Competition in the German Market for Gasoline Retailing

By the School of Public Affairs

of Leuphana University Lüneburg for the award of the degree of

Doctor of Economics

Dr. rer. pol.

approved dissertation by

Mats Petter Kahl

born on 20 August 1992 in Hamburg

Submitted on 19 August 2024.

Oral defense (disputation) on 21 January 2025.

First supervisor: Prof. Dr. Thomas Wein, Leuphana University Lüneburg

Second supervisor: Prof. Dr. Boris Hirsch, Leuphana University Lüneburg

First reviewer: Prof. Dr. Thomas Wein, Leuphana University Lüneburg

Second reviewer: Prof. Dr. Boris Hirsch, Leuphana University Lüneburg

Third reviewer: Prof. Dr. Miriam Beblo, Hamburg University

The individual contributions to the cumulative dissertation project are or will be published as follows, including the framework paper if applicable:

- Article 1 (Chapter 2):
  Kahl, M. P. (2024). Was the German fuel discount passed on to consumers?. *Energy Economics*, *138*, 107843, https://doi.org/10.1016/j.eneco.2024.107843.
- Article 2 (Chapter 3):
  How to Reach the Paradise? Inside the Edgeworth Cycle and Why a Gasoline Station is the First to Raise Its Price (joint work with Prof. Dr. Thomas Wein), accepted for publication in the *Journal of Industrial Economics*.
- Article 3 (Chapter 4):
  Kahl, M. P. (2024). Cross-border competition in the gasoline retail market: Impact of proximity at the German-Polish border. *Energy Economics*, *140*, 107961, https://doi.org/10.1016/j.eneco.2024.107961.

Year of publication: 2025.

Status of Scientific Publications in Refereed Journals and Presentations at Conferences (as of 27 January 2025)

Article	Conference/Workshop Presentation	Publication Status and History
Was the German fuel discount passed on to consumers?	Presented at the European Association for Research in Industrial Economics (EARIE) Conference 2023, Rome	Published: Kahl, M. P. (2024). Was the German fuel discount passed on to consumers?. *Energy Economics*, 138, 107843, https://doi.org/10.1016/j.eneco.2024.107843. (Earlier version published in the University of Lüneburg Working Paper Series in Economics: Kahl (2023))
	Presented at the 5th Workshop for Young Scientists on Applied Economics, Hannover, 2023	
	Presented at the Promotionskolleg Verhaltensoekonomik und gesellschaftliche Transformation Lueneburg, 2023	
	Presented at the Empirical Microeconomics PhD Workshop Lueneburg, 2022	
How to Reach the Paradise? Inside the Edgeworth Cycle and Why a Gasoline Station is the First to Raise Its Price (joint work with Thomas Wein)	Accepted for presentation at the European Association for Research in Industrial Economics (EARIE) Conference 2024, Amsterdam	Accepted for publication in the *Journal of Industrial Economics*. (Earlier version published in the University of Lüneburg Working Paper Series in Economics: Kahl and Wein (2022))
	Presented at the 6th Workshop for Young Scientists on Applied Economics, Hannover, 2024	
	Presented at the Empirical Microeconomics PhD Workshop Lueneburg, 2023	
	Presented at the Empirical Microeconomics PhD Workshop Lueneburg, 2021	
Cross-Border Competition in the Gasoline Retail Market: Impact of Proximity at the German-Polish Border	Presented at the Annual Meeting of the Verein fuer Socialpoitik 2021	Published: Kahl, M. P. (2024). Cross-border competition in the gasoline retail market: Impact of proximity at the German-Polish border. *Energy Economics*, 140, 107961, https://doi.org/10.1016/j.eneco.2024.107961. (Earlier version published in the University of Lüneburg Working Paper Series in Economics: Kahl (2020))

Acknowledgments

Over the past five years, I have benefited enormously from the advice and support of many people. First of all, I owe my academic supervisor, Thomas Wein, an outstanding debt of gratitude for his support of my dissertation. I am thankful for countless discussions about the mechanisms underlying competition in the gasoline retail market and invaluable comments and suggestions that improved this work tremendously. I am infinitely grateful for the support and continued advice of my second academic supervisor, Boris Hirsch, who offered excellent guidance on methodological issues.

I have been spoiled with opportunities to present and discuss my research at various PhD workshops organized for young researchers. A special thanks to Miriam Beblo and Luise Görges for organizing the annual "Empirical Microeconomics PhD Workshop" and offering excellent advice at all stages of my research projects. I also wish to thank Mario Mechtel for organizing the yearly "Promotionskolleg Verhaltensökonomik und gesellschaftliche Transformation" here in Lüneburg.

The support I have received at the Institute of Economics at Leuphana University has improved my research immeasurable, and I am grateful for all the comments of professors Christian Pfeifer, Thomas Huth, Michael J. Lamla, Florian Unger, and Joachim Wagner. A Special thanks to Christoph Wegener for helpful comments and discussion of the methodologies.

Along with the professors, I also wish to give my warmest thanks to my peers and friends at the Institute of Economics, Miguel Abellán-Ossenbach, Jonas Dix, Philipp Lentge, Stefano Maiani, and Huu Tam Nguyen. I am very grateful for the ongoing support of the institute's secretaries, Christina Korf and Maike Mente.

Outside of the academic environment, I owe a debt of gratitude to people I know and love. I especially want to express my heartfelt thanks to my mother, Kerstin, for supporting me in everything I set out to accomplish. Special thanks go to my brothers Lennart, Hannes, and Till and my mother's husband, Thomas, for always being there for me. I am sure that my father, Jens, can also feel my heartfelt gratitude from where he is now. Knowing that you are all there means everything to me.

dedicated to my parents

Contents

1 Introduction

Research on competition in the gasoline retail market is of interest to consumers, regulation authorities, and researchers alike. As an integral part of mobility and transportation costs, gasoline retail prices are in the daily public debate worldwide. Once prices increased, they even led to, at times, violent protests in many countries (Uexkull et al., 2024).

Since August 2013, German gasoline stations have been legally required to report all price changes for the most common fuel types in quasi-real time to the Market Transparency Unit for Fuels (MTUF) at the Federal Cartel Office (German Bundeskartellamt). This transparency unit has been created to improve the cartel authorities' possibilities "to intervene in the case of illegal predatory strategies and other forms of market power abuse" (Bundeskartellamt, 2023). The high-frequency price data is available for research via registered service providers with access to the MTUF data. Despite attempts to collect volume data additionally, no corresponding regulations have been passed to date.

The question of whether retailers are abusing potential market power is one that also concerns scientists. Different research areas have evolved to analyze the various facets of potential market power abuse in gasoline retailing.[1] Eckert (2013), who provided the most comprehensive and recent literature survey, divides the literature into three such areas: 1) studies of retail gasoline price dynamics, 2) determinants of price levels, and 3) non-price choice variables. My dissertation contributes to the empirical research on gasoline price competition with articles related to all these main research areas using detailed German high-frequency data.

Studies of retail gasoline price dynamics can be divided into two main branches (Eckert, 2013). The first branch examines how shocks to wholesale prices are passed through to retail prices. A large part of this branch of literature deals with the speed of pass-through of crude oil price changes to retail prices. Often, input price increases are passed on to consumers rapidly while decreases are passed through slowly. This is referred to as the "rockets and feathers" phenomenon (Bacon, 1991).

The other part of the literature focuses on the pass-through of tax changes, with most articles focusing on a country's average pass-through rate. Detailed studies on variations in pass-through rates by geographic regions and for single brands have not been available to date. In

[1] The literature focusing on the demand side, such as the price elasticity of demand, forms a distinct area of research that is not considered here.

my first article of this dissertation, I estimate the pass-through rates of the German gasoline tax reduction in 2022. The tax reduction (German *Tankrabatt*) was introduced as part of the relief package to mitigate the economic burden on the population, which primarily resulted from the escalation of the conflict between Ukraine and Russia. This German fuel discount was in effect from June to August 2022. It was the first time the German gasoline tax was reduced so extensively. Based on price data for all gasoline stations in France and Germany, I analyze the overall pass-through rate, pioneering the first detailed exploration of its variations across different geographic regions, alongside its evolution over time and brand-specific differences. The spatial analysis is based on thorough data from the German Federal Office for Building and Regional Planning, which includes internationally comparable Eurostat categorizations. Moreover, I use weekly price data for all European Union countries in a robustness check. The average pass-through of the tax reduction remained incomplete for all fuel types and changed tremendously over time and by fuel type. The spatial analysis revealed systematically lower pass-through in rural areas and the south of Germany. There are no brand-specific differences in pass-through rates between the major brands (Aral, Esso, Jet, Shell, and Total) and others. Identifying geographic differences in pass-through rates is a crucial scientific contribution, enabling future research to investigate this phenomenon's causal mechanisms. I show that there are no differences in pass-through rates by brand. Moreover, I find substantial differences in pass-through rates' evolution over time, various regions, and different geographic categorizations concerning urbanization. These results emphasize the importance of local factors for competition and suggest the potential exercise of market power in specific local markets.

The second literature branch of retail gasoline price dynamics studies focuses on retail price dynamics not driven by upstream price changes (Eckert, 2013). This latter branch is dominated by the Edgeworth Cycle Theory, which goes back to the critique of Edgeworth (1925) on the prevailing price competition theory by Bertrand (1883). In contrast to Bertrand, Edgeworth argued that a general static price equilibrium exists when two firms have capacity constraints, which manifests in price cycles. This theory was then formalized by Maskin and Tirole (1988) without even requiring capacity constraints and further generalized and developed in several ways (Eckert, 2003; Eibelshäuser and Wilhelm, 2018; Noel, 2008; Wills-Johnson and Bloch, 2010). In the second article, Thomas Wein and I focus on one German town's daily retail price cycles to explain what factors influence the probability of a retailer being the first to raise prices in the daily price cycles. Previous research has mainly used hourly, daily, or weekly average price data when analyzing price cycles that were either incomplete or from regulated markets.

The second-by-second price data were extensively modified to exploit the fine temporal granularity similar to Wein (2021). We examine the dynamics that influence the so-called relenting phase of the price cycle, which is the upswing of gasoline prices. Our focus is on the determinants of a retailer's likelihood of starting the relenting phase instead of continuing the underbidding. Moreover, we look at factors influencing the magnitude of such a first price increase. Finally, we look at what influences the likelihood of success of such a price-increasing attempt, thus not having a delayed or false start.

Our empirical results reveal that price considerations are not the driving factor motivating a gasoline station to be the first to increase its price. Instead, services offered, location parameters, and especially brand affiliation are relatively more important in deciding whether to raise prices first. The major brands, Aral and Shell, which jointly account for more than 80 percent of price increases in the market, are the major contributors to higher price cycles. Furthermore, our results suggest that the likelihood of a successful price increase depends relatively strongly on the brand affiliation. Factors such as the location, the services offered, and the number of coordinated sites play a less prominent role. Overall, our empirical results for the major brands Aral and Shell suggest that market power is the most crucial driver of the cyclical pricing pattern in the gasoline market.

Eckert's (2013) second area of empirical research on gasoline retailing focuses on determinants of price levels and is split into many branches. The branch aiming to identify the major drivers of station-level price dispersion centers around the effects of location and competition. In my third article, I analyze local price competition along the extreme setting at the German-Polish border based on the comprehensive German price data set. Specifically, I ask how persistently lower gasoline prices in Poland affect the prices set in the German border region. Based on an accurate assessment of driving distances between gasoline stations, I estimate the impact of one additional kilometer distance to the nearest Polish competitor on the price charged by German gasoline stations. I follow Pesaran and Zhou's recently published fixed effects filtered estimator approach (2018). Controlling for various station characteristics, I find no evidence that German gasoline retailers enter price competition with their Polish counterparts.

The third area of empirical research on gasoline retailing deals with non-price choice variables and mainly focuses on the evolution of gasoline retailing, the concentration of gasoline stations, and the determination of station characteristics (Eckert, 2013). The descriptive part of my third article contributes to the existing literature by describing how the gasoline station infrastructure differs in the border region. The results reveal, on the one hand, that the gasoline station density sparsens when approaching the Polish border. Thus, there are fewer gasoline retailers per resident. On the other hand, the share of premium brands increases towards the border relative to inland areas. These changes in the retail infrastructure may reflect that substantially lower taxes in Poland discourage German gasoline retailers from locating their sites near the border. Therefore, cross-border price competition is effectively being ruled out, and consumers' choices regarding where to fuel are limited. The resulting retail infrastructure is dominated by premium brands and likely less competitive. Overall, my findings suggest the presence of fuel tourism, although indirectly.

Further research is needed in all three research areas this dissertation contributes to. The first article reveals substantial variation in pass-through rates for different geographic regions and spatial categorizations. Future studies may focus on explaining the mechanisms causing these pass-through anomalies and how this potentially contributes to the exercise of local market power. The second article empirically analyzes the price cycles, interpreted as Edgeworth-type cycles in the literature. The elaborate data modification led us to limit our study to one local market. Future research may compare different markets to identify how market characteristics shape pricing patterns. Of particular interest would be how a larger market share of major brands shapes the number and the size (height and length) of the price cycles. The emergence of long-run gasoline station infrastructure data will allow future research to follow up on the findings of my third article on cross-border price competition. Changes in cross-country price differentials, which can be attributed to permanent tax changes (or changes in cost components), may influence the development of the gasoline retail infrastructure in border regions. Possibly resulting fiscal and welfare implications, as well as effects on fuel tourism, should be the subject of future research. Finally, the availability of long-run data enables future research to focus on the effects of market entry, market exit, and re-branding on competition in gasoline markets.

Although all three articles deal with the different facets of competition in the German market for gasoline retailing, I have written them as independent contributions.[2] The dissertation is structured as follows. I start with the article on the German gasoline tax reduction in the first chapter, continue with the article on Edgeworth cycles in the second chapter, and end with the article on local competition along the German-Polish border.

[2] Table, figure, appendix, and footnote numbering restart each chapter.

2 Was the German fuel discount passed on to consumers?

Mats Petter Kahl*

2024

Abstract

In this article, I analyze whether German gasoline stations passed on the gasoline tax reduction to consumers. I use a difference-in-differences approach with France as the control group, as well as data for all countries in the European Union. The German fuel discount was in effect from June to August 2022. As I am the first to use complete French and German high-frequency data for the entire treatment period, I can examine how the pass-through of the tax cut evolved over time, varied for different brands, and in various geographic regions. I find a substantial variance in pass-through rates over time and space. On average, the pass-through of the fuel discount was very high but remained incomplete for all fuel types. The pass-through rates were systematically lower in rural regions and in the south of Germany.

Keywords: pass-through, gasoline market, tax reduction, fuel taxes, petrol prices

JEL classification: H22, L13, L41

Statements and Declarations: none

---

* Mats Petter Kahl, Leuphana University Lueneburg, Institute of Economics, Universitaetsallee 1, 21335 Lueneburg, Germany, email: mats.kahl@leuphana.de, ORCID: 0000-0003-3387-6386
The author has no relevant financial or non-financial interests to disclose.
I am grateful to Thomas Wein and Boris Hirsch for their valuable comments and support.

2.1 Introduction - The Fuel Discount

The global energy crisis in 2022 was met by an unprecedented fiscal response from governments throughout Europe. Following the Coronavirus pandemic and the associated lockdowns to contain the pandemic, the economy of the European Union (EU) started to recover in the spring of 2021, with positive quarterly growth rates of real gross domestic product (Organisation for Economic Co-operation and Development, 2023b) and gross domestic product[1] reaching its 2019 level again in 2021 (Organisation for Economic Co-operation and Development, 2023a), and energy demand surged. Furthermore, the Russian invasion of Ukraine on February 24 and the Western sanctions in response (Bown, 2022) restricted the fuel supply to Europe and drove prices further up.[2]

Governments worldwide, especially in Europe, sought to mitigate the effects of enormously increased gasoline prices for consumers by introducing relief packages consisting of tax reductions and additional measures. The German parliament approved a gasoline tax reduction for the period between June 1 and August 31, the so-called fuel discount (referred to as "*Tankrabatt*" in the public debate), that is, a tax reduction of 14.04 Eurocent per liter (cpl) on diesel and 29.55 cpl on both types of petrol, petrol E5, and petrol E10 (Bundesregierung, 2022).[3] Additionally, the 19% value-added tax (VAT) does not apply to the saved tax. Overall, if the discount is fully passed on to consumers, prices should decline by 16.71 cpl for diesel and 35.16 cpl for both types of petrol.[4]

In this article, I analyze the pass-through rate of the temporary tax reduction on fuels in Germany, employing a DID strategy and using French gasoline stations as a control group. I am the first to analyze the temporary tax reduction with spatially granular high-frequency data covering the entire tax reduction period. Data from the same source have also been used by Montag et al. (2020) and Fuest et al. (2022) and contain the universe[5] of price changes at gasoline stations in Germany and France. I am the only one to use the DID strategy with station and date fixed effects and control for public and school holidays at the same time. Moreover, I

---

[1] OECD GDP – output approach, United Kingdom excluded.
[2] Bown (2022) provides a valuable timeline of international sanctions against Russia, which is kept up to date by the Peterson Institute For International Economics.
[3] There are two types of petrol in Germany: 1) petrol E5 (also called *Super E5*), which has an octane rating of 95 and a 5% share of ethanol, and 2) petrol E10 (also called *Super E10*), which has a 10% share of ethanol.
[4] Precisely, the effective price decrease, including saved value-added tax, should be $0.1404 * 1.19 = 0.167076$ Euro per liter of diesel and $0.2955 * 1.19 = 0.351645$ Euro per liter of petrol.
[5] All gasoline prices were reported to federal supervision authorities by those gasoline stations that were obliged to report their price changes in Germany and France.

conduct robustness checks based on data from the European Commission (2022) for the entire EU to show that my results do not depend on France being used as a control group.

Using France as a control group, I found average pass-through rates of 87% to 91%, depending on the fuel type. The complete high-frequency price data allows me to trace the evolution of pass-through rates over time. This analysis is based on daily estimates instead of weekly data, as used by Dovern et al. (2023), Seiler and Stöckmann (2023), and Bernhardt et al. (2023). The pass-through rates vary substantially over time, between -10% and 147% for diesel and between 47% and 114% for petrol E5. The results of weekly estimates based on data for 19 countries in the EU are very similar. Exploiting the granularity of the dataset with France as a control group, I found that pass-through rates vary considerably over space. Using the Eurostat definition for rural and urban areas, I found average pass-through rates of 82% in rural areas and 92% in urban areas. Moreover, pass-through rates vary notably over federal states, reaching an average of 60% in Bavaria and an average rate of 116% in Berlin.

The remainder of the article is structured as follows: Section 2 gives an overview of the related empirical literature. Section 3 introduces the data. I describe the identification strategy in section 4. Section 5 contains the results and is followed by a discussion of the threats to validity and robustness checks in section 6. I summarize and conclude in section 7.

2.2 Literature Review

A wave of literature on the German tax reduction in 2022 is currently emerging. Similar research is being conducted across Europe to examine the impact of policies to address the energy crisis. Before the end of the temporary German tax reduction, Fuest et al. (2022) published the first estimates of the pass-through rates for diesel and petrol (E5 and E10) based on a difference-in-differences (DID) approach using French gasoline stations as a control group but covering only the first two weeks after the tax reduction took effect. Based on high-frequency data for all German and French gasoline stations, they find a pass-through rate of about 100% for diesel, 82% for petrol E5, and 85% for petrol E10. Based on daily consumer price data for seven European countries(Austria, Estonia, Frane, Germany, Italy, Latvia, and Lithuania) from January 1 to August 31, Drolsbach et al. (2023) find pass-through rates of about 90% to 107% for diesel and 104% to 110% for petrol E5, excluding petrol E10 from their analysis. They scraped daily average price data from the information platform Fuelo (fuelo.net). The authors conclude that the pass-through rates vary substantially by fuel type and over time.

