary over the different segments. In most specifications, the Sunday coefficient is statistically and economically significant and indicates a 0.32 to 0.49 cpl higher price compared to Mondays. Similarly, prices appear to be higher on holidays; however, estimation of holiday effects was not feasible in segments with few or no holidays. The segment coefficients indicate that all segments but segment 4 are significantly different from segment one (the base).

So far, the analysis has been based on daily average prices over a 24-h cycle. For robustness, I estimated further regression specifications, including estimations based on minimum and maximum daily prices and analysis based on price data over a 13-h cycle, ranging from 7 a.m. to 8 p.m. Results are shown in Appendix Tables 12 and 13 for estimation of the FEF model and the FD model, respectively.

The shorter 13-h day cycle was considered because more than 90 % of gasoline stations open at 7 a.m. and do not close before 8 p.m. The market composition, and especially the local competition networks, changes tremendously during night hours. However, the coefficient of interest, measuring the effect of distance to the nearest Polish competitor on the prices set in the German border region, does not change notably; neither do any other coefficients. This result also holds when I use the daily minimum or maximum prices instead.

Analogous robustness checks for the first difference regression are provided in Appendix Table 13. There are no notable changes with respect to the Polish average price coefficient; it is still insignificant. The Sunday and holiday coefficients are always as expected, except for the Sunday coefficient in the specification with the maximum daily price, which is insignificant. Overall, the above results are robust.[18] Appendix Tables 15 to 18 present results analogous to Tables 1 to 3 but for the petrol market. The results are very similar to those for the diesel market.

Above, I showed that very different taxes exist on both sides of the border, but my results indicate that German retailers do not enter into cross-border price competition with their Polish opponents. Hence, there is no competition in the short run. This result is not surprising because substantial tax differences between Poland and Germany disable German gasoline stations from competing with their Polish competitors even if they were to reduce their prices to marginal costs.

However, tax rates are relatively rigid over time, and accordingly, retailers may internalize the difference in long-term decisions, e.g., where to locate a gasoline station. Therefore, I now analyze this impact on long-term competition parameters and present the results along with further short-run variables in Table 4.

The first row shows the absolute number of gasoline stations per zone.[19] The second row presents the average population density, calculated based on the population density of all stations in the zone.

In the third row, I take the ratio of the population density to the number of gasoline stations in the respective zone, which can be interpreted as the average number of people per square kilometer and gasoline station. Thus, it is a measure of station density. It varies substantially over the zones, with about 6 in zone A, about 3.9 in zone B, about 4.7 in zone C, and about 3.4 in zone D. Put differently, there are 55.59 % more people per gasoline station and square kilometer in zone A than in zone B. Similarly, there are about 28.36 % more people in zone A than in zone C and approximately 76.03 % more than in zone D. Overall, there are more people per square kilometer and gasoline station in proximity to the border. Put differently, there are fewer gasoline stations near the Polish border. This lack of infrastructure might point to a considerable amount of fuel tourism.

Clemenz and Gugler (2006) analyzed the local competition in Austria and found that gasoline station density increases less than proportionally to population density. I also obtained this finding based on my data. I calculate the population density for all postcode areas and relate it to the number of stations in each area. I provide a visualization in Appendix Fig. 5. I fitted several trends with various functional forms to the scatter plot, of which the quadratic relation fits the data best.[20] This graph suggests a bell-shaped relation between population density and the number of stations with fewer retailers in sparsely and densely populated areas.

Zone A is neither dense nor sparsely populated (as shown in line two of Table 4) and still exhibits fewer retailers relative to the population density than the other zones. Put differently, since higher population

[15] The Wald test statistic is 5.99 with 5 degrees of freedom and a *p*-value of 0.3074.

[16] The Wald test statistic is 35.05 with 5 degrees of freedom and a p-value below 0.0000.

[17] The exact structural break dates are printed in bold font in Appendix Table 5.

[18] Additional statistical tests for the diesel dataset are shown in Appendix Table 14, such as tests for cross-sectional dependence, serial correlation in the idiosyncratic errors, etc.

[19] There are two retailers in zone A, one retailer in zones B and C, and four retailers in zone D, all located on a highway.

[20] Goodness of fit is based on the adjusted R^2, which is 0.2247 for the quadratic, 0.2239 for the cubic, and 0.0849 for the linear regression lines.

Table 2
FD regression of average daily price (24 h) for diesel.

	Dependent variable: Daily Average Price					
	FD - All Zones	FD with Interaction	FD - Zone A	FD - Zone B	FD - Zone C	FD – Zone D
Polish average price (PAP)	−0.0533 (0.1314)	−0.0783 (0.1284)	0.0468 (0.1320)	−0.0136 (0.3106)	−0.2439 (0.4263)	0.2725 (0.4883)
First lag of PAP	0.1049 (0.0927)	0.1457* (0.0782)	0.2306** (0.1065)	0.1507 (0.0967)	0.1294* (0.0727)	0.1124 (0.0898)
Second lag of PAP	0.1091 (0.1018)	0.1118 (0.0982)	0.1410 (0.1122)	0.1033 (0.1027)	0.1460 (0.1053)	0.0772 (0.1076)
Third lag of PAP	0.0032 (0.0792)	−0.0033 (0.0809)	−0.0027 (0.1019)	0.0394 (0.0785)	−0.0207 (0.0836)	−0.0121 (0.0932)
Fourth lag of PAP	−0.0855 (0.1287)	−0.0893 (0.1275)	−0.2181* (0.1203)	−0.0726 (0.1117)	−0.1111 (0.1332)	−0.0142 (0.1575)
Crude oil price (COP)	0.1011 (0.0618)	0.0599 (0.0587)	0.1198* (0.0658)	0.0811 (0.0650)	0.0209 (0.0631)	0.0493 (0.0653)
First lag of COP	0.1912** (0.0802)	0.1799** (0.0796)	0.1807** (0.0835)	0.1785** (0.0772)	0.1575* (0.0854)	0.1973** (0.0845)
Second lag of COP	0.2988*** (0.0782)	0.2377*** (0.0726)	0.2906*** (0.0772)	0.2752*** (0.0749)	0.2560*** (0.0759)	0.1797** (0.0767)
Third lag of COP	0.1530*** (0.0580)	0.1484** (0.0580)	0.1259** (0.0573)	0.1279** (0.0583)	0.1296** (0.0593)	0.1844*** (0.0688)
Fourth lag of COP	0.0472 (0.0779)	0.0370 (0.0768)	0.0767 (0.0874)	0.0529 (0.0741)	0.0277 (0.0744)	0.0152 (0.0828)
Tuesday	−0.2019** (0.0796)	−0.2060*** (0.0796)	−0.1748* (0.0896)	−0.1659** (0.0794)	−0.2865*** (0.0925)	−0.1794** (0.0841)
Wednesday	−0.2263* (0.1257)	−0.1468 (0.1130)	−0.0960 (0.1272)	−0.1207 (0.1118)	−0.2499** (0.1212)	−0.1060 (0.1236)
Thursday	−0.2440** (0.1191)	−0.2303* (0.1274)	−0.1919 (0.1454)	−0.1940 (0.1394)	−0.2902** (0.1345)	−0.2203* (0.1319)
Friday	−0.2705** (0.1135)	−0.2570** (0.1175)	−0.1471 (0.1250)	−0.1871 (0.1154)	−0.3211** (0.1297)	−0.2962** (0.1292)
Saturday	−0.2375** (0.1002)	−0.2286** (0.1007)	−0.1464 (0.1135)	−0.1793* (0.1028)	−0.3891*** (0.1106)	−0.1696 (0.1089)
Sunday	0.3119*** (0.0995)	0.3170*** (0.1005)	0.0826 (0.1193)	0.1282 (0.1081)	0.2508** (0.1096)	0.5682*** (0.1032)
Holiday	0.5764* (0.3020)	0.5919** (0.2873)	0.3781 (0.3729)	0.4181* (0.2330)	0.4831 (0.4278)	0.8570*** (0.2027)
Segment 2		1.5429*** (0.1257)	1.1069*** (0.1355)	1.5434*** (0.1293)	1.5735*** (0.1389)	1.7434*** (0.1401)
Segment 3		2.2574*** (0.2436)	1.5126*** (0.2532)	2.0259*** (0.2528)	2.4821*** (0.2756)	2.5733*** (0.2754)
Segment 4		−0.3325 (0.2569)	−0.6404** (0.2620)	−0.8207*** (0.2766)	−0.4955* (0.2623)	0.1804 (0.3103)
Segment 5		−0.7643** (0.3584)	−0.7359* (0.3933)	−0.9032** (0.3946)	−1.0094*** (0.3816)	−0.5157 (0.4147)
Interaction term		0.0006 (0.0016)	−0.0127* (0.0068)	−0.0023 (0.0113)	0.0042 (0.0101)	−0.0060 (0.0108)
Constant	0.0149 (0.0283)	0.0206 (0.0255)	0.0176 (0.0278)	0.0188 (0.0257)	0.0212 (0.0278)	0.0226 (0.0272)
Observations	55,424	55,424	10,284	9498	15,409	20,233
R^2	0.0635	0.0780	0.0578	0.0782	0.0869	0.1000
Adjusted R^2	0.0632	0.0776	0.0557	0.0761	0.0856	0.0990

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parentheses. Driscoll and Kraay - SCC estimator.

Table 3
FD regression of average daily price (24 h) for diesel.

	Dependent variable: Daily Average Price					
	FD - All Segments	FD - Segment 1	FD - Segment 2	FD - Segment 3	FD - Segment 4	FD - Segment 5
Polish average price (PAP)	−0.0581 (0.1316)	−0.0835 (0.1710)	−0.0028 (0.2189)	0.3994** (0.1899)	0.7036*** (0.2682)	−0.2800** (0.1219)
First lag of PAP	0.1457* (0.0782)	0.1362 (0.1446)	0.0457 (0.0913)	0.0355 (0.2428)	0.4078*** (0.1259)	0.2085* (0.1268)
Second lag of PAP	0.1118 (0.0982)	0.0763 (0.1050)	−0.1086 (0.1079)	−0.0348 (0.2021)	−0.4465*** (0.0960)	0.2653** (0.1352)
Third lag of PAP	−0.0033 (0.0809)	−0.0185 (0.1482)	−0.0094 (0.1422)	0.0280 (0.1177)	−0.7903*** (0.0661)	0.0628 (0.1085)
Fourth lag of PAP	−0.0893 (0.1275)	−0.2097 (0.2201)	−0.1603 (0.1274)	0.6636** (0.3110)	0.5143*** (0.0734)	−0.3379* (0.1860)
Crude oil price (COP)	0.0599 (0.0587)	−0.1198 (0.1223)	−0.1657 (0.1655)	0.1863** (0.0842)	0.3460* (0.1835)	−0.0016 (0.0864)
First lag of COP	0.1799** (0.0796)	0.0864 (0.1277)	0.2017* (0.1037)	0.1371 (0.1024)	−0.0325 (0.1323)	0.3226*** (0.0739)
Second lag of COP	0.2377*** (0.0726)	0.1510*** (0.0583)	0.0487 (0.1199)	0.1009 (0.0992)	0.1351 (0.1581)	0.3301*** (0.0929)
Third lag of COP	0.1484** (0.0580)	0.0998 (0.1004)	−0.0537 (0.1320)	0.0732 (0.0910)	0.2417* (0.1286)	0.2378*** (0.0791)
Fourth lag of COP	0.0370 (0.0768)	−0.0715 (0.0787)	0.0703 (0.1313)	0.2227* (0.1163)	−0.0567 (0.1051)	0.0105 (0.0986)
Tuesday	−0.2060*** (0.0796)	−0.2360* (0.1416)	−0.0789 (0.1166)	−0.5451*** (0.1359)	−0.2085 (0.1784)	−0.0720 (0.1510)
Wednesday	−0.1468 (0.1130)	−0.3037*** (0.1165)	0.1874 (0.1436)	−0.2588 (0.1899)	−0.4753* (0.2592)	0.1894 (0.1780)
Thursday	−0.2303* (0.1274)	−0.1294 (0.1571)	0.1341 (0.1567)	−0.5782*** (0.2063)	−0.7869*** (0.2455)	−0.0331 (0.1780)
Friday	−0.2570** (0.1175)	−0.0171 (0.1303)	−0.0311 (0.1798)	−0.5650** (0.2344)	−0.7854*** (0.2324)	0.0733 (0.2360)
Saturday	−0.2286** (0.1007)	−0.1107 (0.1316)	−0.1671 (0.1628)	−0.1976 (0.2425)	−0.3296** (0.1520)	0.0088 (0.2241)
Sunday	0.3170*** (0.1005)	0.4926*** (0.1246)	0.1647 (0.2045)	0.4191 (0.2593)	0.4343*** (0.1134)	0.1775 (0.2885)
Holiday	0.5919** (0.2873)			0.1755 (0.3771)	0.3302 (0.2177)	
Segment 2	1.5428*** (0.1256)					
Segment 3	2.2576*** (0.2436)					
Segment 4	−0.3324 (0.2569)					
Segment 5	−0.7643** (0.3584)					
Constant	0.0206 (0.0255)	0.1151*** (0.0383)	0.0710 (0.0440)	−0.0235 (0.0610)	0.0393 (0.0487)	0.0344 (0.0611)
Observations	55,424	7945	12,875	9698	12,857	11,190
R^2	0.0780	0.0707	0.0562	0.1225	0.2299	0.1302
Adjusted R^2	0.0776	0.0688	0.0550	0.1209	0.2289	0.1289

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. Driscoll and Kraay - SCC estimator. Some segments have no or too few holidays to estimate the holiday coefficient. PAP = Polish average price; COP = crude oil price.

density tracks with lower gasoline station density, one would expect that there are more people per square kilometer and gasoline station in zones C and D. The opposite is the case, column three reveals that there are substantially more people per square kilometer and gasoline station in zone A, not less. Thus, the infrastructure anomaly along the German border appears not to be driven by different population densities.