Schmerer and Hansen (2023) use price data from all German gasoline stations and daily data on regional petrol E5 and diesel prices from Austria for their DID approach since petrol E10 data is unavailable for Austria. They focus on median daily prices for Austria and all its states. Restricting the period to the first two weeks of June, they found 105% and 108% pass-through rates for petrol E5 and diesel, respectively. For the reinstatement of the regular taxation of gasoline, they focus on the last week of the tax reduction, hence the last week of August, to compare it to the first two weeks of September. They found a 67% and 19% pass-through rate for reinstating the gasoline tax for petrol E5 and diesel, respectively.

For the entire period of the fuel discount, Freitas and Syga (2022) find pass-through rates of 100% for both fuel types. They use weekly price data for Austria, Belgium, Germany, the Netherlands, Poland, and Sweden from the European Commission (2022), even though Sweden decreased its fuel taxes at the beginning of May and increased taxes to below the initial level at the beginning of October 2022. Along with the DID approach, the researchers conducted an event study to estimate the amount of the tax discount passed on to consumers during different periods. They found that the fuel discount was not fully passed on in the initial weeks of June and toward the end of August.

Dovern et al. (2023) use the synthetic differences-in-differences (SDID) method and data for the entire tax reduction period. They conclude that the reduction was passed on to consumers. Moreover, they argue that pass-through started to decline in August while the tax reduction was still in effect. The diesel pass-through rate drops over the course of August, ultimately reaching a level of 50% by the end of the month. However, they only use weekly price data, presumably from the European Commission (2022). Drawing on the same data source and methodology, Bernhardt et al. (2023) focus on the period from January 2021 to the end of August 2022. They find a pass-through of 97% to 99% for petrol E5 and 75% to 86% for diesel. Based on weekly price data, they compare their SDID results using "unregulated" EU countries as the control group with their results of a DID estimate using Franc as a control, obtaining the same results for the first six weeks of the tax reduction period. In contrast, they report different results for the second half of the tax reduction period.[6]

Seiler and Stöckmann (2023) employ the synthetic control method using weekly price data from the European Commission (2022) from January 3 to August 29, 2022. They restrict the donor pool to estimate the counterfactual to all euro area countries other than Germany and Malta, which raises the question of whether countries with policies of their own are included. They

[6] The SDID control group of “unregulated” EU countries includes Luxembourg and France. However, Luxembourg decreased its excise duties for both diesel and petrol in mid-April 2022 European Commission (2022). It is stated that the first fuel discount in France was in place from April until July 2022, although it was from April 14 to August 31, 2022. France changed the amount of the fuel discount from September 1, 2022.

conclude that the pass-through was at least 85% and 65% for petrol E5 and diesel, respectively. It remains somewhat unclear what weight is assigned to what donor country. Moreover, they argue that there was no price increase in anticipation of the fuel discount.

Empirical evidence on the pass-through of tax changes provides several insights. When analyzing the French VAT reforms, Carbonnier (2007) and Benzarti and Carloni (2019) found a less-than-proportional pass-through for tax changes. Similarly, Carare and Danninger (2008) analyzed the German VAT increase in 2007 and reported less than full pass-through while Viren (2009) examined tax changes across EU countries and found less than full pass-through. Benedek et al. (2015) found mixed evidence for countries within the Eurozone. Specifically, they discovered less than full pass-through for reduced VAT rates but roughly 100% pass-through for the standard rate. Recently, Genakos et al. (2023) found higher pass-through in more competitive markets by examining changes in Greek value-added tax changes.

Conversely, Buettner and Madzharova (2021) and Chirakijja et al. (2009) found nearly complete pass-through in member states of the EU and Crossley et al. (2014) found similar results for the United Kingdom. However, Crossley et al. (2014) also noted that at least part of the pass-through of the VAT was reversed after a few months. Poterba (1996) observed full pass-through in the United States while Besley and Rosen (1999) reported over-shifting of sales tax increases.

Montag et al. (2020) recently analyzed the pass-through rate of the temporary value-added tax reduction in Germany. The tax reduction was a fiscal response to the coronavirus pandemic. Based on high-frequency data for Germany and France, they found pass-through rates of 83% for diesel, 40% for petrol E5, and 61% for petrol E10.

These studies focus on country pass-through estimates, usually based on average weekly prices or averages of price samples. They have not been able to analyze spatial differences in pass-through rates. My research fills this gap by drawing on complete high-frequency price data.

2.3 Data Description

This section consists of two subsections. The first subsection introduces the reader to the datasets for the treatment group Germany, the control group France, and the weekly price dataset for all European Union countries. The second subsection is dedicated to the database for the spatially differentiated analysis for Germany.

2.3.1 Data for the Germany-Wide Analysis

The German Market Transparency Unit for Fuels collects German data on gasoline stations and prices. It was created to enable the German federal competition authority (Bundeskartellamt, 2023) to intervene in cases of market power abuse. The data is made publicly available by registered consumer information service providers. I downloaded the German data from tankerkoenig.de, which receives the data directly from the Market Transparency Unit. The data contain all price changes for all German gasoline stations. Montag et al. (2020) describe the German retail fuel market well.

French data are publicly available on the open data website of the French government (Ministère de l'Économie, des Finances et de la Souveraineté industrielle, 2022).[7] The data include all price changes for all gasoline stations that sell more than $500\ m^3$ of gasoline per year and are described in detail by Gautier and Le Saout (2015).[8] The availability of such high-frequency data in Europe is unique to France and Germany. A fuel discount has also been granted in France since April 1, 2022. Important for the DID strategy is that the development of gasoline prices over time in Germany and France was similar before the German tax reduction came into effect, as argued by Fuest et al. (2022). By using France as a control group, I follow Fuest et al. (2022), Freitas and Syga (2022), and Montag et al. (2020), among others, and discuss the assumption of parallel trends in detail in the following section.

My analysis starts on April 14, 2022, similar to previous research, but covers the entire period of the tax reduction and concludes with the termination of the tax reduction on August 31, 2022. I take the daily average price for each German and French gasoline station and date and work with daily data, similar to Montag et al. (2020) and Fuest et al. (2022).[9]

Crude oil prices are presented in descriptive statistics and approximated by the Brent price, as is commonly done in the literature. I retrieved the data from finanzen.net (2022)The crude oil price for days when the stock exchange was closed is approximated by the price from the previous date. I use the closing price when controlling for crude oil and present descriptive statistics in Table 1 of the Appendix. On average, the crude oil price approximated by the Brent closing price was 65.6 cpl before and 65.2 cpl after the tax reduction came into effect.

[7] The author would like to thank Lennart Seeger for help with data preparation.

[8] I focus on French gasoline stations on the mainland, therefore excluding islands like Corsica.

[9] I delete extreme outlier prices that lie above 300 cpl and fall below 50 cpl because such prices are likely mistakes in the data. For diesel, for example, there are 6,275 observations below 50 cpl with a maximum value of 0, a mean of -0.000, and a standard deviation of 0.000. There are 1,604 observations with a price above 300 cpl, a mean of 3.633, and a standard deviation of 0.54.

Data on public and school holidays in Germany come from Calendarpedia (2022). Data on public and school holidays in France are gathered from the French government website data.gouv.fr, created by Augusti (2022). Also, data on French communes were retrieved from that website, which was created by Badaoui (2022). Data on the French holiday zones is publicly available at vacances-scolaires-education.fr (2022).

Table 1: Descriptive Statistics for France and Germany, Diesel, April 14 to August 31

a) Descriptive Statistics Before Tax Reduction, Diesel

	Mean	Median	SD	N
Control Group:				
Daily Average Diesel Price, EUR/l	1.893	1.889	.08	430300
Public or School Holiday	.367	0	.482	428648
Treatment Group:				
Daily Average Diesel Price, EUR/l	2.031	2.026	.057	682098
Public or School Holiday	.226	0	.418	682098

b) Descriptive Statistics After Tax Reduction, Diesel

	Mean	Median	SD	N
Control Group:				
Daily Average Diesel Price, EUR/l	1.99	1.985	.132	828432
Public or School Holiday	.609	1	.488	825212
Treatment Group:				
Daily Average Diesel Price, EUR/l	1.977	1.976	.079	1313545
Public or School Holiday	.482	0	.5	1313545

In Table 1, I show descriptive statistics for the analysis of the German tax reduction with France as a control group. This table is for diesel and contains statistics before the tax reduction in panel a) and after the tax reduction in panel b), differentiating between the treatment group (German gasoline stations) and the control group (French gasoline stations).

Similar descriptive statistics tables for petrol E5 and petrol E10 are presented in Appendix Tables 2 and 3, respectively. The average French diesel price was about 189.3 cpl before the tax reduction and 199 cpl afterward. The average German diesel price was 203.1 cpl before and 197.7 cpl after the tax reduction. In France, about 37% of prices are reported during public or school holidays before the German tax reduction and about 61% afterward, compared to about 23% and 48% in Germany. Given the large proportion of school holidays coinciding with the tax reduction period, controlling for these holidays in the analysis becomes crucial.

Furthermore, I use a data set from the European Commission (2022) that contains weekly gasoline price data for all EU countries for diesel and petrol E5 (but not petrol E10). I exclude all countries with changes in excise duties or value-added taxes between April 14 and August 31, namely Croatia, the Czech Republic, Hungary, Luxembourg, Portugal, and Sweden. Tax changes and relevant relief packages are summarized in Appendix Table 4.[10] The European Commission (2022) also provides data on these changes.

Moreover, I exclude Malta, which regulated the prices for petrol and diesel for the entire year, and Slovenia because price caps were in place for several periods (Sgaravatti et al., 2021). In contrast to the case with daily price data and solely France as a control group, here, with the data for several European countries, I abstain from controlling for holidays when using countries of the EU as a control group.

On July 25, 2022, the Weekly Oil Bulletin data from the European Commission (2022) showed a drastic decrease in petrol and diesel prices for Estonia. Since there is no media coverage of any event that would have caused such a price drop, I assume this single data observation is false, and I exclude it.[11]

Austria did not change its tax during the observation period. Belgium decreased its tax between March 14 and 21 by 14.463 cpl and increased it in small steps starting before September 12 (by 3.305 cpl), but not during the German temporary tax reduction.

The French relief package did technically not consist of a tax or duty reduction but instead of a discount on petrol and diesel, namely *l'aide exceptionnelle à l'acquisition de carburants* (in English, exceptional aid for the acquisition of fuels), as described in the decree (Ministère de la Transition Énergétique, 2022). This subsidy is paid to the gasoline producers, specifically the distributors furthest up the distribution network, and only for quantities sold (Ministère de la Transition Énergétique, 2022). Therefore, it works like the tax reduction, which also occurs at a stage before retailing. I introduced the column "other relief changes" in Appendix Table 4 to account for such cases.

Also, Germany introduced reliefs other than tax reductions, namely the so-called 9-Euro-Ticket for local public transport, which was introduced simultaneously with the tax relief on June 1 and ended on August 31.[12] Based on the analysis of a nationally representative mobility tracking panel, Gaus et al. (2023) conclude that introducing this discounted public transport ticket did not lead to trips being made by public transport instead of by car in everyday mobility. They argue that this effect was exacerbated by the fact that the ticket was only available temporarily,

[10] In April 2022, no prices are available from the European Commission (2022) in the third week. Therefore, the data series starts on April 25.
[11] A request to the "Europe Direct Contact Centre" about this anomaly was not answered in a revealing manner. The author would like to thank the Estonian researcher Katri Urke for looking for relevant information in Estonian.
[12] The ticket was valid for the month of acquisition. Thus, if it was acquired on June 20, then it could be used until the end of June. It was valid for the local public transport in Germany.

and thus, no long-term incentives to switch to public transport could be established. In line with these findings, the assessment of mobile communication data conducted by the Federal Statistical Office of Germany (Statistisches Bundesamt, 2022), abbreviated DESTATIS, corroborates the limited extent of the transition from private car usage to public transportation.

Descriptive statistics for the weekly diesel prices of all EU countries in the control group plus Germany are presented in Appendix Table 5. There are data for six weeks before the German tax reduction and 13 weeks after the tax cut was put into force, covering the entire treatment period plus six weeks before the treatment.[13] Diesel prices (excluding Germany) are, on average, almost 8 cpl higher overall in all countries during the treatment period. Crude oil prices are only 4 cpl higher on average. Similar descriptive statistics for petrol E5 are moved to Appendix Table 6.

2.3.2 Data for the Spatially Differentiated Analysis

For the spatial analysis, I use data and spatial definitions from the Federal Office for Building and Regional Planning (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2023), abbreviated BBSR. I mostly use data on the municipality level because that is the finest granularity available. I focus on three research questions with respect to spatially differentiated pass-through rates. First, I analyze whether pass-through varies across federal states. I also look at differences in pass-through rates for East and West Germany as well as for city-states versus area federal states. Second, I analyze the pass-through rates for rural and urban regions using the Eurostat categorization for international comparability and the finest available categorization provided by the BBSR. Third, I show how the pass-through rates vary along all German border regions separately. Finally, I conduct and discuss robustness checks in the respective section.

In Germany, there are 16 federal states (German Bundesstaaten), of which three, Berlin, Bremen, and Hamburg, are city-states (German Stadtstaaten). The next smaller administrative subdivisions are the districts (German Landkreise or Kreise) and district-free cities. Germany had 294 districts and 106 district-free cities in 2022 (Statistisches Bundesamt, 2023b). The lowest level of administrative division is the municipality level (German Gemeinde). There were 10,786 municipalities in Germany in 2022 (Statistisches Bundesamt, 2023a). Often, major cities that are municipalities are not part of such a district subdivision but form a district of their own that consists only of the municipality itself. Most data I use are available on the smallest administrative division level, thus, at the municipality level (Bundesinstitut für Bau-, Stadt- und

[13] For Estonia, there are only 12 weeks because one week was excluded, as discussed before.

Raumforschung, 2023). I have assigned all retailers to the municipalities by zip code. Detailed zip code data were used from the open data platform www.suche-postleitzahl.org (Marco Schwochow, 2023), which is based on raw data from the OpenStreetMap contributors.

Table 2: The Number of Gasoline Stations in the German Federal States

Federal State	Abbreviation	Number of Gasoline Stations
Baden-Württemberg	BW	1949
Bavaria (Free State)	BY	2623
Berlin[×]	BE	281
Brandenburg*	BB	434
Bremen (Hanseatic City)	HB	102
Hamburg (Hanseatic City)	HH	214
Hesse	HE	1160
Mecklenburg-Western Pomerania*	MV	357
Lower Saxony*	NI	1949
North Rhine-Westphalia	NW	3068
Rhineland-Palatinate	RP	773
Saarland	SL	167
Saxony (Free State)*	SN	590
Saxony-Anhalt*	ST	439
Schleswig-Holstein	SH	605
Thuringia (Free State)*	TH	416

Abbreviations and English names from the Federal Statistical Office of Germany (Statistisches Bundesamt, 2024). *Federal states located in East Germany. [×]Berlin was divided before the German reunification and is considered separately in this analysis.

There are 16 federal states in Germany. The number of gasoline retailers per state is listed in Table 2. The first column shows the name, and the second column is the federal state abbreviation according to DESTATIS (Statistisches Bundesamt, 2024). The third column contains the number of gasoline stations for each federal state. When comparing pass-through rates for German federal states, it should be kept in mind that three city-states (Berlin, Bremen, and Hamburg) differ fundamentally from the territorial states and are more comparable to metropolitan areas. Federal states located in East Germany were part of the German Democratic Republic (German Deutsche Demokratische Republik, DDR) before the reunification in 1990 and are marked with an asterisk in the table. For the second research question regarding the spatial analysis, I adopt the Eurostat categorizations of rural and urban areas. This allows for comparison of future international research. The Eurostat categorization differentiates between "predominantly rural," "intermediate," and "predominantly urban" regions. According to this definition, 3,202 German gasoline stations are located in predominantly rural areas, 6,892 in intermediate regions, and 5,033 in predominantly urban regions. Alternatively, I use the most differentiated typology of rural and urban areas in the BBSR data set. This distinguishes between 17 categories. Table 3 shows the category, the original German phrase, and the number of German gasoline stations located in the respective area. This is a hierarchical order reaching from a Metropolis (category 1) to a small town in a peripheral rural region (category 17), as described by the DESTATIS (Statistisches Bundesamt, 2020).

Table 3: The 17 Regional Statistical Areas as Defined by the BBSR

Category	Key	English	German	Number of Retailers
1	111	Metropolis in metropolitan city region	Metropole in metropolitaner Stadtregion	1547
2	112	Large city in metropolitan city region	Großstadt in metropolitaner Stadtregion	815
3	113	Medium-sized city in metropolitan city region	Mittelstadt in metropolitaner Stadtregion	1080
4	114	Urban area in metropolitan city region	Städtischer Raum in metropolitaner Stadtregion	1257
5	115	Small town, rural area in metropolitan city region	Kleinstädtischer, dörflicher Raum in metropolitaner Stadtregion	474
6	121	Regional center in regiopolitan city region	Regiopole in regiopolitaner Stadtregion	962
7	123	Medium-sized city in regiopolitan city region	Mittelstadt in regiopolitaner Stadtregion	500
8	124	Urban area in regiopolitan city region	Städtischer Raum in regiopolitaner Stadtregion	869
9	125	Small town, rural area in regiopolitan city region	Kleinstädtischer, dörflicher Raum in regiopolitaner Stadtregion	722
10	211	Central city in rural region near city region	Zentrale Stadt in stadtregionsnaher ländlicher Region	594
11	213	Medium-sized city in rural region near city region	Mittelstadt in stadtregionsnaher ländlicher Region	546
12	214	Urban area in rural region near city region	Städtischer Raum in stadtregionsnaher ländlicher Region	919
13	215	Small town, rural area in rural region near city region	Kleinstädtischer, dörflicher Raum in stadtregionsnaher ländlicher Region	1424
14	221	Central city in peripheral rural region	Zentrale Stadt in peripherer ländlicher Region	423
15	223	Medium-sized city in peripheral rural region	Mittelstadt in peripherer ländlicher Region	503
16	224	Urban area in peripheral rural region	Städtischer Raum in peripherer ländlicher Region	617
17	225	Small town, rural area in peripheral rural region	Kleinstädtischer, dörflicher Raum in peripherer ländlicher Region	1875

For the third spatial research question, I use district-level information from the BBSR dataset (Bundesinstitut für Bau-, Stadt- und Raumforschung, 2023). The dataset contains information for each administrative district on whether it is located at a German external border and to which other national state this administrative district borders. At this granularity level, I can identify all border regions and the retailers located there. Germany shares borders with nine countries: Austria, the three Benelux states (Belgium, Netherlands, and Luxembourg), the Czech

Republic, Denmark, France, Poland, and Switzerland. I follow the border region definition of the BBSR and show the number of retailers in each border region in Table 4. I focus on the seven border regions to Austria, Benelux, the Czech Republic, Denmark, France, Poland, and Switzerland. There are at least 122 gasoline stations in a border region (Denmark) and at most 1021 (Benelux).

Table 4: The Number of Gasoline Stations in the Border Regions by Country

Border Region Types	Frequency
Austria	376
Austria and the Czech Republic	19
Austria and Switzerland	15
Benelux	1022
Benelux and France	11
Coastal region Baltic Sea	376
Czech Republic	420
Czech Republic and Poland	86
Denmark	123
France	584
France and Switzerland	34
No border region	11721
Poland	193
Switzerland	147

2.4 Identification Strategy

This section outlines the proposed estimation strategy and examines the control groups. The first subsection presents the econometric model. The second subsection discusses using French gasoline stations as a control group. In contrast, the third subsection examines the use of countries in the European Union as an additional control group.