The last infrastructural variable I discuss is brand composition. I focus on the four largest branded chains: Aral, Shell, Esso, and Total.[21] In Table 4, I present the absolute number of the single brands, the sum (in parenthesis) of the branded chain group, and the share of the branded

[21] I abstain from including JET because it does not charge a significantly higher price than small brands.

Table 4
Summary of infrastructural analysis by zone.

	Zone A	Zone B	Zone C	Zone D
Gasoline Station Infrastructure				
Number of gasoline stations	39	36	59	77
Average population density	235.695	139.823	277.795	264.352
The population density in relation to the number of gasoline stations	6.043	3.884	4.708	3.433
Share of premium brands: Aral, Esso, Shell, Total (SUM) [Percentage]	7, 4, 3, 6, (20), [51.28 %]	3, 5, 5, 5, (18), [50 %]	7, 2, 9, 6, (24), [40.68 %]	14, 4, 6, 12, (36), [46.75 %]
Price Competition and Services				
The average number of price changes per day	14.64	14.41	13.99	13.04
Average service index (= number of services offered on average)	4.89	4.66	5.06	5.06
Local Competition				
Average distance to nearest Polish competitor	7.686	25.569	38.136	51.690
Average driving time to nearest Polish competitor	14.686	28.715	41.495	50.538
Average distance to nearest German competitor	3.252	3.925	4.107	3.318
Average driving time to nearest German competitor	4.952	5.296	5.873	4.825
No. of German competitors within 5 km	3.154	2.889	3.576	3.455
No. of German competitors within 10 km	4.359	3.972	6.441	5.883

group relative to the absolute number of stations in the respective zone (in brackets).

The percentage of premium brands decreases with distance from the Polish border, starting at about 51 % in zone A near the border, continuing at about 50 % in zone B and around 41 % in zone C, and finally reaching a moderately higher level of about 47 % in zone D. An economic explanation may include the fact that non-premium brands compete primarily over price, in contrast to premium brands. Thus, non-premium retailers try to attract consumers by setting a low price instead of providing extra services.[22] However, gasoline stations that compete primarily over the price face an even more difficult situation along the border in light of the solid Polish competition nearby. Hence, the border region exhibits an above-average share of premium brands. The finding is in line with the expectation that premium brands do not compete primarily over price.

There are moderately more price changes closer to the border, with an average of about 14.6 changes per day in zone A, about 14.4 changes in zone B, about 14 changes in zone C, and about 13 changes in zone D. This may indicate a slightly more active competition situation in the proximity of the border. The average number of services provided slightly decreases when approaching the border. Lastly, I show some descriptive statistics for local competition variables in Table 4. There are no extreme and systematic differences between the zones.

The available data is not sufficient for causal inference regarding the effect of price differentials between Germany and Poland and the sparsening German gasoline retail infrastructure in the border region. Therefore, it is left to future research.

In short, the price difference between the Polish and German markets results from tax differences, as discussed before. Thus, it is a permanent disadvantage for German gasoline stations at the border. The results indicate that German gas stations do not enter into price competition with their Polish opponents. Overall, the gasoline infrastructure shows considerable differences with respect to distance from Poland. Station density relative to population gets sparse, while the share of premium brands slightly increases when moving towards the border. Altogether, the results indirectly suggest the presence of fuel tourism.

[22] The average number of services provided by premium brands (ARAL, ESSO, TOTAL, and Shell) is 5.23, compared to 4.69 for all other brands. These numbers are based on the data underlying Table 1.

5. Conclusion

In this paper, I analyzed competition in the German region at the border with Poland, focusing on the effect of closeness to Polish competitors on prices set by German retailers. Moreover, I describe how the gasoline station infrastructure changes with proximity to the border.

Early research identified the importance of spatial variables for competition in the retail gasoline market. Newly available data containing virtually all price changes for all German gasoline stations allows an in-depth analysis of spatial influences on the German gasoline market. I apply panel data econometrics with robust standard error estimation to this new database. Specifically, I use first difference estimation techniques, simultaneously accounting for structural breaks as well as the fixed effects filtered approach proposed by Pesaran and Zhou (2018). Several linear and non-linear regression specifications are considered, and robustness checks include changing the dependent variable to minimum, mean, and maximum prices over different periods (24 h and 13 h).

Moreover, I divide the border region into four 15 km zones in terms of driving distance to the nearest Polish competitor. Based on these zones, I ran further regression models. Focusing on the FEF approach for estimating German gasoline prices while controlling for various station characteristics, I find no evidence of price competition between German and Polish gasoline stations. In fact, the analysis reveals that there is no statistically significant effect on prices set by German stations when located closer to Polish competitors. Furthermore, these insignificant effects are so small that they are economically irrelevant. The result is evident in many different model specifications, including interaction terms, quadratic relations, cubic relations, estimations based on minimum and maximum daily prices, and estimations based on various price variables.

This result is not surprising given the enormous tax differences between Germany and Poland. These tax differences exceed the profit margins of German gasoline stations by far, which means that they cannot compete with Polish gasoline stations even if they were to reduce their prices to marginal costs.

If German gasoline stations do not enter into price competition with their Polish opponents, how does the difference in taxes on gasoline between Germany and Poland impact the German gasoline market? In the short run, gasoline retailers compete over prices because relocating a gasoline station is costly and takes time. However, in the long run, retailing companies and other potential players may internalize this permanent competition influence from Poland and consider it in their decision about where to locate their gasoline stations in the German border region. Following the price analysis based on the different zones, I describe the gasoline station infrastructure in each of them. The results reveal increasingly sparse gasoline station infrastructure when approaching the Polish border, along with an increasing share of premium brands.

More precisely, there are at least 28 % more people per gasoline station and square kilometer in the zone directly at the border compared to the zones inland; the zone directly at the border is defined by a driving distance of no more than 15 km to the nearest Polish competitor. Overall, there are many more people per square kilometer and gasoline stations near the border, or, in other words, much fewer gasoline stations near the Polish border.

Furthermore, I find a higher share of premium brands in proximity to the Polish border. The percentage of premium brands decreases with distance from the Polish border, from about 51 % in the zone closest to the border to between 41 % and 47 % in regions further inland. An economic explanation may include that non-premium brands compete primarily over prices in contrast to premium brands and are located more sparsely at the border. Overall, the border region exhibits an above-average share of premium brands.

This lack of infrastructure and the different brand compositions indicate considerable fuel tourism. A high degree of fuel tourism raises the question of fiscal intervention that may aim at limiting such undesirable behavior in terms of climate and fiscal policy. An estimation of the extent of fuel tourism, similar to Banfi et al. (2005), can only be made based on quantity data, which has not yet been recorded. In a draft law, the Ministry for Economic Affairs and Energy (Bundesministeriums für Wirtschaft und Energie, 2020) recently proposed that the transmission of quantity data to competition authorities be made mandatory. This would enable researchers to carry out new analyses based on which fiscal policy assessments can be made. However, the relevant section was not included in the legislative amendment.

Future research may use long-run data on gasoline station infrastructure to casually analyze the effect of tax and price differentials on the retailer infrastructure in border regions. Moreover, research on the extent of fuel tourism and its welfare implications is required. Finally, the question arises whether spatially graduated taxation may help to mitigate welfare-diminishing consequences.

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CRediT authorship contribution statement

Mats Petter Kahl: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

None.

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Appendix A. Appendix

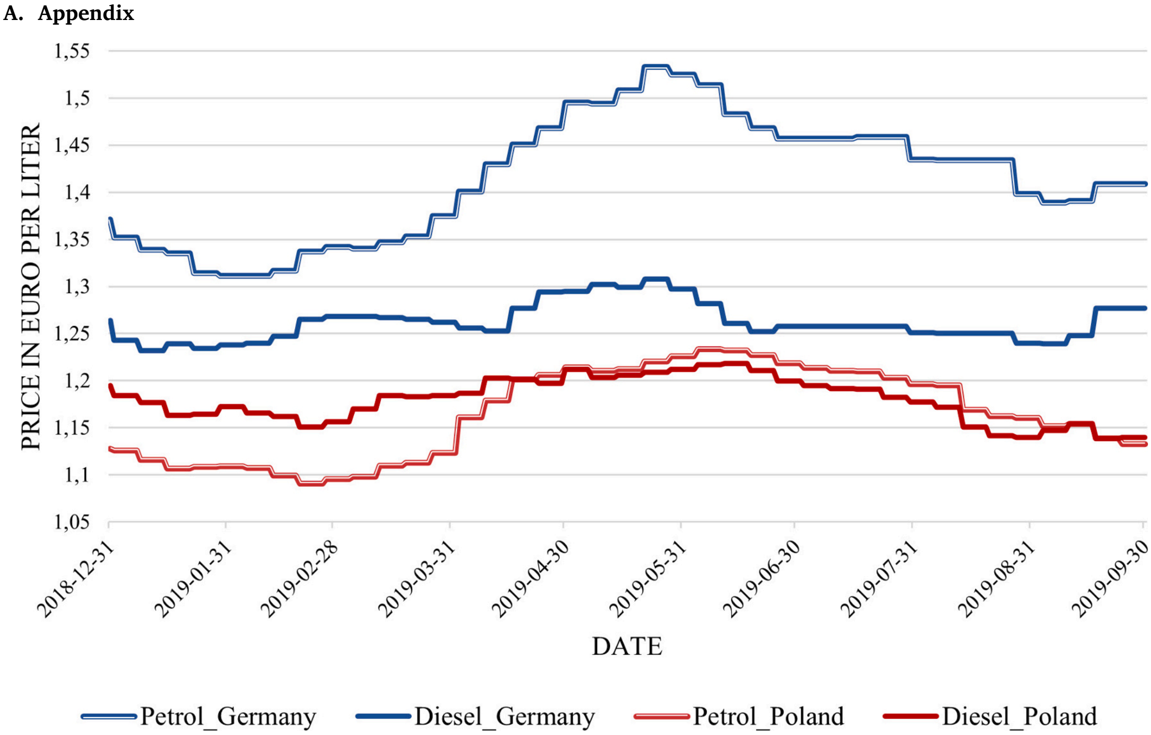

Fig. A1. Average weekly fuel prices for Poland and Germany, January to September 2019.
Appendix Fig. 1 is based on data from globalpetrolprices.com (2019).

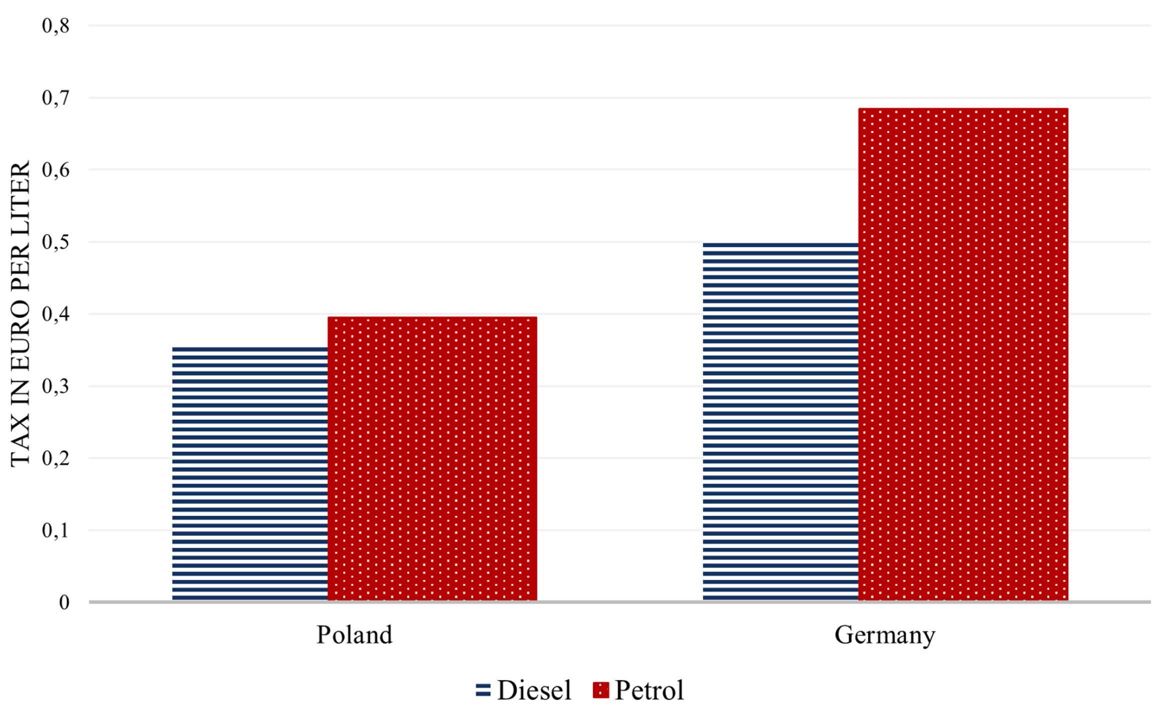

Fig. A2. Effective tax rates on energy use in EUR per liter, 2015.
Appendix Fig. 2 is based on data from the OECD (2018b, 2018c).

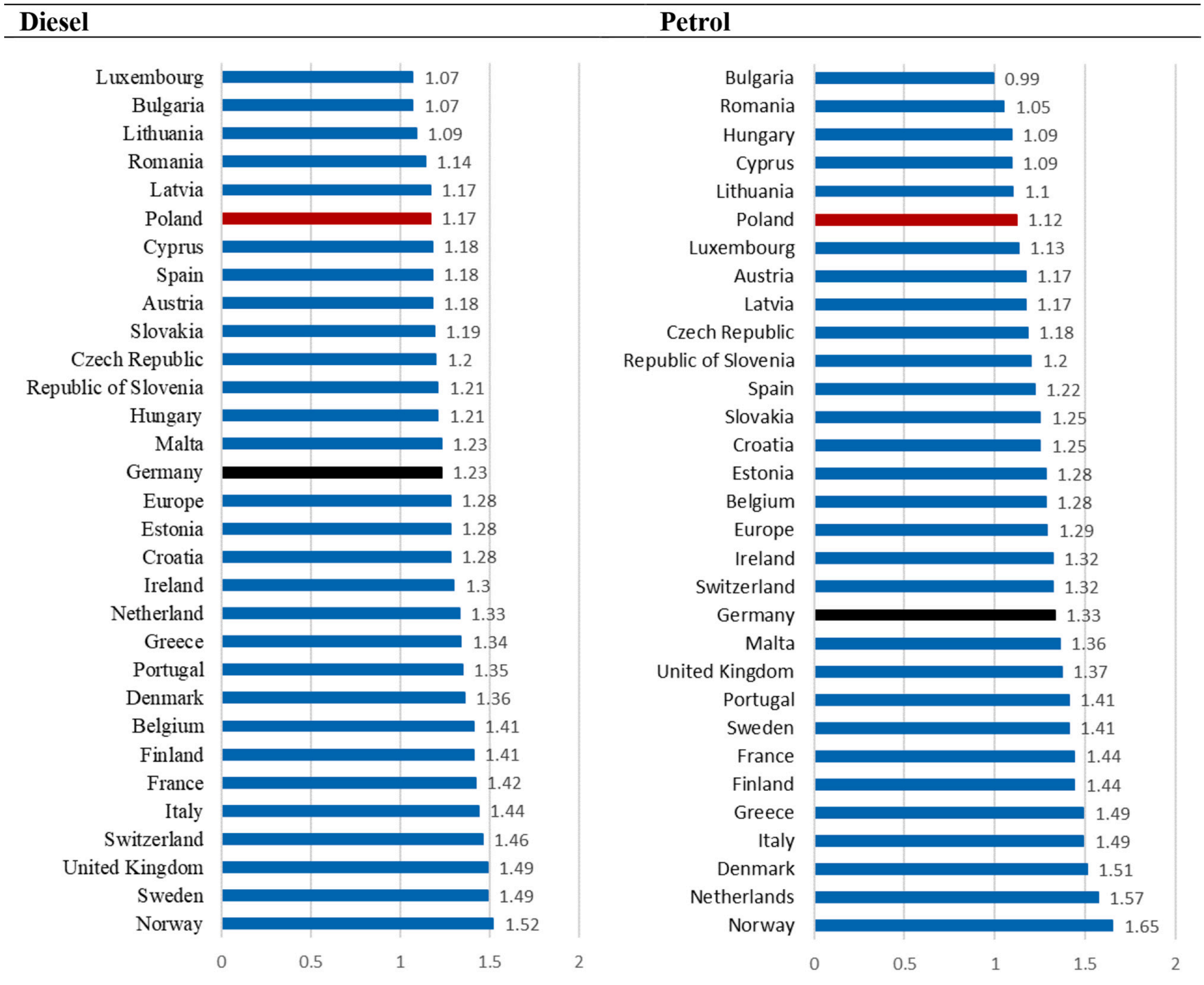

Fig. A3. Diesel prices in EUR per liter for Europe (effective 15th January 2019).
This Figure is based on data from infoRoad GmbH (2019).

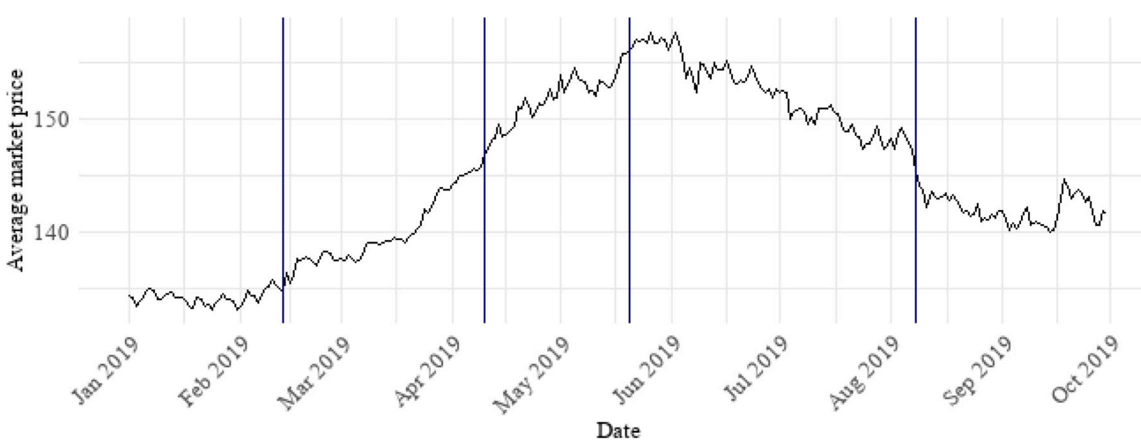

Fig. A4. Average daily market price for petrol and structural breakpoints from January to September 2019.

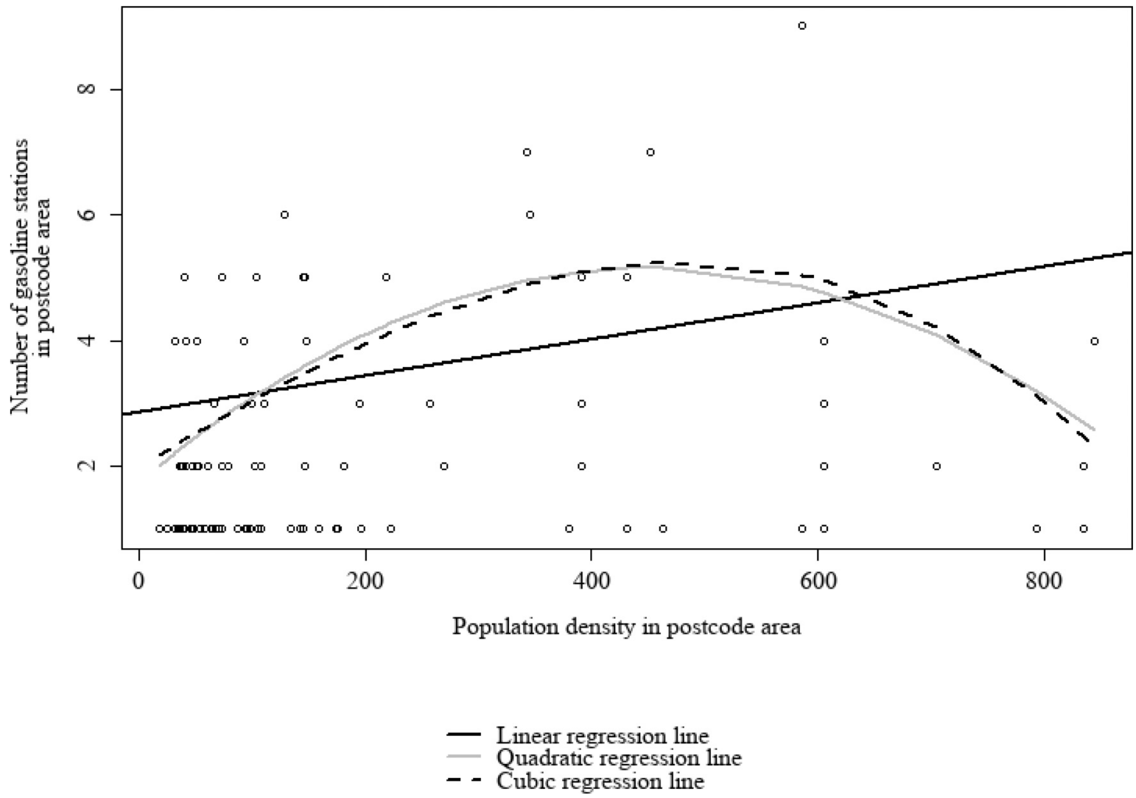

Fig. A5. Number of gasoline stations and population density.

Table A1. Overview of the variables.

Category	Variable
Dependent variables	Average daily price, minimum daily price, maximum daily price (day of 24 h or day of 16 h); average residuals of the fixed effects model in the FEF regression
Brand categories	Brand
	Five branded chains (Aral, Shell, Esso, Total, JET)
	Four branded chains (Aral, Shell, Esso, Total)
Local competition	Dist. nearest Polish competitor
	Time nearest Polish competitor
	Polish average price
	Dist. nearest German competitor
	Time nearest German competitor
	No. German competitors in 5 km
	No. German competitors in 5 min
	No. German competitors in 10 min
	No. German competitors in 15 min
	No. German competitors in 20 min
Input costs	Crude oil
Demand-side controls	Weekday
	Holiday
	Weekend Holiday
	Population density
Station type	Highway
Station characteristics	Shop
	Truck
	Bistro
	Baking station
	Shower
	Vacuum cleaner
	ATM
	Pressure washer
	Car wash
	Tire pump
	Restaurant
	Service station
	Credit card

Table A2. Brand composition in the diesel dataset.