2.4.1 Difference-in-Differences Model

I applied DID estimation techniques to test whether the German fuel discount had been passed on to consumers. First, I use French gasoline stations as the control group, and then I use several countries in the EU as a control group. The model can be formalized as follows:

$$p_{i,t} = \beta_0 + \beta_1 d_i + \beta_2 a_t + \beta_3 a_t * d_i + u_{i,t} \qquad (1)$$

with the dependent variable $p_{i,t}$ being the price of gasoline stations. The coefficient β_0 is the constant. The regressor d_i is a dummy variable that indicates whether a station i is treated. Therefore, it takes the value 1 for German stations and 0 for the control group (e.g., French stations). The coefficient β_1 captures the pre-shock difference in the price between Germany and the control group. The regressor a_t takes the value 1 for the observations in the after-treatment period and 0 otherwise. Thus, β_2 captures the average change in the price from the pre- to post-treatment periods for the control group. Finally, the main coefficient β_3 captures the effect of the tax reduction, hence the average treatment effect (ATE).

I include fixed effects on the station and the date level and control for public and school holidays. The inclusion of the holiday control variable, as well as time and station fixed effects, changes the formal model to:

$$p_{i,t} = \beta_0 + \beta_1 a_t * d_i + \beta_2 h_{i,t} + \mu_i + \delta_t + u_{i,t}. \qquad (2)$$

In equation (2), the ATE is captured by the coefficient β_1 now. The control variable for public and school holidays is $h_{i,t}$. The μ_i and δ_t are station- and date-fixed effects, respectively. Since holidays are collected for each individual retailer and, therefore, vary across entities and time, inserting date-fixed effects does not render controlling for holidays redundant. Finally, I present several robustness checks in section 6 of this article.

2.4.2 France as a Control Group

As a neighboring country of Germany, the French economy is similar to the German economy in many ways. Both countries are of similar size and wealth and located in the west of Europe, which alleviates concerns that transitory shocks could affect them differently. Both countries established mechanisms to promote transparency in the gasoline market, ensuring the availability of very accurate price data.

Two assumptions must be satisfied to causally identify the effect of the German tax reduction on gasoline prices. Firstly, there should be no economic shocks affecting Germany and France asymmetrically other than the tax reduction. Secondly, there should be no spillover effects from the German tax reduction on the French gasoline market.

I use fixed effects on the station level to control for any time-invariant differences between gasoline stations in Germany and France. Date-fixed effects are used to control for symmetric shocks. Due to their geographic proximity, supply shocks should affect German and French gasoline stations similarly and are therefore controlled for through date-fixed effects. Furthermore, both countries are members of the European Single Market; hence, there are no border controls, and regulations are harmonized. Moreover, I control in detail for public and school holidays because they could affect the demand side notably. During the period studied, there were no travel restrictions due to the pandemic in either country.

Figures 1, 2, and 3 show that the assumption of common trends for Germany and France was fulfilled before the treatments for diesel, petrol E5, and petrol E10, respectively. Also, Appendix Figures 1-3 show the common trend depicting the evolution of the difference between average prices in Germany and France over time.

In 2022, the French mainland saw several fuel discounts. The first discount of 18 cpl was introduced on April 1, and it was increased to 30 cpl on September 1. Thus, a robustness check to check for treatment reversal is difficult. The French discount changed to 10 cpl on November 16 and ended on December 31. Overall, there were no tax changes or reforms during the period studied (April 14 to August 31).

Figure 1: Average Diesel Price Germany and France, April 14 to August 31, 2022

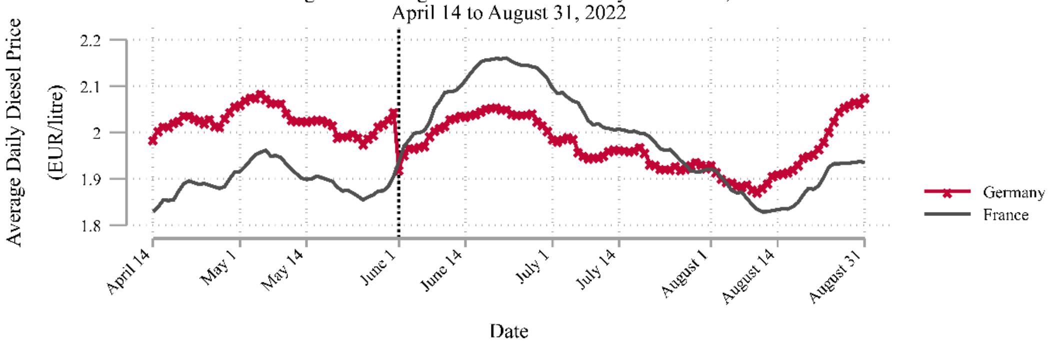


Figure 2: Average E5 Price Germany and France, April 14 to August 31, 2022

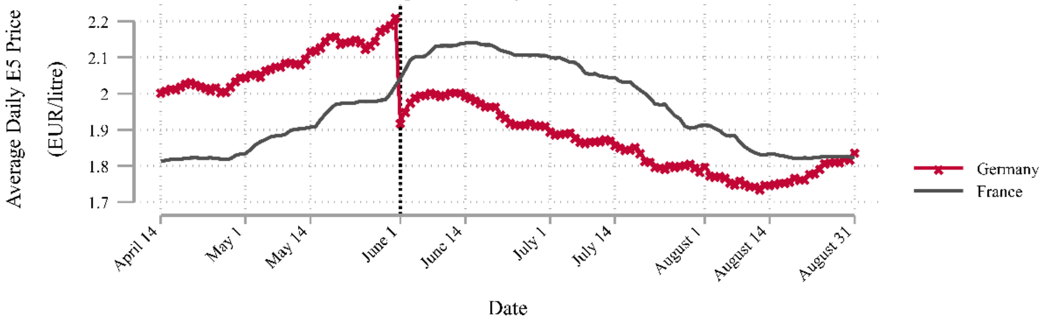
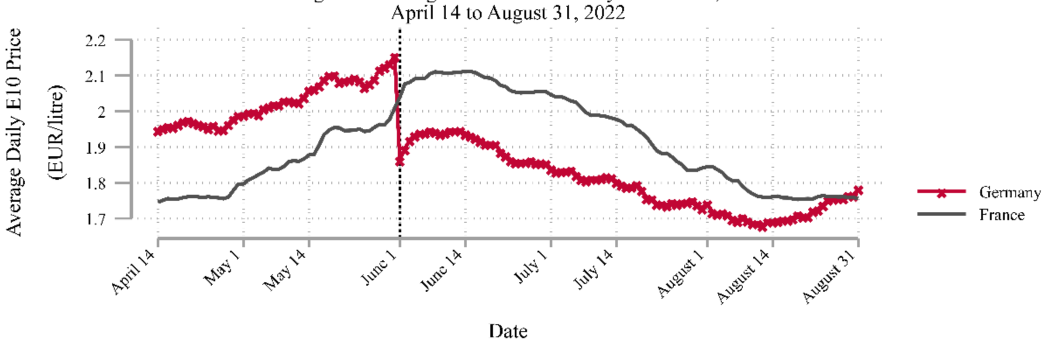


Figure 3: Average E10 Price Germany and France, April 14 to August 31, 2022



2.4.3 Countries in the European Union as a Control Group

Figures 4 and 5 show the weekly diesel price for Germany and those German EU neighboring countries with no tax changes in the relevant period (April 14 to August 31).[14] Similarly, Figures 6 and 7 show prices for petrol E5.

[14] See Appendix Table 4 for country codes.

Figure 4: Weekly Diesel Price for German EU Neighbour Countries (without tax changes), Apr. 14 to Aug. 31, 2022

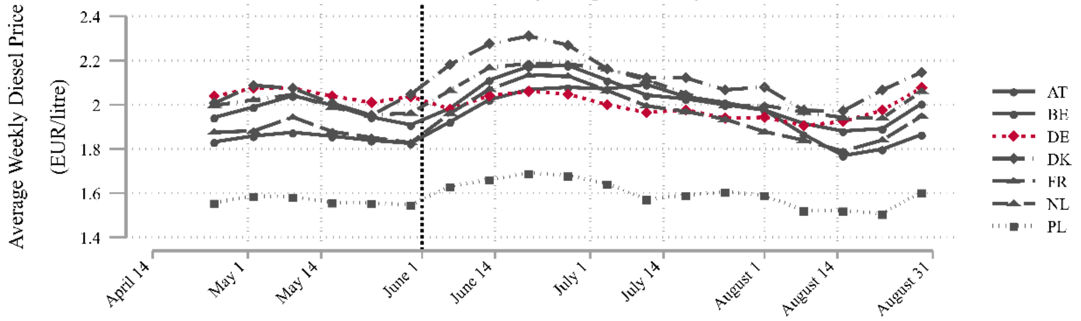


Figure 5: Weekly Diesel Price for Further EU Countries (without tax changes), Apr. 14 to Aug. 31, 2022

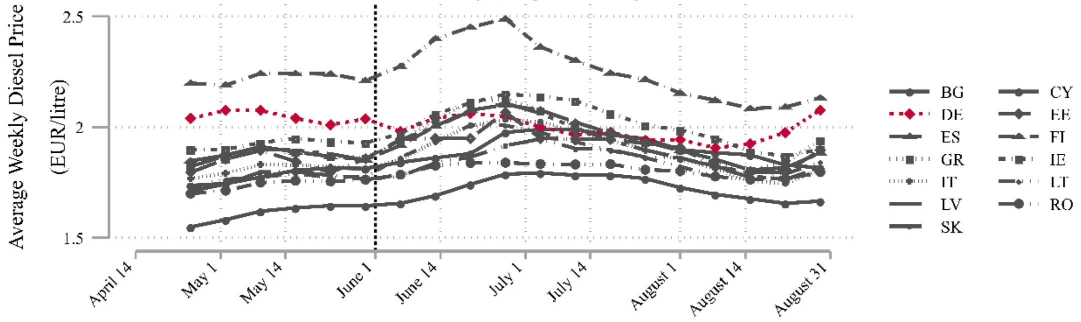


Figure 6: Weekly E5 Price for German EU Neighbour Countries (with no tax changes), Apr. 14 to Aug. 31, 2022

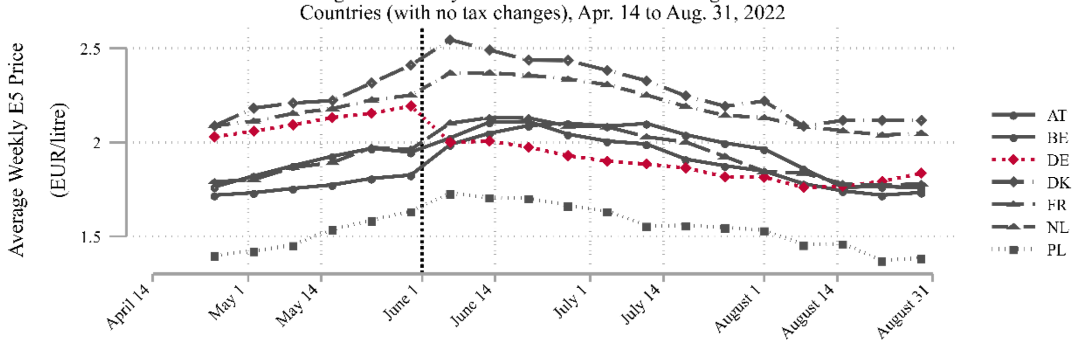
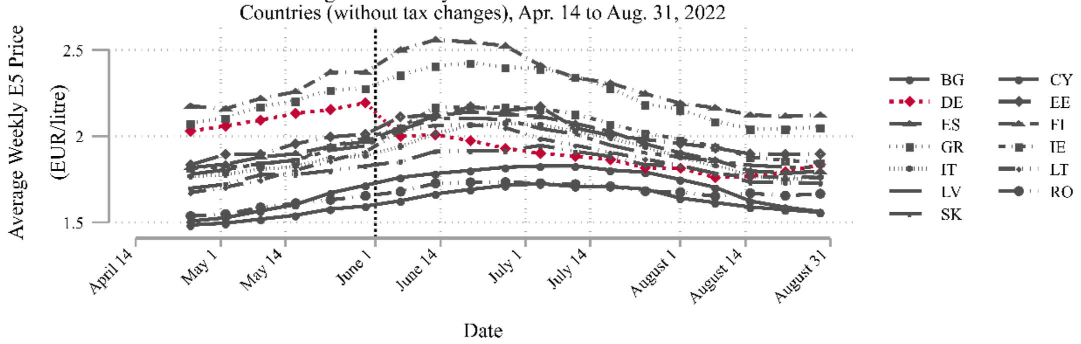


Figure 7: Weekly E5 Price for Further EU Countries (without tax changes), Apr. 14 to Aug. 31, 2022



I exclude all countries that implemented tax changes or reforms in the relevant period, as described in the data section. Again, prices in all these EU countries seem to have followed a similar trend, apart from Germany, before and after the German tax reduction. Price levels, however, vary substantially across different countries. Therefore, I conduct robustness checks with different country groups.

Again, I use station and date-fixed effects in DID regressions to control for time-invariant differences and symmetric shocks. The fact that the EU data are weekly price data makes it redundant to control in detail for public and school holidays because holidays vary substantially from day to day and throughout the regions of each country.

2.5 Results

The present section is partitioned into two subsections. The first subsection features the general regression outcomes when French gasoline stations are used as a control group. In the second subsection, I show detailed results for different geographical areas.

2.5.1 Results With France as a Control Group

Table 5 shows the results for diesel and petrol. The period considered reaches from April 14 to August 31, and French gasoline retailers are the control group.

Table 5: Difference-in-Differences Regressions (Germany & France)

	OLS, Diesel	Station FE, Diesel	Station Date FE, Diesel	Station Date FE, E5	Station Date FE, E10
Treated Stations	0.1315***	0.0000			
	(0.0008)	(.)			
Discount Period	0.1095***	0.1095***			
	(0.0004)	(0.0004)			
Treated Stations # Discount Period	-0.1490***	-0.1488***	-0.1489***	-0.3189***	-0.3056***
	(0.0004)	(0.0004)	(0.0004)	(0.0009)	(0.0006)
Public or School Holiday	-0.0422***	-0.0427***	-0.0130***	-0.0006**	-0.0081***
	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0002)
Brent crude oil closing price	0.6609***	0.6624***			
	(0.0026)	(0.0026)			
Constant	1.4750***	1.5549***	1.9345***	1.9680***	1.8868***
	(0.0018)	(0.0016)	(0.0003)	(0.0003)	(0.0003)
Observations	3249503	3249503	3249503	2466599	2825185
Adjusted R^2	0.302	0.399	0.651	0.886	0.884
Pass-Through Rate	89%	89%	89%	91%	87%
Station FE	No	Yes	Yes	Yes	Yes
Date FE	No	No	Yes	Yes	Yes
No. Clusters	24,113	24,113	24,113	18,492	20,946

Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In Table 5, column 1, the first coefficient of the ordinary least squares estimation (OLS), "Treated Stations," indicates that German gasoline retailers demanded, on average, 12.81 cpl more than their French counterparts before the duty reduction. In columns 1 and 2, the second coefficient, "Discount Period," shows that diesel prices were about 11.22 cpl higher on average for the control group in June, July, and August compared to April 14 to May 31. The coefficient is the same regardless of the use of station-fixed effects.

The third coefficient, "Treated Stations # Discount Period," indicates that the ATE was an average price reduction of 14.89 cpl. It is very similar for all three estimation techniques and most precisely estimated in column 3, the specification with entity and time fixed effects. This corresponds to an average pass-through rate of 89% for diesel. According to the fourth coefficient, "Public or School Holiday," holidays accounted for 1.3 cpl lower diesel prices on average in the entire data set.

Similarly, gasoline stations' average pass-through of the tax reduction was 91% and 87% for petrol E5 and E10, respectively, as shown in the columns to the right of Table 5. The effect of public and school holidays is smaller in magnitude and only statistically significant at the 1 percent confidence level. I present analogous tables to Table 5 for petrol E5 and E10 in Appendix Table 7. Surprisingly, the outcomes obtained from the various specifications with and without fixed effects hardly change (only marginally for petrol E5 and E10). This may be interpreted as evidence that unobserved heterogeneity is not very important in explaining differences in pass-through rates. Therefore, it does not seem too serious that including fixed effects was often overlooked in previous studies.

The next question is how the pass-through of the tax reduction evolved over time. Appendix Figures 1, 2, and 3 show the difference between German and French prices over time. Three observations can be made from these descriptive graphs: 1) It is difficult to tell whether German gasoline stations increased their prices prior to the tax reduction relative to the French stations from looking at the graphs, 2) The difference in prices seems to vary substantially over time, and 3) The German diesel price appears to reach its pre-treatment difference by the end of August, indicating no pass-through of the tax reduction towards the end of the fuel discount.

Next, I turn to whether gasoline stations increased their prices before the tax reduction. I use a DID estimation, focusing on three "pre-treatment" periods to compare them with the entire period before.

The first pre-treatment period is the whole week before the discount, hence the last week of May, because the discount took effect on June 1. The second pre-treatment period would be the last two days, and the third pre-treatment period would be the last day of May. These three periods are compared to the entire time before, e.g., April 14 to May 23 for the first case. I present the results for diesel in Table 6. Again, station and date fixed effects are used, and I control for public and school holidays.

All coefficients are statistically significant and positive, indicating a price increase before the tax discount took effect. However, the absolute change in average German gasoline prices is tiny, 0.5 to 0.8 cpl. Thus, the price increase was, on average, below 1 cpl.

Table 6: Was There a Price Increase in the Last Week/Last Two Days/Last Day Before? DID Regressions (Germany & France), Diesel

	Last Week of May	Last Two Days of May	Last Day of May
Treated Stations # Discount Period	0.0047***	0.0082***	0.0068***
	(0.0005)	(0.0005)	(0.0005)
Public or School Holiday	0.0020***	0.0014***	0.0015***
	(0.0002)	(0.0002)	(0.0002)
Constant	1.9242***	1.9246***	1.9245***
	(0.0003)	(0.0003)	(0.0003)
Observations	1110746	1110746	1110746
Adjusted R^2	0.480	0.480	0.480
Pass-through rate	-3%	-5%	-4%
Station FE	Yes	Yes	Yes
Date FE	Yes	Yes	Yes
No. Clusters	23,969	23,969	23,969

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The pass-through rate is shown as a negative number, which can be interpreted similarly to the pass-through rate of previous tables. Thus, the average German price increase for the week before the tax discount took effect was 3% of the tax discount of around 16.71 cpl for diesel and even increased to 5% for the last two days of the month.

In contrast to these results for diesel, the German gasoline stations slightly lowered the average price for petrol E5 and E10 already in the week before the tax reduction, Appendix Table 8. This price reduction corresponds to a 4% and 10% pass-through rate for petrol E5 and E10, respectively. The effect disappears when focusing on the last two days of the month for petrol E5 and stays roughly the same for petrol E10. Economically, such an early price reduction can result from decreased consumer demand in anticipation of the tax reduction. But why can we observe this price reduction only for petrol E5, an even sharper price reduction for petrol E10, and on the other hand, a weak increase in diesel prices?

Plausibly, diesel is predominantly used for business vehicles and large cars, hence by a group that is either inelastic or unconcerned about prices. Such a lower price elasticity of demand for diesel compared to petrol in the short run is also documented by Bach et al. (2019), Frondel and Vance (2014), Alberini et al. (2022), and Quack and Mechtel (forthcoming). Suppose demand does not decrease before a tax reduction. In that case, gasoline stations can easily maintain a high price, which I observe as a slight statistically significant increase in the average diesel price before the tax reduction. Furthermore, if German gasoline stations want to pretend to pass on the entire tax reduction, then they could raise the price before the tax reduction to achieve an artificially high reference price from which to lower their prices by the amount of the tax reduction while in fact not passing on the entire tax reduction. However, this only works if demand is sufficiently inelastic.