Brand Category	Number of Stations
Brands	
Aral	31
Agip	10
AVIA	5
Esso	15
GO	5
GULF	5
HEM	6
JET	5
OIL!	8
SB	12
Shell	23
Sprint	5
STAR	12
Total	29
Stations belonging to supermarkets	
Supermarket	10
All other stations	
Others	30

Table A3. Unit-root test results for diesel.

Test	Intercept	Trend	Alt. hypoth.	Test statistic	*P*-value (rounded)	Result
Choi's Logit Unit-Root Test (ex. var.: None)			stationarity	L* = 13.324	= 1	Likely non-stationary
Choi's Logit Unit-Root Test (ex. var.: Individual Intercepts)	Yes		stationarity	L* = −20.576	< 0.00000	Likely stationary
Choi's Logit Unit-Root Test (ex. var.: Individual Intercepts and Trend)	Yes	yes	stationarity	L* = −9.1456	<0.00000	Likely stationary
Choi's Logit Unit-Root Test (ex. var.: None) on first-differenced data			stationarity	L* = −185.11	< 0.00000	Likely stationary
Choi's modified P Unit-Root Test (ex. var.: None)			stationarity	Pm = −11.781	= 1	Likely non-stationary
Choi's modified P Unit-Root Test (ex. var.: Individual Intercepts)	Yes		Stationarity	Pm = 24.58	< 0.00000	Likely stationary
Choi's modified P Unit-Root Test (ex. var.: Individual Intercepts and Trend)	Yes	Yes	Stationarity	Pm = 7.9162	= 0.00000	Likely stationary
Choi's modified P Unit-Root Test (ex. var.: None) on first-differenced data			Stationarity	Pm = 320.92	< 0.00000	Likely stationary
Im-Pesaran-Shin Unit-Root Test (ex. var.: Individual Intercepts)	Yes		Stationarity	Wtbar = −19.464	< 0.00000	Likely stationary
Im-Pesaran-Shin Unit-Root Test (ex. var.: Individual Intercepts and Trend)	Yes	Yes	Stationarity	Wtbar = −9.398	< 0.00000	Likely stationary
Im-Pesaran-Shin Unit-Root Test (ex. var.: Individual Intercepts) on first-differenced data	Yes		Stationarity	Wtbar = −83.364	< 0.00000	Likely stationary
Maddala-Wu Unit-Root Test (ex. var.: None)			Stationarity	chisq = 79.738	= 1	Likely non-stationary
Maddala-Wu Unit-Root Test (ex. var.: Individual Intercepts)	Yes		Stationarity	chisq = 1136.1	< 0.00000	Likely stationary
Maddala-Wu Unit-Root Test (ex. var.: Individual Intercepts and Trend)	Yes	Yes	Stationarity	chisq = 651.98	=0.00000	Likely stationary
Maddala-Wu Unit-Root Test (ex. var.: None) on first-differenced data			Stationarity	chisq = 9745.4	<0.00000	Likely stationary

Table A4. Unit-root test results for diesel by segment.

Test	Alt. hypothesis	Test statistic	P-value (rounded)	Result
Segment 1 Maddala-Wu Unit-Root Test (ex. var.: None)	stationarity	chisq = 49.408	= 1	Likely non-stationary
Segment 2 Maddala-Wu Unit-Root Test (ex. var.: None)	Stationarity	chisq = 80.428	= 1	Likely non-stationary
Segment 3 Maddala-Wu Unit-Root Test (ex. var.: None)	Stationarity	chisq = 194.73	= 1	Likely non-stationary
Segment 4 Maddala-Wu Unit-Root Test (ex. var.: None)	Stationarity	chisq = 204.36	= 1	Likely non-stationary
Segment 5 Maddala-Wu Unit-Root Test (ex. var.: None)	Stationarity	chisq = 96.776	= 1	Likely non-stationary
First differenced:				
Segment 1 Maddala-Wu Unit-Root Test (ex. var.: None) on first differenced prices	stationarity	chisq = 3867.4	< 0.00000	Likely stationary
Segment 2 Maddala-Wu Unit-Root Test (ex. var.: None) on first differenced prices	Stationarity	chisq = 8615.8	< 0.00000	Likely stationary
Segment 3 Maddala-Wu Unit-Root Test (ex. var.: None) on first differenced prices	Stationarity	chisq = 2958.2	< 0.00000	Likely stationary
Segment 4 Maddala-Wu Unit-Root Test (ex. var.: None) on first differenced prices	Stationarity	chisq = 9713.1	< 0.00000	Likely stationary
Segment 5 Maddala-Wu Unit-Root Test (ex. var.: None) on first differenced prices	stationarity	chisq = 6816.8	< 0.00000	Likely stationary

Table A5. Structural break test results for diesel.

Time Series	Number of structural breaks	Number of segments	Break dates	Fit: BIC
Average Daily Market Diesel Price	0	1		1411.6
	1	2	03.06.2019	1004.6
	2	3	03.06.2019, 06.08.2019	968.9
	3	4	18.04.2019, 04.06.2019, 06.08.2019	927.4
	4	**5**	**13.02.2019, 17.04.2019, 04.06.2019, 06.08.2019**	**885.8**
	5	6	15.02.2019, 09.04.2019, 02.06.2019, 12.07.2019, 21.08.2019	934.6
Crude Oil Price	0	1		1301.5
	1	2	30.05.2019	965.2
	2	3	22.05.2019, 23.08.2019	880.2
	3	4	12.02.2019, 22.05.2019, 23.08.2019	870.7
	4	**5**	**13.02.2019, 28.03.2019, 22.05.2019, 23.08.2019**	**850.7**
	5	6	13.02.2019, 28.03.2019, 22.05.2019, 02.07.2019, 23.08.2019	851.9
Crude-Oil-Transformed Average Daily Market Price	0	1		988.9
	1	2	07.06.2019	931.1
	2	3	15.03.2019, 06.06.2019	911.1
	3	4	08.03.2019, 17.04.2019, 06.06.2019	909.1
	4	**5**	**08.03.2019, 17.04.2019, 06.06.2019, 18.08.2019**	**908.5**
	5	6	08.03.2019, 17.04.2019, 02.06.2019, 12.07.2019, 21.08.2019	949.3

The number of structural breaks yielding the lowest Bayesian information criterion (BIC) is preferred. The optimal number of breaks appears to be four for all series.

Table A6. Descriptive statistics for Tables 1–3 ($N = 54{,}760$).

Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Price	111.355	126.334	125.686	159.471	5.053	123.054	128.789
Dist. nearest Polish competitor	1.950	35.047	39.340	59.790	16.744	24.420	48.980
Time nearest Polish competitor	3.729	37.292	35.117	149.865	19.686	25.266	50.029
Polish average price	113.875	117.972	118.269	121.817	2.364	116.188	120.133
German average price	123.200	126.194	125.800	130.800	1.995	124.800	127.700
Crude oil price	29.504	36.217	35.939	42.377	2.566	34.290	37.668
Dist. Nearest German competitor	0.100	3.508	1.850	22.390	4.026	0.890	4.180
Time nearest German competitor	0.227	5.058	3.517	25.528	4.608	1.750	6.600
No.German.competitors.in.5 km	1	3.377	3	11	2.150	2	5
No.German.competitors.in.10 km	1	5.474	5	14	3.333	3	7
Highway	0	0.040	0	1	0.195	0	0
National road	0	0.054	0	1	0.226	0	0
Population density	17.838	244.357	145.554	844.884	227.170	64.937	391.431
Agip	0	0.050	0	1	0.217	0	0
Aral	0	0.154	0	1	0.361	0	0
AVIA	0	0.025	0	1	0.156	0	0
Esso	0	0.075	0	1	0.263	0	0
GO	0	0.025	0	1	0.156	0	0
GULF	0	0.020	0	1	0.140	0	0
HEM	0	0.030	0	1	0.170	0	0
JET	0	0.025	0	1	0.156	0	0
OIL	0	0.025	0	1	0.156	0	0
Others	0	0.132	0	1	0.338	0	0
SB	0	0.058	0	1	0.234	0	0
Shell	0	0.114	0	1	0.318	0	0
Sprint	0	0.024	0	1	0.153	0	0
STAR	0	0.060	0	1	0.237	0	0
Supermarket	0	0.041	0	1	0.199	0	0
Total	0	0.144	0	1	0.351	0	0
Oli4	0	0.487	0	1	0.500	0	1
Oli5	0	0.511	1	1	0.500	0	1
Monday	0	0.137	0	1	0.344	0	0
Tuesday	0	0.141	0	1	0.348	0	0
Wednesday	0	0.141	0	1	0.348	0	0
Thursday	0	0.141	0	1	0.348	0	0
Friday	0	0.141	0	1	0.348	0	0
Saturday	0	0.145	0	1	0.352	0	0
Sunday	0	0.131	0	1	0.337	0	0
Holiday	0	0.025	0	1	0.155	0	0
Shop	0	0.867	1	1	0.340	1	1
Truck	0	0.502	1	1	0.500	0	1
Bistro	0	0.506	1	1	0.500	0	1

(continued on next page)

(*continued*)

Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Baking station	0	0.402	0	1	0.490	0	1
Shower	0	0.040	0	1	0.195	0	0
Vacuum cleaner	0	0.218	0	1	0.413	0	0
ATM	0	0.252	0	1	0.434	0	1
Pressure washer	0	0.089	0	1	0.284	0	0
Car wash	0	0.665	1	1	0.472	0	1
Tire pump	0	0.099	0	1	0.298	0	0
Restaurant	0	0.025	0	1	0.156	0	0
Service station	0	0.204	0	1	0.403	0	0
Credit card	0	0.940	1	1	0.237	1	1
Open	0.000	3.623	5.000	9.000	2.839	0.000	6.000
Close	12.000	22.380	22.000	24.000	1.570	22.000	24.000
Open 24 h	0	0.362	0	1	0.480	0	1

Table A7. Descriptive statistics for zone A ($N = 10{,}463$).

Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Price	111.963	126.809	126.257	151.233	4.798	123.552	129.424
Dist. nearest Polish competitor	1.950	7.686	7.100	14.870	3.652	4.320	10.860
Time nearest Polish competitor	3.729	14.703	12.257	96.384	14.779	7.909	14.666
Polish average price	113.875	117.970	118.269	121.817	2.368	116.188	120.133
German average price	123.200	126.200	125.800	130.800	1.996	124.800	127.700
Crude oil price	29.504	36.218	35.939	42.377	2.570	34.252	37.668
Dist. Nearest German competitor	0.100	3.259	1.800	14.060	3.475	0.910	5.250
Time nearest German competitor	0.394	4.957	3.498	18.923	4.448	2.117	7.670
No. German competitors in 5 km	1	3.139	3	7	1.746	1	5
No. German competitors in 10 km	1	4.326	4	8	1.998	3	6
Highway	0	0.052	0	1	0.221	0	0
National road	0	0.052	0	1	0.222	0	0
Population density	34.873	233.464	145.554	834.182	236.025	72.924	391.431
Agip	0	0.078	0	1	0.268	0	0
Aral	0	0.182	0	1	0.386	0	0
AVIA	0	0.026	0	1	0.159	0	0
Esso	0	0.104	0	1	0.305	0	0
GO	0	0.000	0	0	0.000	0	0
GULF	0	0.052	0	1	0.222	0	0
HEM	0	0.000	0	0	0.000	0	0
JET	0	0.000	0	0	0.000	0	0
OIL	0	0.026	0	1	0.159	0	0
Others	0	0.125	0	1	0.331	0	0
SB	0	0.078	0	1	0.268	0	0
Shell	0	0.078	0	1	0.268	0	0
Sprint	0	0.026	0	1	0.159	0	0
STAR	0	0.026	0	1	0.159	0	0
Supermarket	0	0.044	0	1	0.204	0	0
Total	0	0.156	0	1	0.363	0	0
Oli4	0	0.520	1	1	0.500	0	1
Oli5	0	0.520	1	1	0.500	0	1
Monday	0	0.138	0	1	0.345	0	0
Tuesday	0	0.141	0	1	0.348	0	0
Wednesday	0	0.141	0	1	0.348	0	0
Thursday	0	0.141	0	1	0.349	0	0
Friday	0	0.142	0	1	0.349	0	0
Saturday	0	0.145	0	1	0.352	0	0
Sunday	0	0.130	0	1	0.336	0	0
Holiday	0	0.021	0	1	0.144	0	0
Shop	0	0.853	1	1	0.354	1	1
Truck	0	0.390	0	1	0.488	0	1
Bistro	0	0.442	0	1	0.497	0	1
Baking station	0	0.390	0	1	0.488	0	1
Shower	0	0.026	0	1	0.159	0	0
Vacuum cleaner	0	0.208	0	1	0.406	0	0
ATM	0	0.230	0	1	0.421	0	0
Pressure washer	0	0.182	0	1	0.386	0	0
Car wash	0	0.646	1	1	0.478	0	1
Tire pump	0	0.104	0	1	0.305	0	0
Restaurant	0	0.052	0	1	0.222	0	0
Service station	0	0.234	0	1	0.423	0	0
Credit card	0	0.927	1	1	0.260	1	1
Open	0	3.760	5	8	2.770	0	6
Close	12	22.388	22	24	1.476	22	24
Open 24 h	0	0.337	0	1	0.473	0	1

Table A8. Descriptive statistics for zone B ($N = 9658$).

Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Price	111.355	126.712	126.208	148.900	4.646	123.669	129.150
Dist. nearest Polish competitor	18.090	25.549	26.680	29.870	3.487	22.900	28.640
Time nearest Polish competitor	17.668	28.659	30.299	35.117	4.897	25.022	32.617
Polish average price	113.875	117.968	118.269	121.817	2.368	116.188	120.133
German average price	123.200	126.199	125.800	130.800	1.995	124.800	127.700
Crude oil price	29.504	36.218	35.939	42.377	2.568	34.252	37.668
Dist. nearest German competitor	0.190	3.960	1.730	22.130	4.698	1.350	5.750
Time nearest German competitor	0.286	5.335	3.079	22.507	5.219	2.415	7.133
No. German competitors in 5 km	1	2.874	3	10	1.752	1	4
No. German competitors in 10 km	1	3.963	4	13	2.317	2	5
Highway	0	0.028	0	1	0.165	0	0
National road	0	0.056	0	1	0.231	0	0
Population density	31.617	139.997	67.649	605.078	153.644	42.031	148.506
Agip	0	0.056	0	1	0.231	0	0
Aral	0	0.084	0	1	0.278	0	0
AVIA	0	0.056	0	1	0.231	0	0
Esso	0	0.141	0	1	0.348	0	0
GO	0	0.000	0	0	0.000	0	0
GULF	0	0.056	0	1	0.231	0	0
HEM	0	0.000	0	0	0.000	0	0
JET	0	0.028	0	1	0.165	0	0
OIL	0	0.028	0	1	0.165	0	0
Others	0	0.084	0	1	0.278	0	0
SB	0	0.084	0	1	0.278	0	0
Shell	0	0.141	0	1	0.348	0	0
Sprint	0	0.000	0	0	0.000	0	0
STAR	0	0.028	0	1	0.165	0	0
Supermarket	0	0.071	0	1	0.257	0	0
Total	0	0.141	0	1	0.348	0	0
Oli4	0	0.507	1	1	0.500	0	1
Oli5	0	0.535	1	1	0.499	0	1
Monday	0	0.138	0	1	0.345	0	0
Tuesday	0	0.142	0	1	0.349	0	0
Wednesday	0	0.142	0	1	0.349	0	0
Thursday	0	0.142	0	1	0.349	0	0
Friday	0	0.142	0	1	0.349	0	0
Saturday	0	0.145	0	1	0.352	0	0
Sunday	0	0.130	0	1	0.336	0	0
Holiday	0	0.021	0	1	0.143	0	0
Shop	0	0.868	1	1	0.338	1	1
Truck	0	0.563	1	1	0.496	0	1
Bistro	0	0.422	0	1	0.494	0	1
Baking station	0	0.366	0	1	0.482	0	1
Shower	0	0.028	0	1	0.165	0	0
Vacuum cleaner	0	0.197	0	1	0.398	0	0
ATM	0	0.225	0	1	0.418	0	0
Pressure washer	0	0.000	0	0	0.000	0	0
Car wash	0	0.619	1	1	0.486	0	1
Tire pump	0	0.113	0	1	0.316	0	0
Restaurant	0	0.000	0	0	0.000	0	0
Service station	0	0.225	0	1	0.418	0	0
Credit card	0	0.948	1	1	0.222	1	1
Open	0	3.960	5	8	2.792	0	6
Close	16	22.113	22	24	1.645	21	24
Open 24 h	0	0.314	0	1	0.464	0	1

Table A9. Descriptive statistics for zone C ($N = 14{,}589$).

Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Price	113.025	125.966	125.700	140.536	3.876	123.260	128.488
Dist. nearest Polish competitor	30.150	38.012	39.340	44.790	4.786	33.010	42.000
Time nearest Polish competitor	19.117	41.169	40.792	149.865	17.927	31.331	45.748
Polish average price	113.875	117.977	118.269	121.817	2.364	116.188	120.133
German average price	123.200	126.203	125.800	130.800	1.993	124.800	127.700
Crude oil price	29.504	36.223	35.939	42.377	2.570	34.290	37.668
Dist. nearest German competitor	0.280	3.653	2.060	22.390	4.213	0.890	4.520
Time nearest German competitor	0.838	5.273	3.993	25.528	4.490	1.974	6.861
No. German competitors in 5 km	1	3.758	3	11	2.364	2	6
No. German competitors in 10 km	1	6.741	7	14	4.060	3	10
Highway	0	0.019	0	1	0.135	0	0
National road	0	0.034	0	1	0.182	0	0

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Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Population density	17.838	291.464	256.790	605.078	216.153	87.676	451.974
Agip	0	0.056	0	1	0.230	0	0
Aral	0	0.131	0	1	0.337	0	0
AVIA	0	0.019	0	1	0.135	0	0
Esso	0	0.037	0	1	0.189	0	0
GO	0	0.075	0	1	0.263	0	0
GULF	0	0.000	0	0	0.000	0	0
HEM	0	0.075	0	1	0.263	0	0
JET	0	0.037	0	1	0.189	0	0
OIL	0	0.019	0	1	0.135	0	0
Others	0	0.102	0	1	0.303	0	0
SB	0	0.050	0	1	0.218	0	0
Shell	0	0.167	0	1	0.373	0	0
Sprint	0	0.019	0	1	0.135	0	0
STAR	0	0.056	0	1	0.230	0	0
Supermarket	0	0.047	0	1	0.211	0	0
Total	0	0.112	0	1	0.315	0	0
Oli4	0	0.447	0	1	0.497	0	1
Oli5	0	0.484	0	1	0.500	0	1
Monday	0	0.138	0	1	0.345	0	0
Tuesday	0	0.142	0	1	0.349	0	0
Wednesday	0	0.142	0	1	0.349	0	0
Thursday	0	0.142	0	1	0.349	0	0
Friday	0	0.142	0	1	0.349	0	0
Saturday	0	0.146	0	1	0.353	0	0
Sunday	0	0.128	0	1	0.334	0	0
Holiday	0	0.021	0	1	0.144	0	0
Shop	0	0.838	1	1	0.368	1	1
Truck	0	0.578	1	1	0.494	0	1
Bistro	0	0.503	1	1	0.500	0	1
Baking station	0	0.354	0	1	0.478	0	1
Shower	0	0.019	0	1	0.135	0	0
Vacuum cleaner	0	0.205	0	1	0.404	0	0
ATM	0	0.297	0	1	0.457	0	1
Pressure washer	0	0.075	0	1	0.263	0	0
Car wash	0	0.726	1	1	0.446	0	1
Tire pump	0	0.131	0	1	0.337	0	0
Restaurant	0	0.019	0	1	0.135	0	0
Service station	0	0.205	0	1	0.404	0	0
Credit card	0	0.938	1	1	0.241	1	1
Open	0	3.497	5	9	2.933	0	6
Close	17	22.506	22	24	1.427	21	24
Open 24 h	0	0.401	0	1	0.490	0	1

Table A10. Descriptive statistics for zone D ($N = 20{,}050$).

Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
Price	113.686	126.230	125.133	159.471	5.984	122.483	128.479
Dist. nearest Polish competitor	45.070	51.739	50.580	59.790	4.125	48.250	55.720
Time nearest Polish competitor	28.836	50.415	50.552	138.877	14.615	40.157	57.812
Polish average price	113.875	117.967	118.269	121.817	2.370	116.188	120.133
German average price	123.200	126.201	125.800	130.800	1.996	124.800	127.700
Crude oil price	29.504	36.219	35.939	42.377	2.570	34.252	37.668
Dist. nearest German competitor	0.170	3.315	1.780	18.260	3.773	0.500	4.180
Time nearest German competitor	0.227	4.820	3.553	20.789	4.443	1.419	6.484
No. German competitors in 5 km	1	3.467	3	10	2.287	2	5
No. German competitors in 10 km	1	5.880	6	13	3.249	3	8
Highway	0	0.054	0	1	0.227	0	0
National road	0	0.068	0	1	0.251	0	0
Population density	24.334	266.043	146.018	844.884	243.146	72.666	345.474
Agip	0	0.027	0	1	0.162	0	0
Aral	0	0.190	0	1	0.392	0	0
AVIA	0	0.014	0	1	0.116	0	0
Esso	0	0.054	0	1	0.227	0	0
GO	0	0.014	0	1	0.116	0	0
GULF	0	0.000	0	0	0.000	0	0
HEM	0	0.027	0	1	0.162	0	0
JET	0	0.027	0	1	0.162	0	0
OIL	0	0.027	0	1	0.162	0	0
Others	0	0.179	0	1	0.383	0	0
SB	0	0.041	0	1	0.198	0	0
Shell	0	0.081	0	1	0.273	0	0
Sprint	0	0.039	0	1	0.192	0	0

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Statistic	Min	Mean	Median	Max	St. Dev.	Pctl(25)	Pctl(75)
STAR	0	0.095	0	1	0.293	0	0
Supermarket	0	0.023	0	1	0.149	0	0
Total	0	0.163	0	1	0.369	0	0
Oli4	0	0.488	0	1	0.500	0	1
Oli5	0	0.516	1	1	0.500	0	1
Monday	0	0.137	0	1	0.344	0	0
Tuesday	0	0.141	0	1	0.348	0	0
Wednesday	0	0.141	0	1	0.348	0	0
Thursday	0	0.141	0	1	0.348	0	0
Friday	0	0.141	0	1	0.348	0	0
Saturday	0	0.144	0	1	0.351	0	0
Sunday	0	0.135	0	1	0.341	0	0
Holiday	0	0.022	0	1	0.146	0	0
Shop	0	0.893	1	1	0.309	1	1
Truck	0	0.475	0	1	0.499	0	1
Bistro	0	0.581	1	1	0.493	0	1
Baking station	0	0.459	0	1	0.498	0	1
Shower	0	0.068	0	1	0.251	0	0
Vacuum cleaner	0	0.242	0	1	0.428	0	0
ATM	0	0.244	0	1	0.430	0	0
Pressure washer	0	0.093	0	1	0.290	0	0
Car wash	0	0.651	1	1	0.477	0	1
Tire pump	0	0.066	0	1	0.248	0	0
Restaurant	0	0.027	0	1	0.162	0	0
Service station	0	0.176	0	1	0.381	0	0
Credit card	0	0.945	1	1	0.228	1	1
Open	0	3.479	5	9	2.807	0	6
Close	12	22.409	22	24	1.663	22	24
Open 24 h	0	0.368	0	1	0.482	0	1

Table A11. FE regression underlying Table 1, based on the average daily diesel price (24 h).