Private households in Germany predominantly use petrol cars. In 2022, a share of about 64% of German passenger cars ran on petrol E5 or E10 and about 31% on diesel, with the remaining 5% fueling liquid gas, natural gas, or electric (Bundesministerium für Digitales und Verkehr, 2022). Petrol E5 and E10 are not taxed differently; however, petrol E10 prices are, on average, almost 6 cpl lower than petrol E5.[15] This may be partly driven by the relative prices of ethanol and crude oil and partly by a minimum quota of biofuels required to be sold by German gasoline stations (Montag et al., 2020). Thus, price-sensitive consumers are likely to fuel petrol E10 rather than petrol E5 and are also more likely to react by drastically decreasing gasoline demand when expecting a tax decrease. Such a demand reduction negatively affects the market price, which I observe as an economically relevant reduction in the average petrol E10 price before the tax reduction took effect. However, the overall price changes before the tax reduction were relatively small.

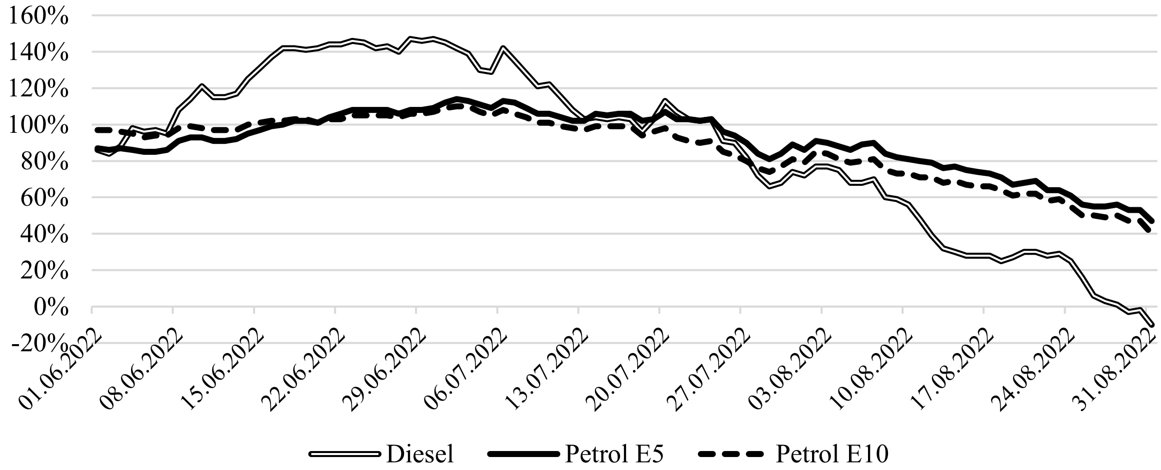
How did the pass-through rates of the German gasoline tax reduction evolve? I conducted DID regressions to estimate the pass-through rates for each week and day in the treatment period (June, July, and August) compared to the entire pre-treatment time (April 14 to the end of May). The results of DID estimates for every week in the treatment period, which I compare separately to the entire period before the tax reduction, are presented in Appendix Tables 9 to 11 for diesel, petrol E5, and petrol E10, respectively. The first week runs from Wednesday, June 1, to Tuesday, June 7; the second week begins on Wednesday, June 8, and so on. The last week extends for eight days, from Wednesday, August 24, to Wednesday, August 31. I use station and date fixed effects and control for public and school holidays. Results for weekly pass-through rates for all fuel types are summarized in Appendix Figure 4.

Similar to the weekly analysis, I conducted DID regressions to estimate pass-through rates for every single day. These results are summarized in Figure 8.[16] Pass-through rates for petrol E5 and petrol E10 evolve very similarly over time. The pass-through rates are below 100% for the first two weeks of June and rise slightly above afterward, peaking at 114% and 110%, respectively, on July 2. The rate for petrol E5 fell below 100% on July 25 and reached its trough of 47% on August 31. On July 11, the rate for petrol E10 fell below 100%, reaching its trough

[15] See descriptive statistics in Appendix Tables 1 and 2.
[16] It is one DID regression with station and date-fixed effects, controlling for public and school holidays for each day and fuel type, hence 276 regressions overall that underlie Figure 8. Results tables are provided on demand.

of 40% on August 31. The pass-through rate was at least 100% on 38 and 27 days out of 92 days for petrol E5 and E10, respectively.

Figure 8: Daily Pass-through Rates of the German Gasoline Tax Reduction Over Time (France as Control Group), 2022



However, for diesel, the deviations from complete pass-through are more extreme. The rate starts at 86% on June 1 and increases subsequently, reaching full pass-through on June 8. The rate rises further and reaches its peak of 147% on June 28 and June 30. It decreases with more substantial fluctuations, reaching a trough of -10% on August 31. The pass-through rate of 100% was reached or exceeded on 48 out of 92 days.

Overall, there were relatively small price changes before the gasoline tax reduction took effect. However, pass-through rates vary substantially over time, and full pass-on of the tax reduction was reached on about half the days for diesel, substantially fewer days for petrol E5, and even fewer days for petrol E10. It can be concluded that, on average, German petrol stations passed on the entire tax discount on about 52% of the days for diesel, 41% for petrol E5, and 29% for petrol E10. The gasoline tax reduction was, on average, not passed on fully, with rates of 89%, 91%, and 87% for diesel, petrol E5, and petrol E10, respectively. All results are statistically significant at the 0.1% confidence level.

2.5.2 Spatial Results

In this subsection, I present results for the spatial analysis of pass-through rates for diesel because the patterns are very similar for the other fuel types. This analysis is only feasible based on the dataset with France as a control group because this dataset provides the fine geographic granularity required for such an analysis.

Table 7: Pass-Through Rates for the Federal States, Diesel

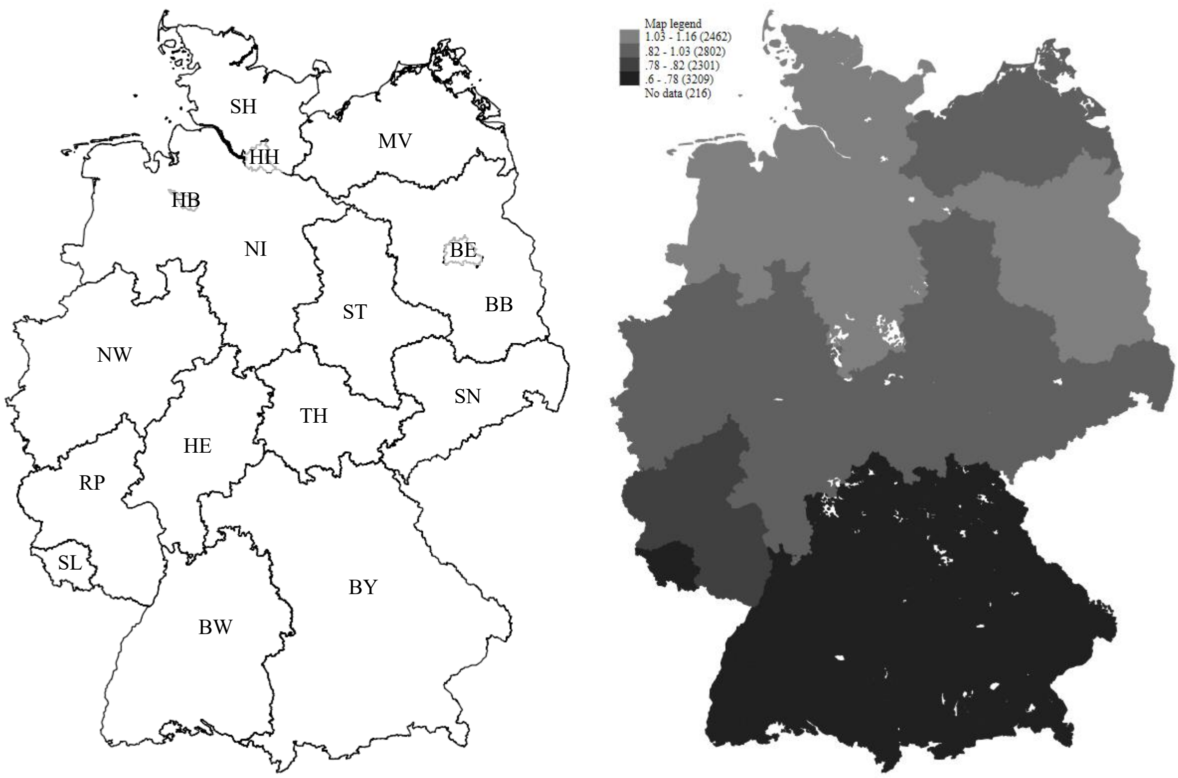
	BB	BE	BW	BY	HB	HE	HH	MV	NI	NW	RP	SH	SL	SN	ST	TH
Discount Period # Treated Stations	-0.181***	-0.194***	-0.131***	-0.100***	-0.177***	-0.141***	-0.185***	-0.171***	-0.174***	-0.168***	-0.138***	-0.181***	-0.128***	-0.140***	-0.159***	-0.144***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Public or School Holiday	-0.007***	-0.003***	-0.002***	-0.016***	0.001**	0.015***	-0.002***	-0.010***	-0.008***	-0.053***	0.011***	-0.010***	0.004***	-0.004***	-0.004***	-0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.839***	1.834***	1.855***	1.867***	1.830***	1.837***	1.833***	1.841***	1.862***	1.898***	1.833***	1.845***	1.829***	1.839***	1.838***	1.835***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	1312895	1292488	1504884	1578159	1267486	1408493	1281794	1303241	1509860	1668902	1356291	1338059	1276138	1334340	1313939	1309326
Adjusted R2	0.826	0.829	0.731	0.691	0.830	0.780	0.831	0.825	0.818	0.802	0.792	0.828	0.819	0.814	0.822	0.818
Pass-through rate	108%	116%	78%	60%	106%	84%	111%	103%	104%	101%	82%	108%	77%	84%	95%	86%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	9,421	9,267	10,941	11,607	9,088	10,145	9,193	9,344	10,936	12,055	9,759	9,600	9,153	9,577	9,426	9,402

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In Table 7, I present the pass-through rates by federal states. There are substantial differences in pass-through rates, ranging from an average of only 60% in Bavaria to 116% in Berlin. The average pass-through rates for East and West Germany are not shown but are estimated to be 94% and 88%.

I excluded Berlin when presenting the rates for East and West Germany because Berlin was divided before the German reunification. Thus, East Germany consisted of today's federal states Brandenburg, Mecklenburg-Western Pomerania, Saxony, Saxony-Anhalt, and Thuringia. The difference of 6 percentage points in pass-through rates is relatively small compared to the difference between federal states. Hence, differences in pass-through rates do not appear to be due to historically evolved disparities in East and West Germany. Such East-West differences could have manifested themselves in systematically different infrastructures, which could be due to different economic policies, or the disparities could have resulted from differences in behavior. Therefore, in the next step, I present the pass-through rates by federal state to reveal possible patterns.

Figure 9: Pass-Through Rates for Different Geographical Regions, Diesel



a) Federal states b) Pass-through rates

In the map in Figure 9[19], the different pass-through rates for the respective states are illustrated by different shading. The shading reveals a systematic difference between the north of Germany, which has high pass-through rates illustrated by lighter shading, and the south of Germany, which has low pass-through rates highlighted by darker shading. The average pass-through rate for the city-states (Berlin, Bremen, and Hamburg) is 112% compared to only 88% for area states. This difference of 24 percentage points is remarkable and could be driven by better outside options in urban areas. Better availability of public transport in urban regions can lead to a higher price elasticity of demand and, thus, result in lower demand as prices increase. Lower demand leads to lower prices that yield higher pass-through rates.[20] Therefore, I will present pass-through rates that differentiate between urban and rural areas next.[21]

Table 8 displays estimation results for the geographical regions according to the Eurostat definition. The pass-through rate is, on average, 82% in predominantly rural areas and 92% in predominantly urban areas.

Table 8: Pass-Through Rates for Rural and Urban Areas (Eurostat Definition), Diesel

	Predominantly rural	Intermediate	Predominantly urban
Discount Period # Treated Stations	-0.137***	-0.150***	-0.154***
	(0.001)	(0.001)	(0.001)
Public or School Holiday	-0.011***	-0.015***	-0.023***
	(0.000)	(0.000)	(0.000)
Constant	1.872***	1.906***	1.896***
	(0.000)	(0.000)	(0.001)
Observations	1660901	2160964	1935358
Adjusted R^2	0.722	0.700	0.725
Pass-Through Rate	82%	90%	92%
Station FE	Yes	Yes	Yes
Date FE	Yes	Yes	Yes
No. Clusters	12,219	15,902	14,033

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The finest granularity with respect to urban-rural classification available from the BBSR dataset provides a hierarchical categorization differentiating 17 urbanization categories as listed in Table 3. I present the respective regression results in Appendix Table 12. The pass-through rate in a Metropolis, larger city, or medium-sized city in a metropolitan city region is, on average, between 94% and 96% (categories 1 to 3). The pass-through rate is between 77% and 88% in urbanization categories 12 to 17, which are either rural or peripheral rural regions. The

[19] The author would like to thank Jonas Dix for help with visualizing the results on maps.
[20] The higher price elasticity of demand in urban areas may have been boosted by the introduction of a discounted ticket for local public transport, as discussed in detail in section 6.
[21] Detailed estimation results for East and West Germany, as well as for city-states, are available on request.

remaining areas have experienced pass-through rates between 85% and 92%. These results underpin the previous results, which I obtained using the Eurostat definition. The results are visualized in Appendix Figure 5. Specifically, it supports the finding of higher pass-through rates in urban areas and lower rates in rural areas, but with a slightly higher pass-through rate in very rural areas. This higher pass-through rate in very rural areas may be due to higher price elasticity of demand. Such higher elasticity may result from the fact that people in very rural regions regularly visit commercial centers (nearby towns or cities) for everyday supplies and, thus, drive more kilometers regularly, giving them more choices about where to fuel.

Next, I present results for different border regions in Table 9. Pass-through rates are much lower at the borders in the south of Germany than in the German inland and much higher at the borders to Denmark, Benelux, Poland, and the Coast to the Baltic Sea.

Table 9: The Pass-Through Rates at Germany's External Borders, Diesel

	AT	BE, NL, LU	CH	CZ	Coast	DE	DK	FR	PL
Discount Period # Treated Stations	-0.090***	-0.162***	-0.120***	-0.130***	-0.173***	-0.150***	-0.193***	-0.136***	-0.182***
	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Public or School Holiday	-0.007***	-0.027***	-0.000	-0.005***	-0.009***	-0.014***	-0.002***	0.003***	-0.003***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.838***	1.856***	1.831***	1.838***	1.842***	1.924***	1.831***	1.836***	1.833***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Observations	1303037	1386647	1272653	1318988	1305616	2808188	1270592	1334159	1280503
Adjusted R^2	0.804	0.811	0.821	0.811	0.826	0.664	0.830	0.795	0.828
Pass-Through Rate	54%	97%	72%	78%	104%	90%	116%	81%	109%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	9,394	10,022	9,133	9,493	9,365	20,716	9,109	9,607	9,179

Robust standard errors in parentheses; * p < 0.05, ** p < 0.01, *** p < 0.001

The Map in Appendix Figure 6 visualizes each border region's different pass-through rates and the geographical demarcation of the border regions. This demarcation is carried out in accordance with the BBSR's definition of border regions at the county level. The pass-through rates are remarkably different for the various border regions and, again, appear to be lowest in the south of Germany.

Overall, there are substantial geographical differences with respect to the pass-through rates of the fuel discount in Germany. Two findings persist across all estimation results. Firstly, the rates are lower in rural regions than in the urban areas, and secondly, the rates are lower in the south than in the north of Germany. Further research is needed to explain these geographical differences. Future research may focus on differences in infrastructure and transportation costs. The latter may have varied due to droughts in the summer months. Droughts can have a significant impact on transportation costs because goods can no longer be transported south by water, which is the usual transport route for fuels (Haas, 2019).

Differences in infrastructure may be related to different mobility policies pursued by the various federal states. States with a large automotive industry may have relied more heavily on the car as a means of transportation. Finally, the media coverage and, thus, the topic salience of the fuel tax reduction may have differed in the federal states, which could have led to differences in the price elasticity of demand and hence contributed to the enormous differences in pass-through rates.

2.6 Discussion of Threats to Validity and Robustness Checks

In this section, I focus on weekly EU price data first, then look at typical robustness checks and discuss possible threats to validity. Thus, I present the regression results for estimates utilizing all countries within the EU that have maintained constant tax policies throughout the period analyzed as a control group in the first subsection. The second subsection shows a placebo test and various further robustness checks. I end with a discussion of the external validity.

2.6.1 Results With Countries in the European Union as a Control Group

The results presented in the results section are based on DID estimates with high-frequency data from all French gasoline stations as a control group. Even though France is commonly used as a control group, as discussed in the introduction, and the common trend assumption seems to be fulfilled, as discussed in section 4.2, I use weekly data for all countries in the EU for further analysis. Also, I stick to data from the European Commission (2022) for Germany and France. First, I look at the average pass-through rate; second, I focus on whether German gasoline stations increased their prices before the tax reduction took effect; and third, I focus on the evolution of pass-through rates over time.

In Table 10, I show the results of DID estimation for diesel and petrol E5 with station and date fixed effects. I use data for all countries in the EU that did not change taxes during the relevant period from April 14 to August 31, 2022. Recall that it is not controlled for public and school holidays, as discussed in section 4.3. Furthermore, there are no data available for petrol E10.

The coefficients are statistically significant at the 0.1 confidence level. The pass-through rates are close to the ones estimated with France as the control group. Namely, the average pass-through rate for diesel is about 85% and about 94% for petrol.

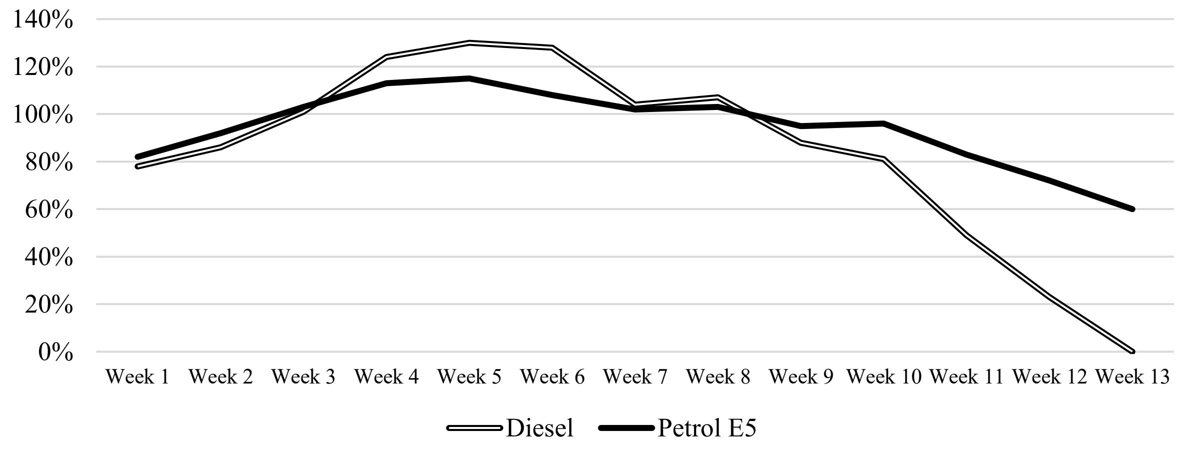
Table 10: Difference-in-Differences Regressions (EU), Diesel and E5

	Diesel	E5
Discount Period # Treated Stations	-0.1412***	-0.3310***
	(0.0065)	(0.0106)
Constant	1.8330***	1.7914***
	(0.0069)	(0.0059)
Observations	360	360
Adjusted R^2	0.771	0.847
Pass-through rate	85%	94%
Station FE	Yes	Yes
Date FE	Yes	Yes
No. Clusters	19	19

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Again, the next question I aim to answer is whether gasoline stations increased their prices prior to the tax reduction. I compare the last week before the tax reduction (the last week of May) to the weeks before. In contrast to the case where I used France as the control group, I cannot present daily results here because there is only weekly data. I cannot find any price increase or decrease the week before the tax reduction, as shown in Appendix Table 13. The coefficients are statistically insignificant and positive for both diesel and petrol E5. The pass-through rate is 2% and 3%, respectively. The last week of May corresponds to one observation in the weekly data for countries in the EU. It is, therefore, not as well suited for analysis of short periods as the data source with high-frequency data for Germany and France.