	Dependent variable: Daily Average Price				
	All zones	Zone A	Zone B	Zone C	Zone D
Polish average price (PAP)	−0.3891*** (0.1452)	−0.1978 (0.1690)	−0.9546*** (0.1838)	−0.1044 (0.1818)	−0.6883*** (0.1946)
First lag of PAP	0.1511 (0.1167)	0.2406 (0.1468)	0.1329 (0.1271)	0.1240 (0.1143)	0.1345 (0.1241)
Second lag of PAP	0.1144 (0.1399)	0.1414 (0.1619)	0.1196 (0.1484)	0.1561 (0.1436)	0.0681 (0.1443)
Third lag of PAP	0.0365 (0.1356)	0.0198 (0.1462)	0.0742 (0.1331)	0.0297 (0.1468)	0.0299 (0.1452)
Fourth lag of PAP	−0.1041 (0.1615)	−0.2192 (0.1632)	−0.0398 (0.1669)	−0.0626 (0.1736)	−0.1061 (0.1673)
Crude oil price (COP)	−0.0501 (0.0687)	−0.0051 (0.0723)	−0.0321 (0.0725)	−0.0784 (0.0799)	−0.0607 (0.0673)
First lag of COP	0.1839** (0.0832)	0.1723* (0.0900)	0.1729** (0.0810)	0.1664* (0.0868)	0.2085** (0.0883)
Second lag of COP	0.2368** (0.0996)	0.2714** (0.1055)	0.2755*** (0.0985)	0.2604*** (0.0968)	0.1834* (0.1076)
Third lag of COP	0.1561** (0.0771)	0.1246 (0.0797)	0.1340* (0.0751)	0.1405* (0.0784)	0.1943** (0.0863)
Fourth lag of COP	0.2219** (0.0862)	0.1956** (0.0944)	0.2019** (0.0888)	0.2510*** (0.0937)	0.2225*** (0.0856)
Tuesday	−0.2245* (0.1218)	−0.2225 (0.1382)	−0.1821 (0.1272)	−0.2920** (0.1341)	−0.1941 (0.1194)
Wednesday	−0.1543 (0.1492)	−0.1204 (0.1733)	−0.1210 (0.1568)	−0.2563* (0.1504)	−0.1096 (0.1527)
Thursday	−0.2657 (0.1737)	−0.2805 (0.1966)	−0.2074 (0.1841)	−0.2984 (0.1843)	−0.2607 (0.1697)
Friday	−0.2572 (0.1641)	−0.1962 (0.1773)	−0.1663 (0.1636)	−0.2981 (0.1831)	−0.3005* (0.1649)
Saturday	−0.2039 (0.1350)	−0.1644 (0.1529)	−0.1284 (0.1383)	−0.3196** (0.1476)	−0.1714 (0.1363)
Sunday	0.3120** (0.1314)	0.0736 (0.1497)	0.1451 (0.1402)	0.2581* (0.1416)	0.5456*** (0.1332)
Holiday	0.7396* (0.3929)	0.4893 (0.3993)	0.8909** (0.4181)	0.7338 (0.5490)	0.7904*** (0.3014)
Segment 2	1.5626*** (0.4352)	1.8396*** (0.4605)	1.5683*** (0.4925)	1.4737*** (0.4800)	1.4866*** (0.3988)
Segment 3	3.8818*** (0.6687)	3.6860*** (0.7290)	3.5293*** (0.7130)	3.7105*** (0.6964)	4.2789*** (0.6429)
Segment 4	1.1739*** (0.3785)	0.7591* (0.4166)	0.8031* (0.4389)	0.9233** (0.4199)	1.7509*** (0.3445)
Segment 5	1.1435*** (0.3335)	0.7924** (0.3507)	0.8856** (0.4073)	0.7777** (0.3858)	1.7196*** (0.2827)
Interaction term	0.0041*** (0.0007)	−0.0197*** (0.0038)	0.0236*** (0.0030)	−0.0042* (0.0023)	0.0109*** (0.0028)
Observations	55,635	10,323	9534	15,468	20,310
R^2	0.6814	0.6556	0.7001	0.7092	0.6831
Adjusted R^2	0.6801	0.6536	0.6983	0.7076	0.6815

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. Driscoll and Kraay - SCC estimator.

Table A12. FEF robustness checks for diesel.

	Dependent variable: Residuals of the FE Stage		
	FEF Min Price (24 h)	FEF Max Price (24 h)	FEF Mean Price (13*h*)
Dist. Nearest Polish competitor (DNPC)	−0.0519** (0.0230)	−0.0435* (0.0242)	−0.0608** (0.0242)
$DNPC^2$	0.0021** (0.0009)	0.0016* (0.0009)	0.0023** (0.0009)
$DNPC^3$	−0.00002** (0.00001)	−0.00002* (0.00001)	−0.00002** (0.00001)

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(*continued*)	Dependent variable: Residuals of the FE Stage		
	FEF Min Price (24 h)	FEF Max Price (24 h)	FEF Mean Price (13*h*)
Dist. nearest Ger. Competitor (DNGC)	−0.0953** (0.0420)	−0.0555 (0.0443)	−0.0936** (0.0442)
$DNGC^2$	0.0104* (0.0055)	0.0088 (0.0058)	0.0109* (0.0058)
$DNGC^3$	−0.0003* (0.0002)	−0.0004** (0.0002)	−0.0004* (0.0002)
No. German competitors in 10 km	0.0070 (0.0164)	0.0024 (0.0173)	0.0043 (0.0172)
Highway	0.2490 (0.1813)	0.2833 (0.1913)	0.3195* (0.1908)
National road	0.2146 (0.1424)	0.4930*** (0.1503)	0.2739* (0.1499)
Population density	0.00001 (0.0002)	−0.0001 (0.0002)	−0.0001 (0.0002)
Agip	0.4236** (0.1830)	0.4926** (0.1931)	0.4042** (0.1926)
Aral	−0.0081 (0.1267)	−0.1025 (0.1337)	0.0131 (0.1334)
AVIA	0.0582 (0.2348)	0.1617 (0.2477)	0.2315 (0.2471)
Esso	0.2593 (0.1667)	0.2286 (0.1759)	0.3078* (0.1754)
SB	−0.2215 (0.1549)	−0.0720 (0.1634)	−0.1065 (0.1630)
GO	0.1813 (0.2244)	−0.1757 (0.2368)	0.1384 (0.2362)
GULF	0.3352 (0.2364)	−0.1319 (0.2495)	0.3279 (0.2488)
HEM	0.0188 (0.2097)	0.1472 (0.2213)	0.0922 (0.2207)
JET	−0.0283 (0.2133)	−0.0419 (0.2251)	−0.0112 (0.2245)
Supermarket	−0.2515 (0.1725)	−0.1441 (0.1820)	−0.1055 (0.1816)
OIL	0.8675*** (0.2081)	0.3121 (0.2196)	0.7749*** (0.2190)
Shell	0.1692 (0.1496)	−0.0062 (0.1578)	0.2071 (0.1575)
Sprint	0.1483 (0.2111)	−0.1124 (0.2228)	0.2044 (0.2222)
STAR	0.0968 (0.1612)	0.0068 (0.1701)	0.1361 (0.1697)
Total	0.1502 (0.1482)	0.0361 (0.1564)	0.1262 (0.1560)
Shop	−0.2739** (0.1320)	0.0832 (0.1393)	−0.1633 (0.1390)
Truck	−0.0875 (0.0744)	−0.1276 (0.0785)	−0.1245 (0.0783)
Bistro	0.0608 (0.1065)	0.1543 (0.1124)	0.1093 (0.1121)
Baking station	−0.0165 (0.1165)	−0.2026 (0.1230)	−0.0964 (0.1226)
Shower	−0.0899 (0.1773)	−0.4086** (0.1871)	−0.0803 (0.1866)
Vacuum cleaner	−0.0003 (0.1035)	−0.1417 (0.1092)	−0.0437 (0.1090)
ATM	0.0847 (0.0849)	0.0884 (0.0896)	0.1095 (0.0894)
Pressure washer	−0.0498 (0.1235)	0.0570 (0.1304)	−0.0663 (0.1300)
Car wash	−0.0512 (0.0796)	−0.1153 (0.0839)	−0.0692 (0.0837)
Tire pump	−0.2099* (0.1160)	−0.0842 (0.1224)	−0.1682 (0.1221)
Restaurant	−0.2186 (0.2153)	−0.2567 (0.2272)	−0.1487 (0.2266)
Service station	0.0457 (0.1093)	0.1694 (0.1153)	0.1825 (0.1150)
Credit card	0.1841 (0.1375)	−0.0781 (0.1451)	0.1135 (0.1447)
Constant	0.3221 (0.2140)	0.4038* (0.2258)	0.4022* (0.2252)
Observations	202	202	202
R2	0.2918	0.2424	0.2508
Adjusted R2	0.1267	0.0658	0.0761

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parenthesis.

Table A13. FD robustness checks for diesel.

	Dependent variable: Daily Average Price		
	FD - Min Price (24 h)	FD - Max Price (24 h)	FD - Mean Price (13 h)
Polish average price (PAP)	0.0534 (0.1312)	−0.1873 (0.1788)	−0.1037 (0.1268)
First lag of PAP	0.1027 (0.0674)	0.1126 (0.0852)	0.1280 (0.0813)
Second lag of PAP	0.0820 (0.0795)	0.0701 (0.0787)	0.1112 (0.1020)
Third lag of PAP	−0.0294 (0.0899)	0.0971 (0.1412)	0.0002 (0.0884)
Fourth lag of PAP	−0.0070 (0.0880)	−0.1509 (0.1660)	−0.1110 (0.1361)
Crude oil price (COP)	0.0722 (0.0473)	−0.0228 (0.0482)	0.0544 (0.0615)
First lag of COP	0.3083*** (0.0802)	0.1440** (0.0571)	0.1618** (0.0812)
Second lag of COP	0.2852*** (0.0490)	0.2679*** (0.0750)	0.2377*** (0.0763)
Third lag of COP	0.0331 (0.0568)	0.2034*** (0.0459)	0.1619*** (0.0599)
Fourth lag of COP	0.1020* (0.0603)	−0.0546 (0.0425)	0.0253 (0.0806)
Tuesday	−0.0814 (0.0672)	−0.2391*** (0.0763)	−0.2108** (0.0835)
Wednesday	−0.0512 (0.0968)	−0.2210** (0.0954)	−0.1523 (0.1181)
Thursday	−0.1773* (0.0970)	−0.2545** (0.1044)	−0.2208 (0.1345)
Friday	−0.0822 (0.0968)	−0.3613*** (0.1299)	−0.2725** (0.1234)
Saturday	0.1321 (0.0828)	−0.3719*** (0.1052)	−0.2688** (0.1095)
Sunday	0.6862*** (0.0999)	−0.0940 (0.0840)	0.3099*** (0.1029)
Holiday	0.8667*** (0.1964)	0.4102*** (0.1388)	0.5668* (0.3160)
Segment 2	1.3850*** (0.0960)	1.1962*** (0.0918)	1.6895*** (0.1327)
Segment 3	1.8370*** (0.1730)	1.8540*** (0.1578)	2.3840*** (0.2567)
Segment 4	1.0045*** (0.1716)	−0.0746 (0.1842)	−0.3421 (0.2694)
Segment 5	0.2828 (0.2654)	−0.1270 (0.2538)	−0.8274** (0.3796)
Interaction term	−0.0005 (0.0020)	0.0012 (0.0029)	0.0013 (0.0018)
Constant	0.0152 (0.0241)	0.0174 (0.0253)	0.0209 (0.0264)
Observations	55,424	55,424	55,413
R^2	0.0904	0.0347	0.0750
Adjusted R^2	0.0900	0.0343	0.0747

Remarks: Significance Level: *** p < 0.01, ** p < 0.05, * p < 0.1; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. Driscoll and Kraay - SCC estimator. The segments were identified for each data set separately using structural break tests following Bai and Perron (2003). The structural breaks for the minimum daily price (24 h) are "2019-02-13," "2019-04-08," "2019-06-03," and "2019-08-06"; for the maximum daily price (24 h) are "2019-02-14," "2019-04-19," "2019-06-05," and "2019-08-08"; and for the average daily price (13 h) are "2019-02-14," "2019-04-18," "2019-06-05," and "2019-08-07".

Table A14. Statistical tests for the diesel dataset (mean price over 24 h).

Test	Test statistic	df	p-value	Alternative hypothesis	Result
Breusch-Pagan test for heteroskedasticity	BP = 18,807	df = 213	p-value <0.0000	Presence of heteroskedasticity	The test indicates the presence of heteroskedasticity. Hence, robust covariance matrix estimation must be applied.
Lagrange Multiplier Test - (Breusch-Pagan) for unbalanced panels – RE vs *pooled OLS*	chisq = 1,005,600	df = 1	p-value <0.0000	significant effects	There is evidence of significant differences across stations; therefore, a random effects model would be preferred over simple OLS.
Lagrange Multiplier Test - time effects (Breusch-Pagan) for unbalanced panels - FE	chisq = 6390	df = 1	p-value <0.0000	significant effects	Basically, same result as with the test above this one.
Breusch-Pagan LM test for cross-sectional dependence in panels - FE	chisq = 646,714	df = 22,155	p-value <0.0000	cross-sectional dependence	There is cross-sectional dependence.
Breusch-Pagan LM test for cross-sectional dependence in panels – pooled OLS	chisq = 1,297,857	df = 20,910	p-value <0.0000	cross-sectional dependence	There is cross-sectional dependence.
Breusch-Pagan LM test for cross-sectional dependence in panels – RE	chisq = 1,297,951	df = 20,910	p-value <0.0000	cross-sectional dependence	There is cross-sectional dependence.
Pesaran CD test for cross-. dependence in panels – pooled OLS, RE, FE	z > 515		p-value <0.0000	cross-sectional dependence	There is cross-sectional dependence.
Breusch-Godfrey/Wooldridge test for serial correlation in panel models - FE	chisq = 31,835	df = 54	p-value <0.0000	serial correlation in idiosyncratic errors	The null hypothesis states that there is no serial correlation. Results indicate that there is serial correlation in idiosyncratic errors. The result is basically the same for different orders of correlation.
Breusch-Godfrey/Wooldridge test for serial correlation in panel models (order 1–3) - FE	Different values >28,800		p-value <0.0000		
Breusch-Godfrey/Wooldridge test for serial correlation in panel models (up to order 3) – pooled OLS	Different values >38,900		p-value <0.0000	serial correlation in idiosyncratic errors	There is serial correlation in idiosyncratic errors.
Breusch-Godfrey/Wooldridge test for serial correlation in panel models (up to order 3) – RE	Different values >30,900		p-value <0.0000	serial correlation in idiosyncratic errors	There is serial correlation in idiosyncratic errors.
Breusch-Godfrey/Wooldridge test for serial correlation in panel models (up to order 3) – FD	Different values >5300		p-value <0.0000	serial correlation in idiosyncratic errors	There is serial correlation in idiosyncratic errors.

Remarks: Pooled OLS = pooled ordinary least squares regression, RE = random effects regression, FE = fixed effects regression, FD = first difference regression, df = degrees of freedom. FD and FE specifications have interaction terms, segment indicators, and lags.

Table A15. FEF regression results for petrol.

	Dependent variable: Residuals of the FE Stage				
	FEF - All Zones	FEF – Zone A	Zone B	Zone C	Zone D
Dist. Nearest Polish competitor (DNPC)	−0.0385* (0.0224)	−0.8662 (0.6084)	−5.6566 (11.4059)	14.7919 (9.5149)	−5.7457 (5.6995)
DNPC^2	0.0015* (0.0008)	0.1148 (0.0825)	0.2178 (0.4731)	−0.3968 (0.2572)	0.1066 (0.1097)
DNPC^3	−0.00002* (0.00001)	−0.0024 (0.0027)	−0.0028 (0.0065)	0.0035 (0.0023)	−0.0007 (0.0007)
Dist. nearest Ger. Competitor (DNGC)	−0.0422 (0.0414)	−0.2869 (0.2439)	0.0347 (0.5023)	0.0711 (0.2310)	−0.0343 (0.0674)
DNGC^2	0.0029 (0.0054)	0.1593 (0.0978)	−0.0358 (0.0856)	−0.0224 (0.0270)	0.0103 (0.0109)
DNGC^3	−0.00005 (0.0002)	−0.0150 (0.0080)	0.0023 (0.0054)	0.0011 (0.0008)	−0.0004 (0.0004)
No. German comp. in 10 km	−0.0002 (0.0162)	0.4182* (0.1649)	−0.0592 (0.1312)	0.0138 (0.0646)	0.0399* (0.0228)
Highway	0.3476* (0.1764)	−3.3024* (1.2332)	0.0009 (0.0024)	−0.0006 (0.0010)	1.3476*** (0.2792)
National road	0.1347 (0.1394)	0.5837 (0.3295)	7.7748 (27.2471)	−0.7046 (1.0230)	0.0077 (0.1890)
Population density	−0.0001 (0.0002)	−0.0003 (0.0004)	0.0002 (0.6826)	−0.6271 (0.7307)	−0.0004 (0.0003)
Agip	0.2610 (0.1805)	1.8496* (0.7275)	−5.8359 (24.2471)	−1.0349 (1.2138)	−0.0467 (0.3951)
Aral	−0.0763 (0.1251)	3.3125* (1.0713)	−8.1487 (27.7782)	−0.3136 (0.7850)	−0.0289 (0.1455)
AVIA	−0.0651 (0.2374)	0.8109 (1.3960)	−3.9688 (14.0092)	−1.3362* (0.7247)	1.1057*** (0.3564)
Esso	0.1771 (0.1620)	3.8225* (1.4223)		−0.9439 (0.8240)	−0.1379 (0.1974)
SB	−0.3060** (0.1545)	3.0127* (0.9862)	−0.1479 (0.7906)		−0.1560 (0.2259)
GO	−0.0098 (0.2185)			−0.5285 (0.6225)	0.2793 (0.3325)
GULF	0.1597 (0.2318)	16.8223* (6.9051)	−0.0991 (12.0379)	−0.9655 (0.9767)	
HEM	0.1030 (0.2053)		−2.2488 (10.1941)	−0.8410 (0.7745)	0.1739 (0.2658)
JET	−0.0148 (0.2101)		−3.8819 (14.2685)	−0.9693 (1.2477)	−0.0087 (0.2569)
Supermarket	−0.2650 (0.1754)	−0.8862 (1.2104)	−3.8097 (13.5580)	−0.0847 (0.6962)	0.3512 (0.2729)
OIL	0.4468** (0.2041)	−1.7716 (0.9814)		−0.3191 (0.9735)	−0.5504** (0.2396)
Shell	0.1594 (0.1457)	2.7397* (0.8722)	−3.3988 (14.2952)	−0.8047 (0.9375)	−0.1600 (0.1933)
Sprint	0.1413 (0.2068)	−0.3559 (0.8955)	4.0667 (13.4101)	−1.0130 (0.8049)	0.1453 (0.2161)
STAR	0.0174 (0.1550)	6.2315* (2.4383)	−1.8628 (10.3777)	−0.1802 (0.7783)	−0.3219* (0.1698)
Total	0.0233 (0.1458)	0.7214 (0.6134)	4.0575 (14.1689)	0.0729 (0.4170)	−0.1542 (0.1765)
Shop	−0.2728** (0.1352)	−3.8317 (1.9021)	−0.4516 (0.5359)	0.2680 (0.4672)	0.6171*** (0.1770)
Truck	−0.0359 (0.0744)	−1.5171* (0.6408)	0.0746 (0.7825)	−0.1517 (0.4440)	0.0736 (0.1061)
Bistro	0.1460 (0.1010)	1.9610 (0.8857)	−2.7911 (13.9204)	−0.7767 (1.2894)	−0.0470 (0.1375)
Baking station	−0.1305 (0.1120)	−0.8595 (0.8238)	4.4508 (14.0081)	−0.6977 (0.6137)	0.1720 (0.1371)

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	Dependent variable: Residuals of the FE Stage				
	FEF - All Zones	FEF – Zone A	Zone B	Zone C	Zone D
Shower	−0.2877* (0.1729)	−11.1449 (5.5925)	0.6218 (0.5437)	−0.3378 (0.4117)	−0.1873 (0.2715)
Vacuum cleaner	−0.1254 (0.1001)	−0.6040 (0.5574)		−0.1252 (0.5175)	0.0317 (0.1281)
ATM	0.0973 (0.0830)	−0.4039 (0.2685)	−0.2025 (0.2993)	−0.0678 (0.4286)	0.3213** (0.1191)
Pressure washer	0.0935 (0.1205)	−0.4514 (0.3557)	−0.1461 (0.4605)	−0.3187 (0.4346)	−0.0511 (0.1627)
Car wash	−0.0459 (0.0760)	0.0752 (0.2653)		0.4343 (0.8838)	−0.1032 (0.1144)
Tire pump	−0.1422 (0.1113)	−1.5075 (0.6688)	−8.1403 (27.4287)	0.4890 (0.5953)	−0.1466 (0.1875)
Restaurant	−0.1850 (0.2106)		−2.6422 (10.3427)	−1.0090 (0.8324)	−1.1492*** (0.3485)
Service station	0.1121 (0.1065)	2.5705* (0.8247)	53.9264 (102.5361)	−180.6148 (116.5050)	−0.0893 (0.1437)
Credit card	−0.1925 (0.1407)	1.3158 (1.4285)	−5.6566 (11.4059)	14.7919 (9.5149)	−0.0041 (0.1793)
Constant	0.7490*** (0.2202)	−1.3314 (0.8229)	0.2178 (0.4731)	−0.3968 (0.2572)	101.9581 (98.4333)
Observations	203	38	39	54	74
R^2	0.2410	0.9616	0.8809	0.8565	0.7776
Adjusted R2	0.0652	0.5264	0.3535	0.5774	0.5489
Residual Std. Error	0.3808 (df = 164)	0.2398 (df = 3)	0.3849 (df = 7)	0.5390 (df = 18)	0.2766 (df = 36)

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. In some subsample model specifications, some coefficients likely cannot be estimated due to collinearity issues.

Table A16. FE regression results underlying Table A15 based on the average daily petrol price (24 h).

	Dependent variable: Daily Average Price				
	All zones	Zone A	Zone B	Zone C	Zone D
Polish average price (PAP)	0.3556** (0.1508)	0.2962* (0.1690)	0.2950 (0.1838)	0.5164*** (0.1818)	−0.1710 (0.1946)
First lag of PAP	0.1382 (0.1168)	0.1107 (0.1468)	0.1334 (0.1271)	0.1659 (0.1143)	0.1338 (0.1241)
Second lag of PAP	0.1506 (0.1399)	0.2044 (0.1619)	0.1563 (0.1484)	0.1315 (0.1436)	0.1350 (0.1443)
Third lag of PAP	0.1720 (0.1356)	0.1188 (0.1462)	0.1671 (0.1331)	0.1935 (0.1468)	0.1853 (0.1452)
Fourth lag of PAP	0.2812* (0.1615)	0.2916* (0.1632)	0.3095* (0.1669)	0.2776 (0.1736)	0.2659 (0.1673)
Crude oil price (COP)	−0.1458** (0.0687)	−0.1361* (0.0723)	−0.1226* (0.0725)	−0.1490* (0.0799)	−0.1592** (0.0673)
First lag of COP	0.1303 (0.0832)	0.1258 (0.0900)	0.1266 (0.0810)	0.1011 (0.0868)	0.1567* (0.0883)
Second lag of COP	0.2360** (0.0996)	0.2606** (0.1055)	0.2975*** (0.0985)	0.2561*** (0.0968)	0.1787* (0.1076)
Third lag of COP	0.1562** (0.0772)	0.1271 (0.0797)	0.1297* (0.0751)	0.1477* (0.0784)	0.1898** (0.0863)
Fourth lag of COP	0.1736** (0.0862)	0.1911** (0.0944)	0.1980** (0.0888)	0.1960** (0.0937)	0.1371 (0.0856)
Tuesday	−0.2550** (0.1218)	−0.2547* (0.1382)	−0.2905** (0.1272)	−0.2509* (0.1341)	−0.2404** (0.1194)
Wednesday	−0.1479 (0.1492)	−0.1619 (0.1733)	−0.2315 (0.1568)	−0.1070 (0.1504)	−0.1304 (0.1527)
Thursday	−0.4347** (0.1737)	−0.4799** (0.1966)	−0.5207*** (0.1841)	−0.3755** (0.1843)	−0.4139** (0.1697)
Friday	−0.3437** (0.1641)	−0.2759 (0.1773)	−0.3763** (0.1636)	−0.3153* (0.1831)	−0.3817** (0.1649)
Saturday	−0.2181 (0.1350)	−0.2843* (0.1529)	−0.2807** (0.1383)	−0.2044 (0.1476)	−0.1656 (0.1363)
Sunday	0.2591** (0.1314)	0.0557 (0.1497)	0.0801 (0.1402)	0.1264 (0.1416)	0.5328*** (0.1332)
Holiday	0.4050 (0.3933)	0.0705 (0.3993)	0.3759 (0.4181)	0.3001 (0.5490)	0.6328** (0.3014)
Segment 2	3.7322*** (0.4352)	4.0583*** (0.4605)	3.7836*** (0.4925)	3.6374*** (0.4800)	3.6199*** (0.3988)
Segment 3	4.4342*** (0.6687)	5.0002*** (0.7290)	4.3978*** (0.7130)	4.3496*** (0.6964)	4.2410*** (0.6429)
Segment 4	3.6280*** (0.3785)	4.0673*** (0.4166)	3.6200*** (0.4389)	3.3131*** (0.4199)	3.6505*** (0.3445)
Segment 5	1.7147*** (0.3335)	1.8985*** (0.3507)	1.7992*** (0.4073)	1.4666*** (0.3858)	1.7699*** (0.2827)
Interaction term	0.0010	0.0100*** (0.0038)	0.0007 (0.0030)	−0.0034 (0.0023)	0.0118*** (0.0028)
Observations	54,423	9893	9516	14,806	20,208
R^2	0.9058	0.9254	0.9093	0.9012	0.9012
Adjusted R^2	0.9054	0.9250	0.9088	0.9007	0.9007