Figure 10: Weekly Pass-through Rates of the German Gasoline Tax Reduction Over Time (EU as Control Group), 2022



Finally, I show how the pass-through rate changes over time when using countries in the EU as a control group instead of French gasoline stations. I visualize the pass-through rates in Figure

10, which is based on EU countries as a control group and very similar to Appendix Figure 4, which was based on France as a control group. I present the regression output underlying Figure 10 in Appendix Tables 14 and 15 for diesel and petrol E5, respectively.

The pattern of the evolution of pass-through rates of the German tax reduction over time, which is based on the analysis of weekly data from 19 countries in the EU, matches the results based on high-frequency data for Germany and France. The pattern appears to be less pronounced when using all countries in the EU which did not change taxes. The rates for diesel appear to be systematically lower (than in the case with France as the control group), starting at 78% and peaking at 130% in Week 5 (in contrast to 92% and 144%, respectively, in the France case). Then, the rate decreases, very similar to the case with France, to about 0% pass-through at the end of August.

The evolution of pass-through rates for petrol E5 when using countries in the EU as a control group is very similar to the results when using France as a control group. They start at 82% and 86%, peak at 115% and 111% in week 5, and decrease to 60% and 53% for the EU and France cases, respectively. Differences in topic salience could explain this difference in pass-through rates over time because pass-through increases with the share of well-informed consumers, as discussed by Montag et al. (2023). Dovern et al. (2023) suspect that a rise in demand before the termination of the tax reduction and increasing transportation costs due to lower river water levels resulting from the drought in the summer of 2022 may have led to lower pass-through rates towards the end of August.

The average weekly pass-through rates for diesel and petrol E5 were six weeks above and seven weeks below full pass-through for EU data. When using solely French gas stations as a control group, the average weekly pass-through rate for diesel was seven weeks above full pass-through. However, diesel rates dropped very far below full pass-through toward the end of August in this latter case.

Overall, the results are insensitive to changing the control group from French gasoline stations to weekly data on gasoline prices for countries in the EU. On average, pass-through rates were below 100% for all gasoline types. The average estimates are pass-through rates of 89% and 85% for diesel and 91% and 94% for petrol E5 for the control groups France and the EU.

I present two robustness checks with respect to varying the control group, which consists of countries in the EU. Firstly, I excluded the three countries with the lowest price levels, and secondly, I have only included countries that are not neighboring countries of Germany.

For simplicity, I exclude the three countries with the lowest price levels. I look at the mean price from the descriptive statistics tables, Appendix Tables 5 and 6, for diesel and petrol E5, respectively. Namely, I exclude Bulgaria, Poland, and Romania and present results analogous to Table 10 in Appendix Table 16. Results are robust with respect to this selection – only the pass-through rate for diesel increases by about one percentage point.

Next, I look at pass-through rates when the control group is limited to German non-neighboring countries in the EU that did not change their taxes in the relevant period. I present the results in Appendix Table 17. The pass-through rate for diesel is one percentage point above the one in Table 10, and the pass-through rate for petrol E5 is three percentage points higher. Overall, the weekly analysis using different countries in the EU is very similar.

2.6.2 Further Robustness Checks

For the placebo test, I split the month of May in half, treating the second half as if it were the policy period. Thus, I took the data from May 1 to May 31 and set May 15 as the first treatment day. I include station- and date-fixed effects. Additionally, I control for public and school holidays in the case of French gasoline stations as the control group. The results for the case with French stations as the control group are presented in Appendix Table 18. There is a slightly negative pass-through rate of -3% for diesel and low positive rates of 3% for petrol E5 and 8% for petrol E10. This could still be biased by what happened in the last week. Excluding the last week of May and setting the first treatment day to May 13 decreases all pass-through rates to 0%, 1%, and 6%, respectively (Appendix Table 19). It appears that there was a minor decrease in petrol E10 prices.[22] Overall, the placebo test yields the expected results, namely that there is no effect, supporting the common-trend assumption. Moreover, German pass-through rates obtained using French gasoline stations as the control group may be less robust towards the end of the tax reduction because France reduced its fuel discount on September 1, 2022.

My results show that the pass-through rate in Germany varies over time. This time-varying rate follows a clear pattern over the fuel discount period. On average, the pass-through rate is below 100% in the first week and above full pass-through in the following weeks, eventually declining in the last half of the treatment period. If the same time-varying nature of pass-through rates also applies to the French case, then the time-varying results are blurred when using France as a control group. Thus, estimates of the pass-through rates for longer periods are not reliable. However, the results are supported by estimates that use all countries of the EU as a control

[22] Results for the very same placebo test based on data with countries of the EU as a control group are not statistically significant at the 0.1% level.

group, which may indicate that there is no or a less pronounced temporal variation in the pass-through rates of the French reliefs.

Due to the availability of high-frequency data on the station level for France and Germany, average pass-through rates for single brands can be estimated. I found no significant differences in the major brands' pass-through rates (Aral, Shell, Esso, Total, and Jet), as presented for diesel in Appendix Table 20.[23]

I present robustness checks for the spatial analysis in Appendix Tables 21 and 22. For the robustness checks, I used different spatial delineation definitions offered by the BBSR, as indicated in the first row below the title. In Appendix Table 21, the first definition refers to the population. According to this definition, there are marginally lower pass-through rates in predominantly rural areas compared to predominantly urban areas. The spatial delineation with respect to location reveals higher pass-through rates in very central regions compared to peripheral regions. However, higher pass-through rates for very peripheral regions indicate a U-shaped relation between urbanization and pass-through rates with higher pass-through rates in urban and very peripheral regions. The BBSR classification of rural and urban confirms that pass-through rates are lower in rural areas. I present estimates for the BBSR settlement structure types in Appendix Table 22, which confirm a U-shape relation. The second classification for which I present estimates in this table distinguishes the cities and municipalities according to their size. Larger cities and towns have higher pass-through rates compared to smaller ones. Rural municipalities have marginally higher pass-through rates than smaller towns.

The results are similar for the other fuel types. Pass-through estimates for federal states for petrol E5 and E10 are less pronounced than for diesel and are presented in Appendix Tables 23 and 24, respectively. For petrol E5 (E10), the average pass-through rate in predominantly rural areas was 87% (83%) and in predominantly urban areas 93% (90%). The pattern along the border regions is similar to the one for diesel but less pronounced.[24]

Pass-through rates may be slightly overestimated because, at the same time as the tax reduction on gasoline, the German government introduced a monthly 9-Euro-Ticket for local public transport, which could have negatively affected demand during the gasoline tax reduction. This negative demand shock could have led to lower gasoline prices than the counterfactual. Hence, the estimates presented here, which already suggest an under-proportional pass-through, are high in the sense that they may already capture price-lowering effects from the negative demand

[23] There are no surprises with respect to the results for single brands and petrol E5 or petrol E10.
[24] Detailed estimation results for petrol E5 and E10 are available on request.

shock caused by the 9-Euro-Ticket. In other words, pass-through estimates might have been lower in the absence of the 9-Euro-Ticket because demand might have been higher. However, this effect is expected to be small because switching from care usage to public transport was rare (Gaus et al., 2023; Statistisches Bundesamt, 2022), as discussed in the data description section. The external validity might still be limited when looking at exact pass-through rates; however, the mechanisms are likely to occur as observed here in similar gasoline markets, such as the evolution of the pass-through rates over time.

Finally, I am providing estimation results of robustness checks with respect to relaxing the parallel trends assumption following Rambachan and Roth (2023). This robustness check is limited to the dataset with EU countries as a control group.[25] The post-treatment coefficients appear to reflect a substantial pass-through rate compared to any pre-treatment coefficients (Appendix Figure 7). This visualization shows that there appears to have been a difference in trends before the treatment. Nevertheless, the post-treatment coefficients appear to be substantially larger in magnitude than any of the pre-treatment coefficients. Appendix Figure 8 shows robust confidence sets for the treatment effect in the first period using different values for the maximum parallel trends violation, abbreviated $\bar{M}$ (Mbar). For example, $\bar{M} = 1$ implies that I restrict the post-treatment violations of parallel trends to be no larger than the maximal pre-treatment violation (Rambachan and Roth, 2023). I present the confidence bands for various values of $\bar{M}$ in Appendix Figure 8, to the right of the original confidence set. The conclusion of a significant pass-through rate holds even if I restrict post-treatment violations of parallel trends to be no larger than three times as large as the maximal pre-treatment violation.

2.7 Conclusion

Governments of Western economies worldwide introduced relief packages to mitigate the effects of rocketing energy prices during the global post-pandemic economic recovery and the Russian aggression towards Ukraine. Germany reduced the gasoline tax from the beginning of June to the end of August 2022. The German gasoline market is being intensively researched, and all price data are collected by federal authorities to be able to intervene in cases of market power abuse.

I am the first to present results based on high-frequency data for Germany and France and on weekly data for all countries in the EU for the entire period in which the tax reduction was in effect. I control for public and school holidays when using high-frequency data for Germany

[25] Estimation based on the far more extensive dataset with French gasoline stations as a control group was not feasible, presumably due to a lack of computing power.

and France. In addition to providing precise estimates of the average pass-through of the tax reduction, I present results for different brands and results on the evolution of pass-through rates over time. Moreover, I am the first to reveal the enormous differences in pass-through rates over space. General results show that the average pass-through is high but incomplete, with rates of 85% to 89% for diesel, 91% to 94% for petrol E5, and 87% for petrol E10. In contrast to public opinion, there was no price increase before the tax reduction came into effect.

Furthermore, the high-frequency data yielded interesting insights into the evolution of pass-through rates over time. Pass-through was incomplete at the beginning of the tax reduction and decreased to zero for diesel and about 45% to 60% for petrol by the end of August, just before the tax reduction terminated. Thus, pass-through rates vary substantially over time, which could be explained by falling media attention, decreasing presence in the public debate, higher demand in anticipation of rising taxes, and higher costs in southern Germany due to lower river water levels resulting from the drought in summer 2022.

Finally, the price dataset's geographical granularity, with French gasoline stations as the control group, allows for estimating pass-through rates for different areas. There are substantial differences in pass-through rates for the German federal states, reaching from 60% for Bavaria to 116% for Berlin. There is only a slight difference between average pass-through rates for East and West Germany. City-states have much higher pass-through rates on average than area federal states. The estimates reveal considerably higher pass-through rates in the north of Germany compared to the south. Various specifications provide robust evidence that the pass-through rates are higher in urban than in rural regions. According to the Eurostat spatial delineation of rural and urban areas, the average diesel pass-through rate is 82% in predominantly rural and 92% in predominantly urban areas. Tremendous differences in pass-through rates over border regions seem to be driven by the south-north differences. These results are very similar for the various fuel types. Furthermore, I found no differences in the major brands' pass-through rates.

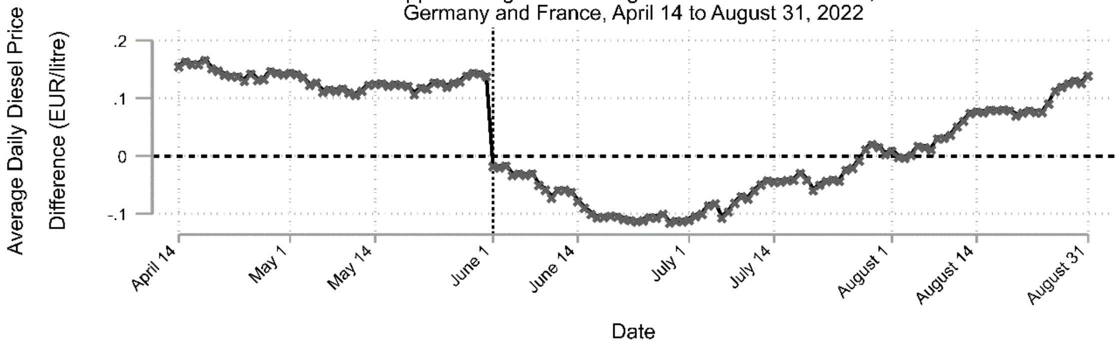
Generally, results are confirmed when using weekly data for all countries in the EU as a control group, which did not change their taxes during the relevant period, compared to using all French gasoline stations as a control group. Not surprisingly, the peaks are more moderate when looking at the evolution of pass-through rates over time using countries in the EU as a control group because weekly averages instead of daily data are used. Results are robust to changes in the composition of the control group.

The key results are that pass-through was high but incomplete on average and that pass-through rates of the tax reduction varied substantially over time and space. Further research may focus on the determinants of these anomalies in pass-through rates over time and space and spillover effects in border regions. The results of this article suggest that the urban structure and the available infrastructure should be looked at closely. Furthermore, transportation costs and media attention may explain the differences in pass-through rates over space and time.

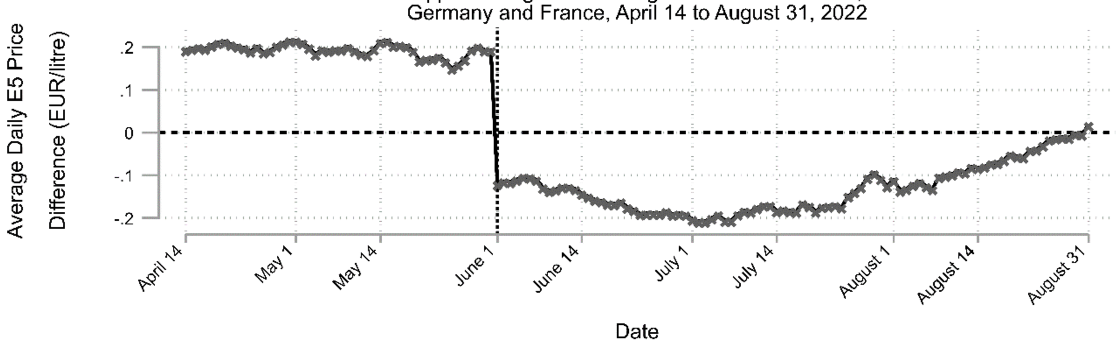
2.8 Appendix

2.8.1 Appendix Figures

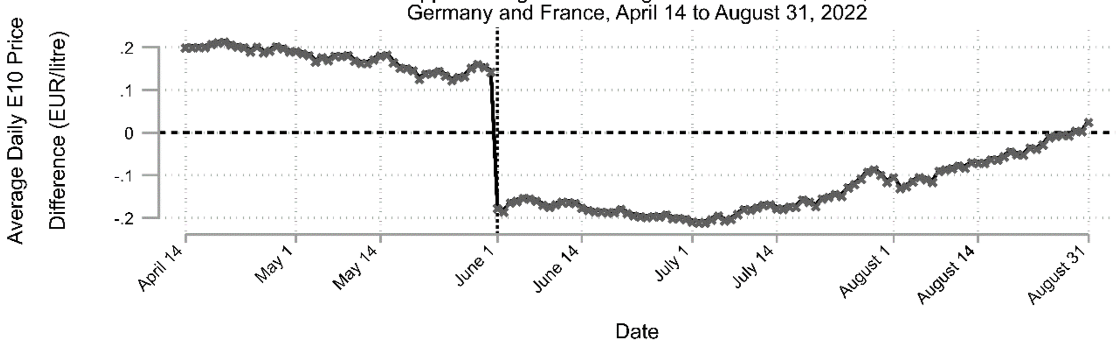
Appendix Figure 1: Average Diesel Price Difference, Germany and France, April 14 to August 31, 2022



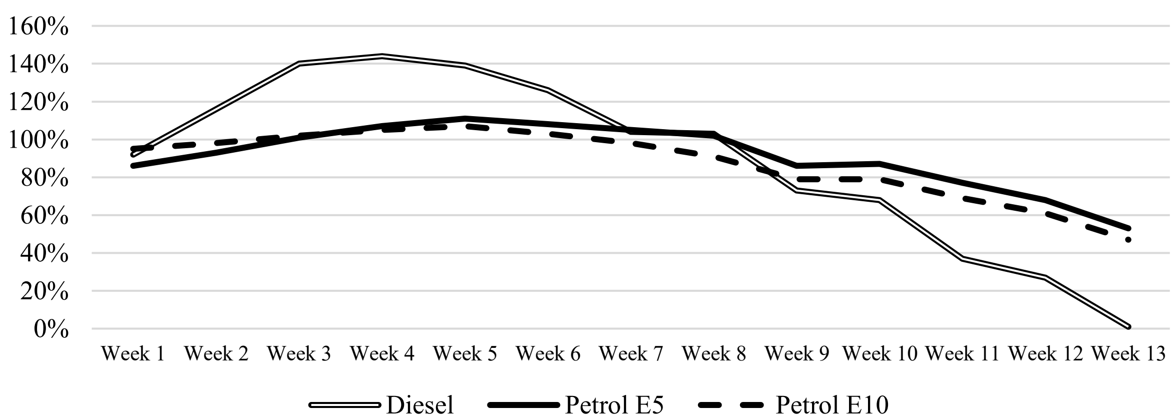
Appendix Figure 2: Average E5 Price Difference, Germany and France, April 14 to August 31, 2022



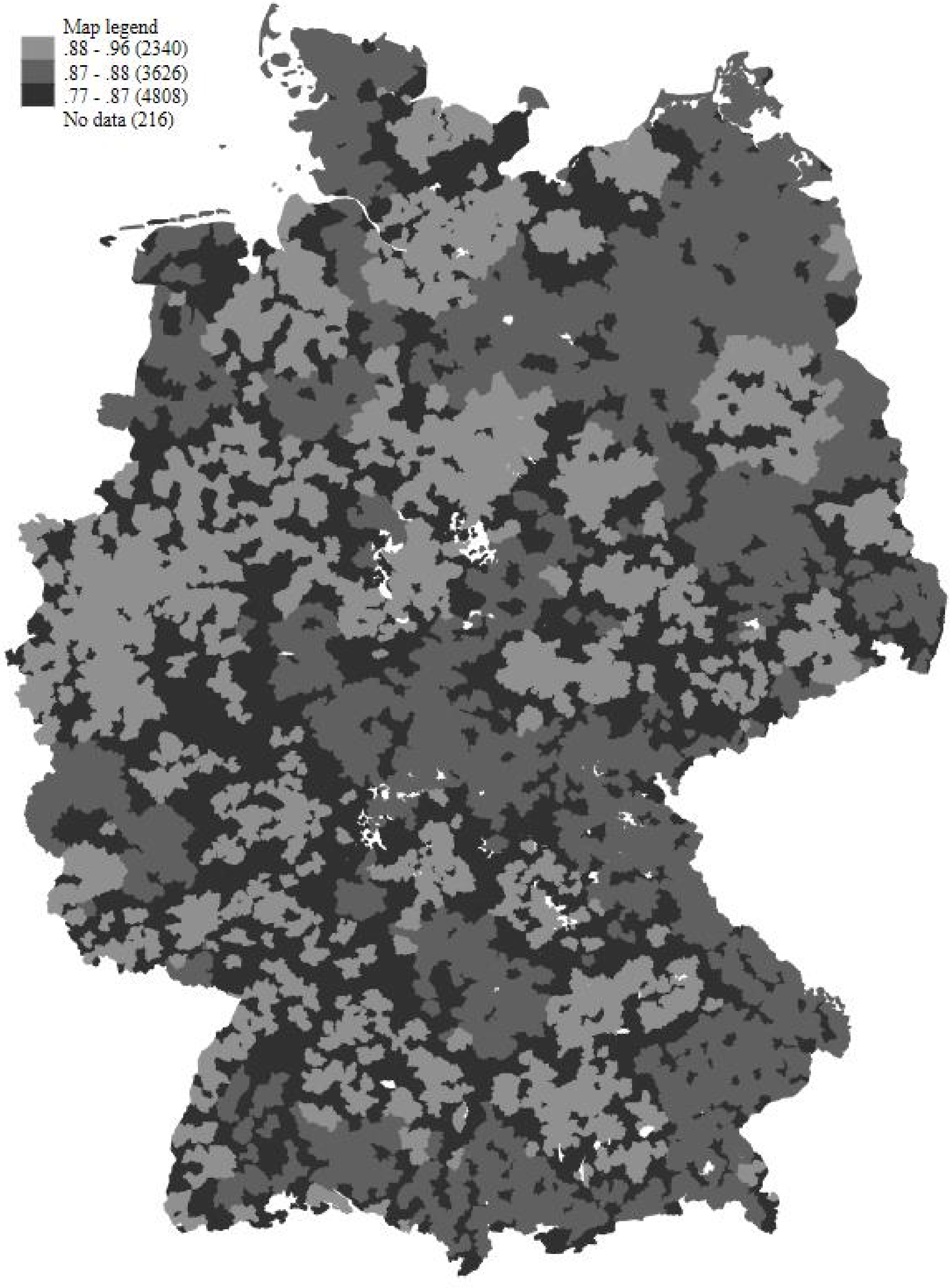
Appendix Figure 3: Average E10 Price Difference, Germany and France, April 14 to August 31, 2022