Remarks: Significance Level: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. Driscoll and Kraay - SCC estimator.

Table A17. FD regression results for the average daily petrol price (24 h).

	Dependent variable: Daily Average Price					
	FD - All Zones	FD with Interaction	FD - Zone A	FD - Zone B	FD - Zone C	FD – Zone D
Polish average price (PAP)	0.0980 (0.0739)	0.0415 (0.0708)	0.0824 (0.0708)	−0.2800 (0.2132)	−0.1261 (0.2571)	0.4066 (0.2749)
First lag of PAP	0.1471** (0.0661)	0.1704** (0.0669)	0.1311* (0.0669)	0.1568** (0.0751)	0.1977*** (0.0719)	0.1762** (0.0695)
Second lag of PAP	0.1310* (0.0747)	0.1415* (0.0774)	0.2005*** (0.0774)	0.1532** (0.0702)	0.1174 (0.0767)	0.1257 (0.0946)
Third lag of PAP	0.1804** (0.0833)	0.1743** (0.0818)	0.1157 (0.0818)	0.1632 (0.1009)	0.1952** (0.0905)	0.1932*** (0.0720)
Fourth lag of PAP	0.0590 (0.0763)	0.0567 (0.0753)	−0.0269 (0.0753)	0.0364 (0.0628)	0.0510 (0.0776)	0.1109 (0.0953)
Crude oil price (COP)	0.1027* (0.0535)	0.0777 (0.0575)	0.0661 (0.0575)	0.0604 (0.0521)	0.0620 (0.0601)	0.1034 (0.0789)
First lag of COP	0.1177 (0.0724)	0.1090 (0.0722)	0.0967 (0.0722)	0.0989 (0.0620)	0.0759 (0.0690)	0.1448* (0.0836)
Second lag of COP	0.2928*** (0.0699)	0.2530*** (0.0712)	0.2793*** (0.0712)	0.3084*** (0.0758)	0.2688*** (0.0762)	0.2009*** (0.0725)
Third lag of COP	0.1641*** (0.0474)	0.1611*** (0.0468)	0.1314*** (0.0468)	0.1314*** (0.0450)	0.1516*** (0.0495)	0.1982*** (0.0631)
Fourth lag of COP	0.0411 (0.0771)	0.0349 (0.0769)	0.0475 (0.0769)	0.0505 (0.0776)	0.0269 (0.0761)	0.0270 (0.0846)
Tuesday	−0.2196*** (0.0723)	−0.2187*** (0.0730)	−0.1866** (0.0730)	−0.2348*** (0.0674)	−0.2186*** (0.0821)	−0.2259*** (0.0856)
Wednesday	−0.2352** (0.1095)	−0.1882* (0.1032)	−0.1752* (0.1032)	−0.2570** (0.1041)	−0.1492 (0.1131)	−0.1902 (0.1183)
Thursday	−0.3143*** (0.1013)	−0.3197*** (0.1000)	−0.3068*** (0.1000)	−0.4087*** (0.1130)	−0.2770** (0.1093)	−0.3153*** (0.1080)
Friday	−0.3274*** (0.0936)	−0.3288*** (0.0938)	−0.2095** (0.0938)	−0.3696*** (0.1046)	−0.3109*** (0.1021)	−0.3816*** (0.1086)

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	Dependent variable: Daily Average Price					
	FD - All Zones	FD with Interaction	FD - Zone A	FD - Zone B	FD - Zone C	FD – Zone D
Saturday	−0.1759* (0.0912)	−0.1765** (0.0899)	−0.1880** (0.0899)	−0.2448*** (0.0922)	−0.1875* (0.1021)	−0.1309 (0.0993)
Sunday	0.2907*** (0.0950)	0.2908*** (0.0953)	0.1066 (0.0953)	0.0944 (0.0909)	0.1401 (0.1054)	0.5726*** (0.1157)
Holiday	0.6110** (0.2503)	0.6193** (0.2462)	0.4591* (0.2462)	0.5627*** (0.2115)	0.5038 (0.3078)	0.7998*** (0.1931)
Segment 2		1.6019*** (0.1337)	1.1724*** (0.1337)	1.5837*** (0.1281)	1.7374*** (0.1361)	1.7294*** (0.1548)
Segment 3		1.9883*** (0.2684)	1.4737*** (0.2684)	1.6158*** (0.2514)	2.3335*** (0.2753)	2.1626*** (0.3215)
Segment 4		0.4590* (0.2773)	0.3142 (0.2773)	0.4039 (0.2927)	0.7567*** (0.2908)	0.3365 (0.2960)
Segment 5		0.3479 (0.3594)	0.0420 (0.3594)	0.3409 (0.3752)	0.4330 (0.4148)	0.4442 (0.4104)
Interaction term		0.0016** (0.0008)	−0.0031*** (0.0008)	0.0134 (0.0086)	0.0063 (0.0059)	−0.0055 (0.0060)
Constant	0.0120 (0.0329)	0.0121 (0.0324)	0.0153 (0.0324)	0.0131 (0.0331)	0.0123 (0.0344)	0.0100 (0.0334)
Observations	54,215	54,215	9855	9480	14,749	20,131
R^2	0.0685	0.0772	0.0657	0.0738	0.0664	0.1086
Adjusted R^2	0.0683	0.0768	0.0636	0.0716	0.0650	0.1076

Remarks: Significance Level: *** p < 0.01, ** p < 0.05, * p < 0.1; Heteroskedasticity and serial correlation consistent standard errors in parentheses. Driscoll and Kraay - SCC estimator. No robust standard errors for zone A. The structural break dates are “2019-02-14,” “2019-04-11,” “2019-05-21,” and “2019-08-09”.

Table A18. FD regression results for the average daily petrol price (24 h).

	Dependent variable: Daily Average Price					
	FD - All Segments	FD - Segment 1	FD - Segment 2	FD - Segment 3	FD - Segment 4	FD - Segment 5
Polish average price (PAP)	0.0985 (0.0730)	−0.2661*** (0.0735)	0.8039*** (0.0413)	1.6058*** (0.0672)	1.4208*** (0.0626)	0.4801*** (0.0521)
First lag of PAP	0.1704** (0.0669)	−0.1355* (0.0692)	0.2904*** (0.0203)	−0.0643*** (0.0243)	0.3726*** (0.0637)	0.0915*** (0.0148)
Second lag of PAP	0.1415* (0.0774)	−0.2057*** (0.0680)	−0.2147*** (0.0187)	0.1327*** (0.0253)	0.0315 (0.0609)	−0.1174*** (0.0160)
Third lag of PAP	0.1743** (0.0818)	0.4825*** (0.0965)	−0.0664*** (0.0237)	−0.1130*** (0.0317)	−0.2137*** (0.0463)	0.3726*** (0.0183)
Fourth lag of PAP	0.0567 (0.0753)	0.2838***	−0.0012 (0.0208)	0.1303*** (0.0372)	−0.5082*** (0.0610)	0.0147 (0.0215)
Crude oil price (COP)	0.0778 (0.0575)	−0.1958** (0.0509)	0.5698*** (0.0417)	0.3099*** (0.0302)	0.6106*** (0.0184)	0.1589*** (0.0176)
First lag of COP	0.1090 (0.0722)	−0.0986 (0.0784)	−0.1573*** (0.0270)	0.3015*** (0.0255)	0.0165 (0.0219)	0.3427*** (0.0175)
Second lag of COP	0.2530*** (0.0712)	−0.0616 (0.0697)	0.2330*** (0.0314)	0.1984*** (0.0231)	0.1836*** (0.0194)	0.3271*** (0.0164)
Third lag of COP	0.1612*** (0.0468)	0.2219*** (0.0382)	0.0081 (0.0329)	0.0711** (0.0357)	0.0909*** (0.0142)	0.2483*** (0.0131)
Fourth lag of COP	0.0349 (0.0769)	−0.0393	−0.0577** (0.0282)	0.2445*** (0.0317)	0.1648*** (0.0170)	−0.1293*** (0.0146)
Tuesday	−0.2187*** (0.0730)	−0.3127*** (0.0743)	−0.7896*** (0.0453)	−1.4519*** (0.0635)	−0.1133*** (0.0294)	0.1105** (0.0444)
Wednesday	−0.1883* (0.1032)	−0.5306*** (0.1102)	−0.9039*** (0.0488)	−1.4918*** (0.0614)	−0.2591*** (0.0366)	0.2570*** (0.0450)
Thursday	−0.3198*** (0.1000)	−0.7736*** (0.1130)	−0.6784*** (0.0532)	−1.7061*** (0.0625)	−0.6133*** (0.0381)	−0.1688*** (0.0432)
Friday	−0.3288*** (0.0938)	−0.2598*** (0.1045)	−0.4665*** (0.0445)	−0.9918*** (0.0538)	−0.6041*** (0.0403)	−0.0199 (0.0404)
Saturday	−0.1765** (0.0899)	−0.1510 (0.0951)	−0.2941*** (0.0429)	−0.4272*** (0.0533)	−0.6335*** (0.0308)	0.1164*** (0.0350)
Sunday	0.2908*** (0.0953)	0.3208 (0.0871)	−0.0381 (0.0400)	0.3507*** (0.0540)	0.1700*** (0.0329)	0.4693*** (0.0398)
Holiday	0.6193** (0.2462)			0.1650** (0.0796)	0.0279 (0.0834)	
Segment 2	1.6020*** (0.1338)					
Segment 3	1.9883*** (0.2685)					
Segment 4	0.4591* (0.2774)					
Segment 5	0.3477 (0.3596)					
Constant	0.0122 (0.0324)	0.0390 (0.0346)	−0.0008 (0.0106)	−0.0015 (0.0121)	−0.0018 (0.0095)	−0.0004 (0.0092)
Observations	54,215	7772	11,312	8035	16,168	10,736
R^2	0.0771	0.0498	0.4511	0.4438	0.3900	0.1552
Adjusted R^2	0.0768	0.0478	0.4503	0.4426	0.3894	0.1540

Remarks: Significance Level: *** p < 0.01, ** p < 0.05, * p < 0.1; Heteroskedasticity and serial correlation consistent standard errors in parenthesis. Driscoll and Kraay - SCC estimator. Some segments have no or too few holidays to estimate the holiday coefficient. PAP = Polish average price; COP = crude oil price.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2024.107961.

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