Appendix Figure 4: Weekly Pass-through Rates of the German Gasoline Tax Reduction Over Time (France as Control Group), 2022

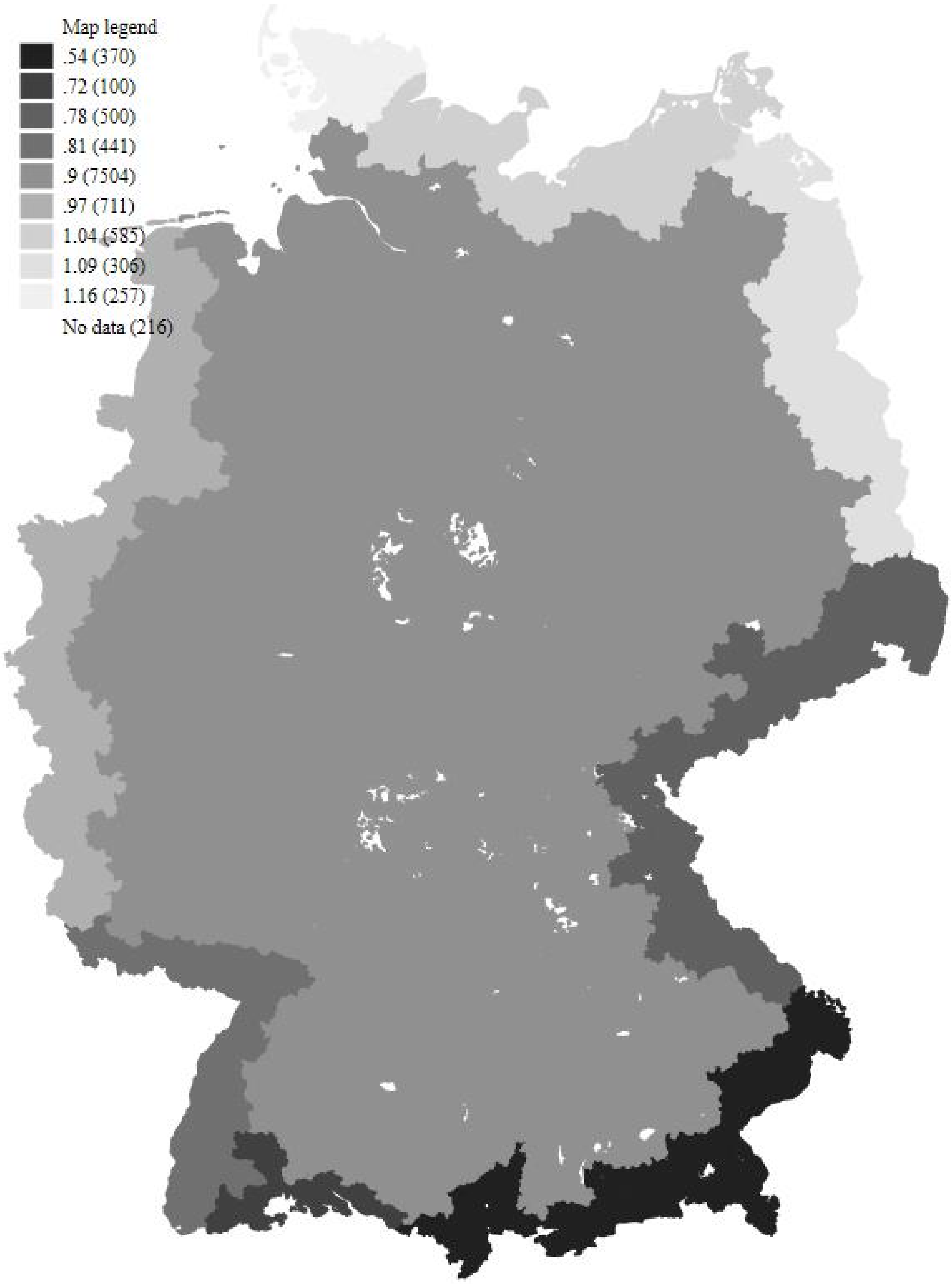


Appendix Figure 5: The Pass-Through Rates for 17 Different BBSR Region Types, Diesel



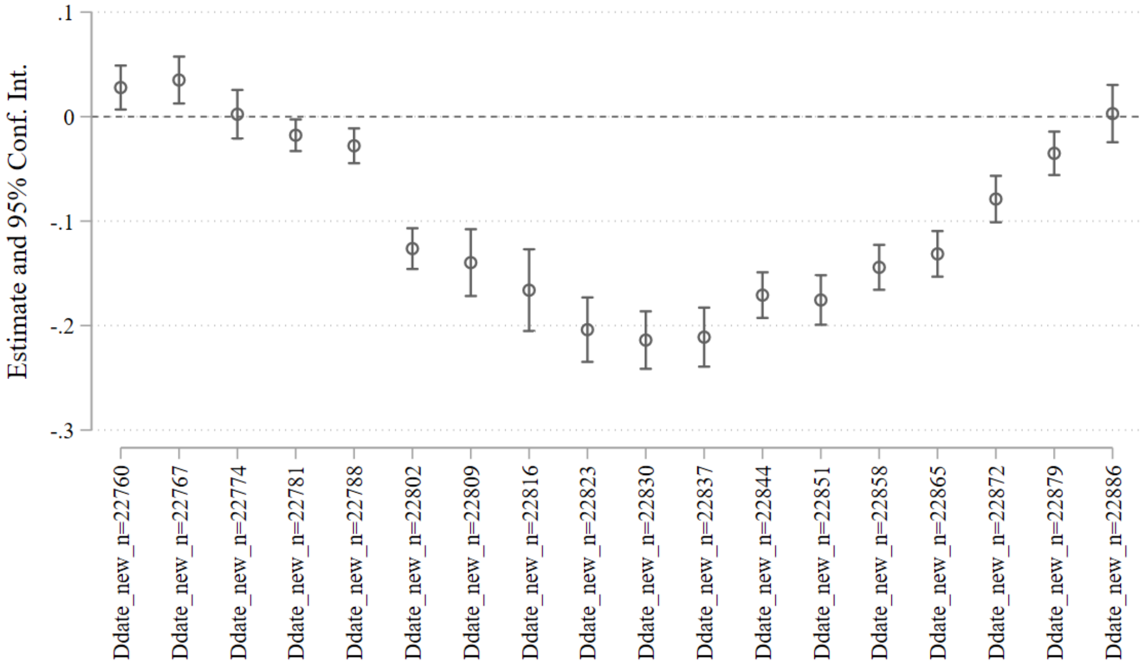
The municipalities in dark gray have an average pass-through rate below 87%. The lighter shading represents higher pass-through rates. No data is available for the areas colored white on the map, which are regions without retailers, large forests, mountains, and lakes.

Appendix Figure 6: The Pass-Through Rates at Germany's External Borders, Diesel

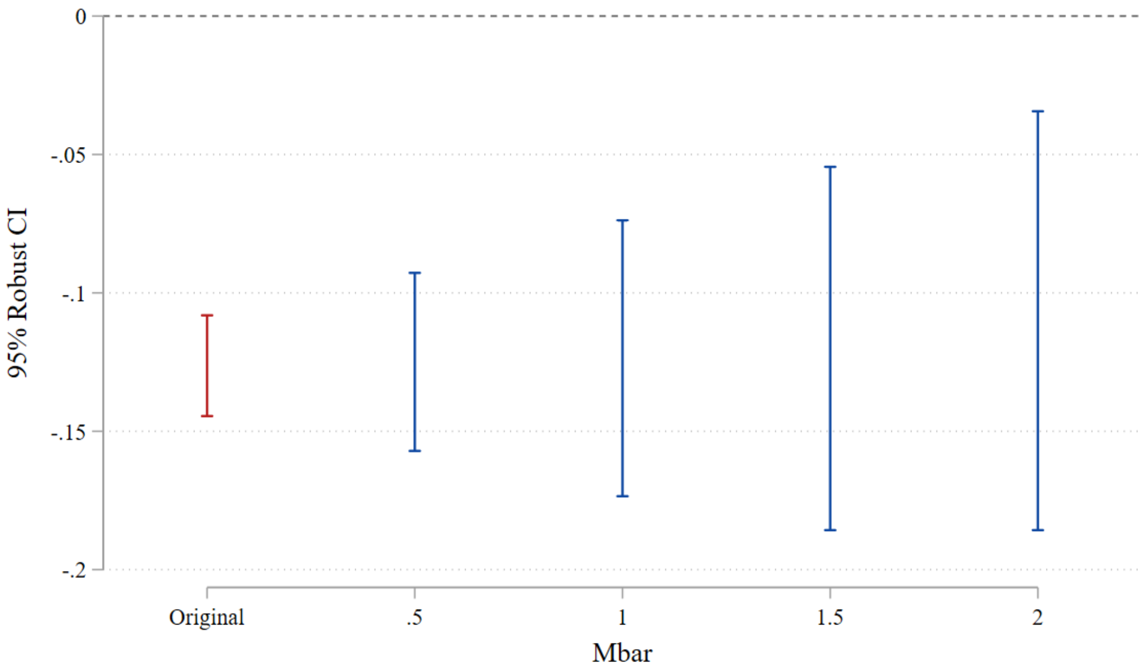


The darker the shading, the lower the pass-through rates.

Appendix Figure 7: HonestDiD, Effect on Price,
Germany and European Union, April 14 to August 31, 2022



Appendix Figure 8: HonestDiD, Robust Confidence Set,
Germany and European Union, April 14 to August 31, 2022



2.8.2 Appendix Tables

Appendix Table 1: Descriptive Statistics for Crude Oil Prices, April 14 to August 31

Descriptive Statistics Before Tax Reduction, Diesel

	Mean	Median	SD	N
Brent crude oil closing price	.656	.654	.027	48
Brent crude oil opening price	.651	.654	.024	48
Brent crude oil high price	.666	.669	.024	48
Brent crude oil low price	.64	.638	.027	48

Descriptive Statistics After Tax Reduction, Diesel

	Mean	Median	SD	N
Brent crude oil closing price	.652	.658	.043	92
Brent crude oil opening price	.651	.649	.044	92
Brent crude oil high price	.664	.664	.043	92
Brent crude oil low price	.637	.634	.042	92

Appendix Table 2: Descriptive Statistics for France and Germany, E5, April 14 to August 31

Descriptive Statistics Before Tax Reduction, E5

	Mean	Median	SD	N
Control Group:				
Daily Average E5 Price, EUR/l	1.89	1.882	.097	172688
Public or School Holiday	.37	0	.483	172688
Treatment Group:				
Daily Average E5 Price, EUR/l	2.086	2.076	.077	669333
Public or School Holiday	.226	0	.418	669333

Descriptive Statistics After Tax Reduction, E5

	Mean	Median	SD	N
Control Group:				
Daily Average E5 Price, EUR/l	1.989	1.999	.156	335695
Public or School Holiday	.611	1	.487	335695
Treatment Group:				
Daily Average E5 Price, EUR/l	1.866	1.864	.101	1288883
Public or School Holiday	.482	0	.5	1288883

Appendix Table 3: Descriptive Statistics for France and Germany, E10, April 14 to August 31

Descriptive Statistics Before Tax Reduction, E10

	Mean	Median	SD	N
Control Group:				
Daily Average E10 Price, EUR/l	1.847	1.834	.107	321668
Public or School Holiday	.367	0	.482	321668
Treatment Group:				
Daily Average E10 Price, EUR/l	2.029	2.018	.078	643065
Public or School Holiday	.227	0	.419	643065

Descriptive Statistics After Tax Reduction, E10

	Mean	Median	SD	N
Control Group:				
Daily Average E10 Price, EUR/l	1.933	1.949	.158	622190
Public or School Holiday	.61	1	.488	622190
Treatment Group:				
Daily Average E10 Price, EUR/l	1.808	1.806	.102	1238262
Public or School Holiday	.482	0	.5	1238262

Appendix Table 4: Tax Changes for all Countries in the EU, 2022

Country	Country Code	Tax change for E5	Tax change for diesel	Other relief changes	In control group?
Austria	AT	0	0		Yes
Belgium	BE	8	1		Yes
Bulgaria	BG	0	0		Yes
Croatia	HR	2	2		No
Cyprus	CY	1	1		Yes
Czech Republic	CZ	2	1		No
Denmark	DK	1	1		Yes
Estonia	EE	0	0		Yes
Finland	FI	0	0		Yes
France	FR	0	0	3	Yes
Germany	DE	2	2	2 (Introduction and end of subsidized public local transport ticket)	-
Greece	GR	0	0		Yes
Hungary	HU	20	20		No
Ireland	IE	3	3		Yes
Italy	IT	1	1		Yes
Latvia	LV	0	0		Yes
Lithuania	LT	0	0		Yes
Luxembourg	LU	3	3		No
Malta	MT	0	0	Subsidies: fixed prices for petrol E5 to 1.21 €/l and diesel to 1.34 €/l	No
Netherlands	NL	2	2		Yes
Poland	PL	1	1		Yes
Portugal	PT	11	11		No
Romania	RO	1	1		Yes
Slovakia	SK	0	0		Yes
Slovenia	SI	1	1	Price regulation: max of 1.56 €/l for petrol and 1.668 €/l for diesel in March and April 2022	No
Spain	ES	0	0		Yes
Sweden	SE	3	3		No

Note that a change is either an increase or a decrease. In the case of Germany, there was one tax decrease on June 1 and one increase on September 1.

Appendix Table 5: Germany and EU Control Group Countries: Descriptive Statistics, Diesel

a) Before Tax Reduction

	Mean	Median	SD	N
AT diesel with tax	1.848	1.849	.019	6
BE diesel with tax	1.971	1.967	.048	6
BG diesel with tax	1.612	1.627	.039	6
CY diesel with tax	1.781	1.789	.035	6
DE diesel with tax	2.046	2.039	.025	6
DK diesel with tax	2.029	2.027	.05	6
EE diesel with tax	1.84	1.85	.039	6
ES diesel with tax	1.873	1.87	.024	6
FI diesel with tax	2.22	2.225	.024	6
FR diesel with tax	1.877	1.877	.039	6
GR diesel with tax	1.869	1.865	.029	6
IE diesel with tax	1.923	1.929	.02	6
IT diesel with tax	1.808	1.816	.025	6
LT diesel with tax	1.767	1.772	.022	6
LV diesel with tax	1.869	1.874	.03	6
NL diesel with tax	1.995	1.993	.035	6
PL diesel with tax	1.565	1.558	.016	6
RO diesel with tax	1.739	1.751	.026	6
SK diesel with tax	1.765	1.772	.034	6
Crude Oil Closing Price, EUR/l	.657	.656	.04	6
b) After Tax Reduction				
AT diesel with tax	1.968	2.01	.111	13
BE diesel with tax	2.023	2.005	.098	13
BG diesel with tax	1.724	1.726	.054	13
CY diesel with tax	1.904	1.884	.062	13
DE diesel with tax	1.987	1.977	.055	13
DK diesel with tax	2.135	2.122	.107	13
EE diesel with tax	1.914	1.945	.078	12
ES diesel with tax	1.95	1.933	.1	13
FI diesel with tax	2.255	2.244	.138	13
FR diesel with tax	1.966	1.961	.111	13
GR diesel with tax	1.964	1.941	.104	13
IE diesel with tax	2.016	2.009	.098	13
IT diesel with tax	1.895	1.894	.1	13
LT diesel with tax	1.882	1.863	.085	13
LV diesel with tax	1.928	1.939	.115	13
NL diesel with tax	2.064	2.061	.092	13
PL diesel with tax	1.602	1.605	.06	13
RO diesel with tax	1.807	1.807	.028	13
SK diesel with tax	1.848	1.861	.059	13
Crude Oil Closing Price, EUR/l	.657	.661	.044	13

Appendix Table 6: Germany and EU Control Group Countries: Descriptive Statistics Before and After the Tax Reduction in Germany, E5

a) Before Tax Reduction

	Mean	Median	SD	N
AT diesel with tax	1.769	1.765	.042	6
BE diesel with tax	1.884	1.901	.079	6
BG diesel with tax	1.536	1.53	.044	6
CY diesel with tax	1.599	1.585	.082	6
DE diesel with tax	2.11	2.112	.061	6
DK diesel with tax	2.238	2.215	.112	6
EE diesel with tax	1.931	1.925	.068	6
ES diesel with tax	1.89	1.888	.058	6
FI diesel with tax	2.258	2.237	.093	6
FR diesel with tax	1.881	1.879	.077	6
GR diesel with tax	2.183	2.188	.083	6
IE diesel with tax	1.877	1.849	.071	6
IT diesel with tax	1.822	1.816	.049	6
LT diesel with tax	1.782	1.774	.091	6
LV diesel with tax	1.858	1.851	.064	6
NL diesel with tax	2.168	2.166	.063	6
PL diesel with tax	1.506	1.496	.094	6
RO diesel with tax	1.594	1.599	.046	6
SK diesel with tax	1.766	1.776	.048	6
Crude Oil Closing Price, EUR/l	.657	.656	.04	6

b) After Tax Reduction

	Mean	Median	SD	N
AT diesel with tax	1.966	1.996	.134	13
BE diesel with tax	1.914	1.91	.142	13
BG diesel with tax	1.654	1.665	.057	13
CY diesel with tax	1.741	1.784	.093	13
DE diesel with tax	1.873	1.864	.085	13
DK diesel with tax	2.285	2.246	.16	13
EE diesel with tax	2.029	2.025	.111	12
ES diesel with tax	1.98	2.026	.137	13
FI diesel with tax	2.318	2.307	.172	13
FR diesel with tax	1.961	2.001	.143	13
GR diesel with tax	2.244	2.279	.154	13
IE diesel with tax	2.034	2.049	.123	13
IT diesel with tax	1.931	1.941	.121	13
LT diesel with tax	1.908	1.905	.122	13
LV diesel with tax	1.957	1.947	.113	13
NL diesel with tax	2.206	2.19	.13	13
PL diesel with tax	1.562	1.556	.121	13
RO diesel with tax	1.694	1.681	.031	13
SK diesel with tax	1.844	1.852	.078	13
Crude Oil Closing Price, EUR/l	.657	.661	.044	13

Appendix Table 7: Difference-in-Differences Regressions (Germany & France), E5 & E10

	OLS, E5	Station FE, E5	OLS, E10	Station FE, E10
Treated Stations	0.1841***	0.0000	0.1671***	0.0000
	(0.0010)	(.)	(0.0008)	(.)
Discount Period	0.1192***	0.1191***	0.1107***	0.1105***
	(0.0009)	(0.0009)	(0.0005)	(0.0005)
Treated Stations # Discount Period	-0.3178***	-0.3174***	-0.3046***	-0.3041***
	(0.0009)	(0.0009)	(0.0006)	(0.0006)
Public or School Holiday	-0.0843***	-0.0844***	-0.1034***	-0.1035***
	(0.0004)	(0.0004)	(0.0004)	(0.0004)
Constant	1.9213***	2.0673***	1.8851***	1.9963***
	(0.0010)	(0.0002)	(0.0008)	(0.0002)
Observations	2466599	2466599	2825185	2825185
Adjusted R^2	0.537	0.618	0.502	0.585
Pass-through rate	90%	90%	87%	86%
Station FE	No	Yes	No	Yes
Date FE	No	No	No	No
No. Clusters	18,492	18,492	20,946	20,946

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 8: Was There a Price Increase in the Last Week/Last Two Days/Last Day Before Tax Reduction? Difference-in-Differences Regressions, E5 & E10

	Last Week of May, E5	Last Two Days of May, E5	Last Day of May, E5	Last Week of May, E10	Last Two Days of May, E10	Last Day of May, E10
Treated Stations # Discount Period	-0.0135***	0.0007	-0.0003	-0.0366***	-0.0282***	-0.0318***
	(0.0009)	(0.0011)	(0.0012)	(0.0006)	(0.0007)	(0.0008)
Public or School Holiday	0.0006**	0.0017***	0.0017***	-0.0016***	0.0023***	0.0020***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Constant	1.9676***	1.9668***	1.9668***	1.8824***	1.8797***	1.8799***
	(0.0003)	(0.0003)	(0.0003)	(0.0002)	(0.0002)	(0.0002)
Observations	842021	842021	842021	964733	964733	964733
Adjusted R^2	0.834	0.833	0.833	0.850	0.844	0.844
Pass-through rate	4%	0%	0%	10%	8%	9%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	18,326	18,326	18,326	20,759	20,759	20,759

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 9: Difference-in-Differences Regressions for Single Weeks, Diesel

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Week before tax reduction # Treated Stations	-0.1536***	-0.1935***	-0.2334***	-0.2404***	-0.2326***	-0.2099***	-0.1732***	-0.1715***	-0.1219***	-0.1138***	-0.0618***	-0.0456***	-0.0015
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0005)	(0.0006)	(0.0005)	(0.0006)	(0.0006)	(0.0007)	(0.0008)	(0.0008)	(0.0008)
Public or School Holiday	0.0005***	0.0001	-0.0002	0.0010***	-0.0003*	-0.0032***	-0.0047***	-0.0097***	-0.0069***	0.0014***	0.0084***	0.0124***	0.0215***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)
Constant	1.9252***	1.9254***	1.9256***	1.9248***	1.9257***	1.9277***	1.9288***	1.9323***	1.9304***	1.9247***	1.9198***	1.9172***	1.9108***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)
Observations	1273703	1273071	1272464	1272814	1273007	1273311	1273591	1273601	1273609	1273717	1273320	1274268	1297979
Adjusted R^2	0.598	0.709	0.790	0.795	0.734	0.660	0.617	0.615	0.562	0.625	0.613	0.483	0.404
Pass-through rate	92%	116%	140%	144%	139%	126%	104%	103%	73%	68%	37%	27%	1%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	23,974	23,983	23,989	23,995	24,014	24,027	24,043	24,071	24,083	24,090	24,103	24,107	24,112

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 10: Difference-in-Differences Regressions for Single Weeks, E5

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Week before tax reduction # Treated Stations	-0.3027***	-0.3260***	-0.3550***	-0.3779***	-0.3888***	-0.3802***	-0.3692***	-0.3575***	-0.3038***	-0.3061***	-0.2711***	-0.2379***	-0.1861***
	(0.0014)	(0.0014)	(0.0013)	(0.0012)	(0.0011)	(0.0011)	(0.0011)	(0.0013)	(0.0013)	(0.0013)	(0.0014)	(0.0013)	(0.0013)
Public or School Holiday	0.0014***	0.0036***	0.0040***	-0.0001	-0.0005*	-0.0038***	-0.0053***	-0.0094***	-0.0123***	0.0015***	0.0139***	0.0146***	0.0192***
	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0003)	(0.0004)
Constant	1.9670***	1.9652***	1.9649***	1.9679***	1.9682***	1.9707***	1.9719***	1.9750***	1.9772***	1.9669***	1.9576***	1.9572***	1.9538***
	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0004)
Observations	965739	965190	964596	964948	965121	965401	965705	965753	965807	965921	965570	966491	984609
Adjusted R^2	0.853	0.857	0.869	0.887	0.896	0.899	0.901	0.909	0.907	0.916	0.919	0.913	0.896
Pass-through rate	86%	93%	101%	107%	111%	108%	105%	102%	86%	87%	77%	68%	53%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	18,338	18,348	18,354	18,360	18,377	18,388	18,409	18,441	18,455	18,467	18,482	18,487	18,492

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 11: Difference-in-Differences Regressions for Single Weeks, E10

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Week before tax reduction # Treated Stations	-0.3356***	-0.3443***	-0.3589***	-0.3690***	-0.3779***	-0.3617***	-0.3448***	-0.3190***	-0.2770***	-0.2779***	-0.2429***	-0.2158***	-0.1667***
	(0.0008)	(0.0008)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0007)	(0.0008)	(0.0008)	(0.0008)	(0.0009)	(0.0009)	(0.0009)
Public or School Holiday	0.0019***	0.0032***	0.0032***	0.0005***	0.0002	-0.0026***	-0.0033***	-0.0062***	-0.0080***	0.0018***	0.0108***	0.0114***	0.0148***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)
Constant	1.8800***	1.8790***	1.8789***	1.8808***	1.8810***	1.8830***	1.8836***	1.8856***	1.8870***	1.8801***	1.8737***	1.8734***	1.8709***
	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0003)	(0.0003)	(0.0002)	(0.0003)	(0.0003)	(0.0003)
Observations	1106280	1105814	1105311	1105645	1105818	1106014	1106381	1106434	1106530	1106655	1106327	1107129	1127643
Adjusted R^2	0.875	0.883	0.889	0.894	0.899	0.896	0.895	0.899	0.899	0.909	0.913	0.908	0.891
Pass-through rate	95%	98%	102%	105%	107%	103%	98%	91%	79%	79%	69%	61%	47%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	20,771	20,789	20,797	20,802	20,816	20,833	20,854	20,882	20,899	20,914	20,932	20,937	20,944

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 12: The Pass-Through Rates for 17 Different BBSR Region Types, Diesel

	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6	Category 7	Category 8	Category 9	Category 10	Category 11	Category 12	Category 13	Category 14	Category 15	Category 16	Category 17
Discount Period # Treated Stations	-0.159***	-0.160***	-0.157***	-0.142***	-0.153***	-0.152***	-0.152***	-0.143***	-0.151***	-0.151***	-0.151***	-0.143***	-0.145***	-0.141***	-0.144***	-0.128***	-0.146***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)
Public or School Holiday	-0.019***	-0.022***	-0.018***	-0.006***	-0.005***	-0.011***	-0.010***	-0.008***	-0.007***	-0.009***	-0.010***	-0.007***	-0.009***	-0.005***	-0.005***	-0.006***	-0.010***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.860***	1.851***	1.854***	1.849***	1.838***	1.850***	1.841***	1.845***	1.844***	1.843***	1.842***	1.845***	1.853***	1.837***	1.838***	1.840***	1.858***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	1464343	1365979	1400310	1419482	1315373	1384507	1321503	1370003	1348092	1334727	1325777	1374141	1435757	1310320	1319574	1331667	1489708
Adjusted R^2	0.794	0.806	0.799	0.780	0.817	0.799	0.813	0.791	0.807	0.809	0.811	0.793	0.783	0.812	0.811	0.800	0.770
Pass-through rate	95%	96%	94%	85%	92%	91%	91%	86%	91%	90%	91%	86%	87%	84%	86%	77%	88%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	10,534	9,803	10,074	10,262	9,499	9,948	9,491	9,894	9,742	9,587	9,540	9,942	10,504	9,412	9,510	9,628	10,942

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 13: Was There a Price Increase in the Last Week Before the Tax Reduction? Difference-in-Differences Regressions (EU), Diesel and E5

	Diesel	E5
Discount Period # Treated Stations	-0.0039	-0.0090
	(0.0076)	(0.0092)
Constant	1.8329***	1.7916***
	(0.0044)	(0.0062)
Observations	114	114
Adjusted R^2	0.373	0.892
Pass-through rate	2%	3%
Station FE	Yes	Yes
Date FE	Yes	Yes
No. Clusters	19	19

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 14: Difference-in-Differences Regressions for Single Weeks (EU), Diesel

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Discount Period # Treated Stations	-0.1296***	-0.1430***	-0.1693***	-0.2072***	-0.2171***	-0.2143***	-0.1741***	-0.1792***	-0.1475***	-0.1346***	-0.0821***	-0.0383**	-0.0003
	(0.0080)	(0.0113)	(0.0145)	(0.0115)	(0.0109)	(0.0134)	(0.0117)	(0.0129)	(0.0121)	(0.0126)	(0.0138)	(0.0125)	(0.0120)
Constant	1.8329***	1.8329***	1.8329***	1.8329***	1.8329***	1.8329***	1.8329***	1.8331***	1.8329***	1.8329***	1.8329***	1.8329***	1.8329***
	(0.0043)	(0.0038)	(0.0040)	(0.0045)	(0.0049)	(0.0052)	(0.0053)	(0.0054)	(0.0053)	(0.0055)	(0.0056)	(0.0053)	(0.0046)
Observations	133	133	133	133	133	133	133	132	133	133	133	133	133
Adjusted R^2	0.568	0.778	0.829	0.882	0.842	0.744	0.684	0.547	0.427	0.332	0.388	0.349	0.338
Pass-through rate	78%	86%	101%	124%	130%	128%	104%	107%	88%	81%	49%	23%	0%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	19	19	19	19	19	19	19	19	19	19	19	19	19

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 15: Difference-in-Differences Regressions for Single Weeks (EU), E5

	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13
Discount Period # Treated Stations	-0.2887***	-0.3222***	-0.3636***	-0.3971***	-0.4051***	-0.3814***	-0.3589***	-0.3619***	-0.3323***	-0.3369***	-0.2928***	-0.2523***	-0.2097***
	(0.0147)	(0.0126)	(0.0124)	(0.0128)	(0.0132)	(0.0166)	(0.0170)	(0.0194)	(0.0171)	(0.0180)	(0.0161)	(0.0163)	(0.0148)
Constant	1.7916***	1.7916***	1.7916***	1.7916***	1.7916***	1.7916***	1.7916***	1.7911***	1.7916***	1.7916***	1.7916***	1.7916***	1.7916***
	(0.0076)	(0.0069)	(0.0064)	(0.0060)	(0.0056)	(0.0053)	(0.0049)	(0.0050)	(0.0053)	(0.0047)	(0.0052)	(0.0052)	(0.0052)
Observations	133	133	133	133	133	133	133	132	133	133	133	133	133
Adjusted R^2	0.895	0.926	0.930	0.925	0.915	0.872	0.842	0.804	0.803	0.798	0.826	0.827	0.836
Pass-through rate	82%	92%	103%	113%	115%	108%	102%	103%	95%	96%	83%	72%	60%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	19	19	19	19	19	19	19	19	19	19	19	19	19

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 16: Difference-in-Differences Regressions (EU-countries with no Tax Changes as Control Group), Excluding BG, PL, and RO

	Diesel	E5
Discount Period # Treated Stations	-0.1433***	-0.3314***
	(0.0067)	(0.0124)
Constant	1.8765***	1.8511***
	(0.0065)	(0.0068)
Observations	303	303
Adjusted R^2	0.808	0.881
Pass-through rate	86%	94%
Station FE	Yes	Yes
Date FE	Yes	Yes
No. Clusters	16	16

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 17: Difference-in-Differences Regressions (EU-countries with no Tax Changes as Control Group), Only Countries that do not Border Germany

	Diesel	E5
Discount Period # Treated Stations	-0.143***	-0.340***
	(0.008)	(0.009)
Constant	1.817***	1.784***
	(0.007)	(0.007)
Observations	246	246
Adjusted R^2	0.763	0.851
Pass-through rate	86%	97%
Station FE	Yes	Yes
Date FE	Yes	Yes
No. Clusters	13	13

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 18: Difference-in-Differences Regressions, Diesel, E5 & E10, May 2022

	Diesel	E5	E10
Discount Period # Treated Stations	0.0054^{***}	-0.0098^{***}	-0.0294^{***}
	(0.0005)	(0.0008)	(0.0005)
Public or School Holiday	-0.0059^{***}	-0.0001	-0.0016^{***}
	(0.0003)	(0.0004)	(0.0004)
Constant	2.0091^{***}	2.0059^{***}	1.9271^{***}
	(0.0003)	(0.0004)	(0.0004)
Observations	717731	544067	623300
Adjusted R^2	0.555	0.773	0.788
Pass-through rate	-3%	3%	8%
Station FE	Yes	Yes	Yes
Date FE	Yes	Yes	Yes
No. Clusters	23,959	18,317	20,747

French gasoline stations as the control group. Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 19: Difference-in-Differences Regressions, Diesel, E5 & E10, May 2022 Without Last Week

	Diesel	E5	E10
Discount Period # Treated Stations	0.0004	-0.0039^{***}	-0.0214^{***}
	(0.0004)	(0.0007)	(0.0005)
Public or School Holiday	0.0041^{***}	0.0051^{***}	0.0007
	(0.0006)	(0.0009)	(0.0006)
Constant	2.0009^{***}	2.0011^{***}	1.9250^{***}
	(0.0005)	(0.0008)	(0.0006)
Observations	555014	420610	481973
Adjusted R^2	0.555	0.743	0.753
Pass-through rate	0%	1%	6%
Station FE	Yes	Yes	Yes
Date FE	Yes	Yes	Yes
No. Clusters	23,942	18,296	20,730

French gasoline stations as the control group. Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 20: Difference-in-Differences Regressions for Single Brands (France as Control Group), Diesel

	Only Aral	Only Esso	Only Jet	Only Shell	Only Total	Only others
Discount Period # Treated Stations	-0.1515***	-0.1457***	-0.1461***	-0.1534***	-0.1547***	-0.1472***
	(0.0008)	(0.0011)	(0.0012)	(0.0008)	(0.0010)	(0.0005)
Public or School Holiday	-0.0147***	-0.0085***	-0.0098***	-0.0139***	-0.0105***	-0.0170***
	(0.0005)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0003)
Constant	1.8721***	1.8510***	1.8423***	1.8642***	1.8474***	1.9069***
	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0006)	(0.0004)
Observations	1558404	1396441	1349001	1494492	1372361	2348104
Adjusted R^2	0.762	0.786	0.805	0.777	0.803	0.679
Pass-through rate	91%	87%	87%	92%	93%	88%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	11,240	10,024	9,670	10,729	9,850	17,530

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 21: Robustness Checks for the Spatial Analysis, Diesel

	BBSR Spatial Type Reference: Population on the Municipality Level			BBSR Spatial Type Reference: Location on the Municipality Level				BBSR Regional Statistical Area Type 2 (Urban and Rural)	
	Predominantly urban	Partly urban	Predominantly rural	Very central	Central	Peripheral	Very peripheral	Urban region	Rural region
Discount Period # Treated Stations	-0.151***	-0.147***	-0.146***	-0.154***	-0.146***	-0.142***	-0.162***	-0.152***	-0.145***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)
Public or School Holiday	-0.017***	-0.016***	-0.013***	-0.023***	-0.012***	-0.012***	-0.011***	-0.018***	-0.014***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.914***	1.873***	1.879***	1.900***	1.889***	1.881***	1.846***	1.914***	1.902***
	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)
Observations	2415304	1623549	1718370	2016632	1875791	1758630	1360030	2358712	2144651
Adjusted R^2	0.683	0.747	0.735	0.721	0.709	0.717	0.813	0.695	0.680
Pass-through rate	90%	88%	87%	92%	87%	85%	97%	91%	86%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	17,776	12,055	12,926	14,646	13,753	13,036	9,848	17,264	15,920

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 22: Robustness Checks for the Spatial Analysis, Diesel

	BBSR Settlement Structure Type (urban-rural regions)			BBSR Differentiated by City and Municipality Type						
	Urban region	Densely populated rural	Sparsely populated rural	Larger city	Smaller city	Larger medium town	Smaller medium town	Larger small town	Smaller small town	Rural municipality
Discount Period # Treated Stations	-0.151***	-0.140***	-0.149***	-0.160***	-0.156***	-0.153***	-0.149***	-0.146***	-0.141***	-0.144***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Public or School Holiday	-0.016***	-0.010***	-0.014***	-0.019***	-0.022***	-0.019***	-0.018***	-0.012***	-0.008***	-0.010***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.920***	1.867***	1.870***	1.860***	1.866***	1.859***	1.877***	1.870***	1.865***	1.861***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	2590771	1585810	1580642	1458772	1497500	1444892	1664757	1613784	1578881	1514077
Adjusted R^2	0.680	0.738	0.763	0.796	0.780	0.788	0.743	0.743	0.745	0.766
Pass-through rate	90%	84%	89%	96%	93%	92%	89%	87%	84%	86%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	19,033	11,590	11,558	10,494	10,773	10,402	12,123	11,846	11,696	11,187

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 23: Pass-Through Rates for the Federal States, E5

	BB	BE	BW	BY	HB	HE	HH	MV	NI	NW	RP	SH	SL	SN	ST	TH
Discount Period # Treated Stations	-0.362***	-0.377***	-0.314***	-0.264***	-0.321***	-0.326***	-0.337***	-0.329***	-0.332***	-0.334***	-0.319***	-0.331***	-0.321***	-0.318***	-0.339***	-0.317***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)
Public or School Holiday	-0.008***	-0.004***	0.018***	0.000	0.002**	0.033***	-0.003***	-0.016***	-0.011***	-0.044***	0.029***	-0.019***	0.015***	-0.003***	-0.002***	0.002***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	1.839***	1.831***	1.872***	1.885***	1.820***	1.841***	1.827***	1.839***	1.888***	1.932***	1.829***	1.851***	1.815***	1.843***	1.836***	1.832***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	565769	547023	757785	826272	522009	661914	536317	554456	755739	916809	609536	590027	530661	588048	566061	562810
Adjusted R^2	0.811	0.808	0.809	0.737	0.794	0.804	0.803	0.801	0.841	0.865	0.791	0.816	0.792	0.799	0.804	0.797
Pass-through rate	103%	107%	89%	75%	91%	93%	96%	94%	95%	95%	91%	94%	91%	90%	96%	90%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	4,098	3,958	5,617	6,239	3,779	4,826	3,884	4,010	5,558	6,688	4,441	4,272	3,844	4,260	4,099	4,085

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Appendix Table 24: Pass-Through Rates for the Federal States, E10

	BB	BE	BW	BY	HB	HE	HH	MV	NI	NW	RP	SH	SL	SN	ST	TH
Discount Period # Treated Stations	-0.349***	-0.362***	-0.299***	-0.251***	-0.307***	-0.314***	-0.324***	-0.316***	-0.319***	-0.321***	-0.306***	-0.318***	-0.308***	-0.305***	-0.325***	-0.303***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
Public or School Holiday	-0.005***	-0.003***	0.004***	-0.011***	0.001**	0.020***	-0.003***	-0.012***	-0.013***	-0.044***	0.017***	-0.016***	0.007***	-0.003***	-0.003***	0.001*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	1.758***	1.753***	1.784***	1.798***	1.746***	1.761***	1.751***	1.759***	1.793***	1.833***	1.753***	1.767***	1.744***	1.761***	1.757***	1.753***
	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Observations	999526	982358	1188042	1247257	957348	1092109	971372	987925	1172425	1341501	1042576	1020404	965564	1020863	998056	994621
Adjusted R^2	0.891	0.892	0.868	0.816	0.888	0.875	0.890	0.887	0.891	0.900	0.874	0.892	0.886	0.881	0.887	0.884
Pass-through rate	99%	103%	85%	71%	87%	89%	92%	90%	91%	91%	87%	90%	88%	87%	93%	86%
Station FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Date FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. Clusters	7,203	7,078	8,686	9,205	6,899	7,904	7,002	7,117	8,532	9,719	7,534	7,356	6,960	7,360	7,193	7,178

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3 How to Reach the Paradise? Inside the Edgeworth Cycle and Why a Gasoline Station is the First to Raise Its Price

Mats Petter Kahl[1]
Leuphana University of Lueneburg

Thomas Wein[2]
Leuphana University of Lueneburg

2024

Abstract

Competition in the German gasoline retail market is characterized by strong intraday price cycles. The literature describes the cycles as corresponding to the well-known Edgeworth cycles. Cyclical patterns are observable all over Germany and throughout the world. So far, research has mainly focused on analyzing price cycles based on hourly, daily, or weekly average price data. We study the initiation of new price cycles by looking at the exact timing of competition in the daily cycle on a second-by-second level. What determines that a specific gasoline station increases its price to initiate a new price cycle? And what determines the probability of success? We analyze whether the theoretically and economically significant price differences of the Edgeworth cycles predict the behavior of the price-increasing retailer or whether brand affiliation, local characteristics, or services offered do. To do justice to the complexity of analyzing second-by-second intraday price cycles, we limit ourselves to one local market in Germany. We find that price considerations play a minor role in explaining why a gasoline station is the first to increase its price. Services offered, location parameters, and especially brand affiliation are much more important in a gasoline station's decision on whether it will be the first to raise prices. The dominant suppliers, Aral and Shell, who jointly account for more than 80 percent of price increases in the market, are the major drivers of the cycle size. Furthermore, we analyze the probability of success of price restoration attempts, thus not having a delayed or false start. We show that it depends relatively strongly on the brand affiliation and, to a lesser extent, on the location, the services offered, and the number of coordinated sites. Together, the strong results for oligopoly players Aral and Shell suggest that market power is the major driver of the cyclical pricing pattern in the gasoline market.

JEL codes: L13, L41, K21
Keywords: Edgeworth cycles, gasoline prices, dynamic pricing, gasoline market
Declarations of interest: none

---

[1] Corresponding author. Leuphana University of Lueneburg; Institute of Economics, Universitaetsallee 1, 21335 Lueneburg, Germany, mats.kahl@leuphana.de
[2] Leuphana University of Lueneburg; Institute of Economics, Competition and Regulation Institute, Universitaetsallee 1, 21335 Lueneburg, Germany, wein@leuphana.de

3.1 Introduction

In 2013, interest surged in the competition for selling retail gasoline in the German market. The change followed the German federal cartel office, Bundeskartellamt, creating the Market Transparency Unit for Fuels (MTU). In August 2013, the Bundeskartellamt made it mandatory for all gasoline retailers in Germany to report price changes of the most common fuel types within a few minutes (Bundeskartellamt, 2021). The federal cartel authority introduced price monitoring to assess if there is market power abuse.

The concept of the Edgeworth cycle theory goes back to Edgeworth (1925), who showed in his critique of Bertrand (1883) that no general static price equilibrium exists when there are capacity constraints on firms. Maskin and Tirole (1988) formalized this theory without requiring capacity constraints, which is now the prevailing concept in explaining the cyclical pricing patterns in fuel retailing. Maskin and Tirole (1988) focus on a duopoly competition and describe their Edgeworth cycles in two phases. In the first phase, the so-called price war, the duopolists successively undercut each other to increase their market share until they reach marginal costs. The second phase, the so-called war of attrition, follows, in which each firm waits for the other to raise its price. Maskin and Tirole (1988) call this price increase "relenting." As price undercutting begins again, the cycle starts anew. The Edgeworth cycle theory has been notably advanced with respect to competition in retail fuel markets by Eckert (2003), Noel (2008), Wills-Johnson and Bloch (2010), and Eibelshäuser and Wilhelm (2018).

We contribute to the already rich literature by looking at the second-by-second order of events to analyze price restorations rigorously.[3] This research is based on high-frequency data, the necessity of which has been emphasized in previous research (e.g., Eckert and West (2004), Atkinson (2008), Lewis (2012), Noel (2018b), and Bragoudakis et al. (2020)) and is based on a methodology that exploits this fine temporal granularity. The core idea that large brands engage in price leadership originates from earlier research (e.g., Noel (2007b), Atkinson (2009), Lewis (2012), and Neukirch and Wein (2016a, 2016b)) and is a focal point here.

We observed cycles similar to the pricing patterns described by Maskin and Tirole (1988); however, the theory might describe the symptoms rather than the cause. What are the factors causing the price cycles we observe worldwide? Hw is the price restored after a series of

[3] High-frequency data are required to reliably identify the retailer that first restores the price level. Lewis (2012) discusses that his data are "not ideal for identifying the earliest movers" and develops an approximation strategy.

underbidding to reach the paradise? What role do other factors, such as brand affiliation, local characteristics, and services offered, play?

We are the first to study what factors affect the probability of price increases that initiate a new price cycle by restoring the price level, referred to as the "paradise" by Wein (2021). Our analysis is similar and based on the same data set as Wein (2021), but instead of looking at the underbidding phase of the price cycle, we look at the price-increasing phase. We modified the data to analyze local competition on a second-by-second basis. This kind of data modification is superior to previous research because it allows us to identify how each gasoline station reacts to competitors. Accordingly, we apply logit and Poisson estimation techniques. We identify the factors determining whether a specific retailer will increase its price to relent. Moreover, we look at the factors determining the magnitude of the price increase. Finally, we look at what determines the probability of success in the relenting attempt.

We find that price considerations play a minor role in explaining why a gasoline station is the first to increase prices. Services offered, location parameters, and especially brand affiliation are more important in a gasoline station's decision to relent. While it is already established that certain major brands act as price leaders, we show that the dominant suppliers, Aral and Shell, are the major drivers of the price cycle size. Jointly, they account for more than 80 percent of price increases in the market. Analyzing false starts, we show that the probability of successful price restoration increases in the number of coordinated gasoline stations; however, this increase is only marginal. The likelihood of success depends relatively strongly on the brand affiliation and, to a lesser extent, on a retailer's location.

This article is structured as follows. We review the related literature in section 2. Section 3 discusses the most relevant theories related to cyclical pricing patterns in fuel retailing. In section 4, we present the data and explain the data modification in detail. We describe our estimation approach in section 5 and present the descriptive results in section 6. In section 7, we present and discuss the regression results. We dedicate section 8 to robustness checks and the discussion of validity. We summarize and conclude in section 9.

3.2 Literature Review

The body of empirical literature on gasoline retailing has been growing rapidly over the last decades, and the last systematic literature surveys were carried out a decade ago, Byrne (2012) and Eckert (2013). Data from many different markets and periods have been employed to address various questions, focusing on different facets of competition in gasoline retail markets. These data sets vary in aggregation from the regional to the station level and in frequency from annual data to complete high-frequency data.

Excellent research on cyclical pricing patterns in retail fuel markets has been conducted based on data from Australia, Austria, Canada, China, Germany, Norway, and the United States of America. Despite the enormous scope of research in this field, we offer a comprehensive overview of the empirical contributions most relevant for answering and motivating our research project. We develop the literature review according to the chronological sequence of empirical research for each country, starting with the one for which the first empirical studies were conducted, namely the USA.

Castanias and Johnson (1993) tested Maskin and Tirole's (1988) theory based on weekly price data for the Los Angeles area. They concluded that the Edgeworth cycle theory is capable of explaining pricing behavior. Further empirical investigations found supporting evidence for using the Edgeworth cycle theory in economies worldwide. Lewis (2009) differentiates between cycling and non-cycling cities in the United States. He concludes that cities with price cycles exhibit lower prices on average than other cities, based on average daily price data for different regions. In line with this result, Zimmerman et al. (2013)find that prices are lower in US areas that began to cycle.

Doyle et al. (2010) gathered station-level data on a daily basis and argued that the least and most concentrated US markets are less likely to be cycling ones. Moreover, they conclude that more independent gasoline stations increase the likelihood of an area exhibiting cycling behavior of daily gasoline retail prices. Lewis and Noel (2011)look at price patterns in the United States and find that constant movements within price cycles allow firms to pass on cost fluctuations more easily. Also, based on US daily price data, Lewis (2012) finds first evidence that certain retail chains act as price leaders by initiating price restorations. In contrast to other empirical studies, Hosken et al. (2008) conclude that data are largely inconsistent with cycling behavior based on data from the US. González and Hurtado (2019) analyze consumer-reported prices on a daily level for the US. They find that cycling stations target price-sensitive consumers while non-cycling retailers target inelastic consumers. The results of a more recent study based on the same data set show that average prices are lower for price cycle retailers (González and Hurtado, 2021). They argue that the asymmetric price cycles cannot be standard Edgeworth cycles because the duration would not be random.

There has been much empirical research on retail fuel markets in Canada. Eckert (2002) found the first evidence for Edgworth cycles and, in a later study, that the existence of such cycles depends on the number of retail outlets operated by the firms (Eckert, 2003). Eckert and West (2004) emphasize the importance of high-frequency data for analyzing price cycles. Based on weekly price data for three Canadian cities, Noel (2007a) finds that cycles are more prevalent when more small firms are in the market. In another study drawing on twelve-hourly price data, he finds evidence consistent with the Edgeworth theory (Noel, 2007b). Moreover, he finds that larger firms are more likely to initiate new relenting rounds and less likely to lead the undercutting.

Atkinson (2008) uses two- and twelve-hourly price data for almost all gas stations in the local Canadian market of Guelph and argues that such data may be reliable for daily prices of company-operated major brands but not for answering questions requiring high-frequency data and prices for independent retailers. Based on the same data, Atkinson (2009) argues that price movements are more consistent with the Edgeworth cycle theory than other pricing theories. Moreover, he finds "sub-cycles" similar but not identical to false starts.[4] In another study with this data set, Atkinson et al. (2009) found a domino-like price-decreasing pattern and a location and source-based pricing pattern for price increases.

Noel (2009) analyses the role of price cycles for asymmetric passthrough of cost shocks for the Toronto retail fuel market. Based on consumer-reported prices for Canada, Atkinson et al. (2014) find that temporary events can trigger a permanent change in equilibrium behavior. Moreover, they argue that weekly average prices cannot describe pricing dynamics in retail fuel markets. Based on daily Canadian data, Byrne et al. (2015) find that consumer responsiveness exhibits cycles that move with price fluctuations and that the forward-looking stockpiling behavior of consumers plays a central role in generating price cycles. Noel (2015) estimates lower margins and lower prices in the presence of Edgeworth price cycles based on daily regional average data for Canada. Noel (2018b) uses a natural experiment to show, based on consumer-reported high-frequency data, that consumer search rises when price dispersion increases. Byrne (2019) uses daily consumer-reported data on gasoline prices in Canada to show that the local market concentration is positively related to price asymmetry.

Research on retail fuel markets in Australia has mainly drawn on high-frequency data from Western Australia. Since 2001, certain gasoline retailers in Western Australia have been required to report all prices to a central office at noon before the effective date, which publishes them on the Fuel Watch website. The regulation forces retailers to set prices

[4] Atkinson (2009) explains in footnote 37 why his sub-cycles differ from the false starts theoretically predicted by Noel (2008). However, Noel (2015) writes that "Atkinson also observes the false starts predicted by Noel (2008)" and a similar interpretation in a later publication (Noel (2019)).

simultaneously without knowing rival's prices (Wang, 2009a). The price must then remain unchanged for 24 hours. Thus, the research on price cycles and competition is mainly conducted based on data from a regulated market and might, therefore, be incomparable to price-unregulated markets, such as German retail fuel markets.[5] One exception is Wang (2008), who analyzes the Australian retail fuel market based on a data set from trial records that contain prices and communication patterns. He concludes that the Edgeworth cycle equilibrium captures collusive pricing behavior and communication. Moreover, he discusses difficulties in coordinating price restorations to prevent delayed and false starts.

Based on a sample of Fuel Watch data from the regulated retail fuel market of Western Australia, the Perth metropolitan area, Wang (2009a) finds that before regulation, a single large firm was the price leader. In contrast, price leadership is distributed among the three largest firms due to the higher cost of price leadership under 24-hour price commitment regulations. He concludes that both with and without regulation, the gasoline pricing behavior is characterized by the Edgeworth price cycle equilibrium, however, with different patterns of price leadership. Based on a data sample of eight retail sites in the Perth metropolitan area, Wang (2009b) concludes that consumers react very sensitively to station-level gasoline price differentials. This result emphasizes the importance of local and price competition aspects in retail fuel markets.

Also, based on data from the "unique regulatory regime known as" Fuel Watch for the Perth metropolitan area in Western Australia, Bloch and Wills-Johnson (2010a) model the market as a competition network and cut it into sub-markets. They find that local market structure influences pricing, particularly at the sub-marked level during the downswing. They find retailers at the link between two sub-markets to reduce the transmission of price signals and that majors use outlets they have more control over to lead prices up. Moreover, outlets on the periphery of the Perth market charge higher prices rather than trying to compete with non-peripheral outlets for the customers. In another study based on the same data set, Bloch and Wills-Johnson (2010b) find that independent brands raise their prices more cautiously and use cycles less than Shell, as do retailers with a superior or peripheral location. Furthermore, they find that outlets with cycles with sharper upswings are also likely to exhibit shorter cycles.

[5] The cost for a particular retailer to set the price too high or to engage in price leadership is relatively high if the price has to remain unchanged for one day. In contrast, a retailer in an unregulated market can correct its own price and react more quickly to competition. Accordingly, price patterns may differ in such markets.

Based on price data of about 80 percent of retail sites in Western Australia, Roos and Katayama (2013) find evidence for frequent asymmetric price cycles of substantial amplitude, with retailers changing prices in almost every period. The authors argue that this limits the relevance of the Edgeworth cycle theory. Based on the daily average retail price for five Australian markets, Noel and Chu (2015) find that consumers can reduce purchase prices below the market average by using simple decision rules about the time of consumption. They exclude relenting attempts that they identify as false starts by requiring cumulative price increases to be at least 2 cents per liter. By supplementing volume data to average daily price data for the same five Australian markets, Noel (2019) finds a high intraday price elasticity of demand along with a calendar-synchronized pricing pattern.
Foros and Steen (2013) analyze the Norwegian retail fuel market based on daily price collections for seven retailers and on prices reported by consumers. They conclude that their evidence is characterized by coordinated behavior rather than the Edgeworth cycle theory.
In Germany, the interest in gasoline retailing surged with the availability of complete retail price data for the entire country from the end of 2013, which was mandated by regulation authorities to be able to intervene in case of market power abuse (Bundeskartellamt, 2023). Prices are made available to so-called service providers and can be accessed by consumers and retailers in real time via web pages and apps. Haucap et al. (2016) conclude that German retail fuel market pricing patterns are similar to Edgeworth-type cycles. Neukirch and Wein (2016a) show descriptive results indicating that the two major brands, Aral (belonging to BP) and Shell, act as price leaders and are the first to follow. Moreover, these two major brands follow a high-price strategy; the two other big players, Esso and Total, do not so much, and others follow a low-price strategy (Neukirch and Wein, 2016b).

Based on evidence from hourly price data for more than 16,500 gas stations in Austria and Germany, Boehnke (2017) concludes that price fluctuations in Austria and Germany cannot be explained using the Edgeworth cycle theory but rather by retailers' temporal price discrimination of different customer groups. In contrast, Siekmann (2017) finds evidence of Edgeworth cycles across German municipalities based on high-frequency price data. He concludes that more substantial cycle asymmetry and intensity exist in more concentrated markets, which decreases with a higher share of non-major brands. Also, based on high-frequency data from all German gasoline stations, Eibelshäuser and Wilhelm (2017) and Eibelshäuser and Wilhelm (2018) describe that large retail brands perform price increases earlier than small brands. They give insights about price setting and automatization thereof from interviews with practitioners. Based on all prices for seven German cities in one state, Cabral et al. (2018) analyze how a price-matching guarantee of a major retailer interrupts the Edgeworth price cycles. Haas (2019) builds hourly averages to research whether the price cycles observed in Cologne and Hamburg resemble the well-known Edgeworth cycles and finds evidence that prices do not fall to marginal costs. He concludes that this is not in line with Edgeworth cycles.

Similar to Boehnke (2017), Linder (2018) argues that a strategy of intertemporal price discrimination between different types of consumers drives the daily cycle. She uses hourly prices for her empirical analysis. Also, based on hourly data, Neukirch and Wein (2019) find no evidence that pricing behavior in the evening/night is a consequence of market power abuse. Wein (2021) uses the same high-frequency raw price data for one German local market as we do here. He focuses his analysis on the underbidding phase within price cycles and finds that the characteristics of gasoline retailers are more important than the price difference to competitors' average price in determining the likelihood of a specific retailer initiating the underbidding phase of the price cycle.

Based on daily station-level price data for Inner Mongolia, Cui et al. (2023) find that price caps may serve as focal points for gasoline retailers to collude tacitly. Moreover, they find a buffering effect of price caps on price cycles for this region of China.

3.3 Related Theories

The concept of the Edgeworth cycle theory goes back to Edgeworth (1925), who showed in his critique of Bertrand (1883) that no general static price equilibrium exists when there are capacity constraints on firms. Maskin and Tirole (1988) formalized this theory without requiring capacity constraints, which is now the prevailing concept in explaining the cyclical pricing patterns in fuel retailing. Maskin and Tirole (1988) focus on a duopoly competition and describe their Edgeworth cycles in two phases. In the first phase, the so-called price war, the duopolists undercut each other to increase their market share until they reach marginal costs. The second phase, the so-called war of attrition, follows, in which each firm waits for the other to raise its price and thus to "relent." As price undercutting begins again, the cycle starts anew. The Edgeworth cycle theory has been notably advanced concerning competition in retail fuel markets by Eckert (2003), Noel (2008), Wills-Johnson and Bloch (2010), and Eibelshäuser and Wilhelm (2018).

Eckert (2003) extends the duopoly model by allowing for more than just two competing firms in a market and taking into account the number of small chains in a market and the fraction of stations in a market operated by vertically integrated brands (or refinery brands).

A chain in a market is said to be small if the percentage of the number of stations operated by this chain is below 5% of the total number of stations in this market. The model allows constant price (rigid price) and price cycle equilibria. Based on the average price data of samples taken in multiple Canadian cities once a week, Eckert (2003) finds more cycling in the increasing presence of small firms or independent retailers. Moreover, markets tend to be of the cycling type for higher dispersion in the size of firms. An empirical contribution to Eckert's theory would require data for multiple markets along with detailed information about all firms.

Noel (2008) extends the Edgeworth cycle model by including fluctuating marginal costs[6], capacity constraints, and product differentiation, allowing for a triopoly instead of a duopoly competition. Cycles are not restricted to duopoly settings but also occur under triopoly, with coordination challenges such as delayed and false starts. He defines a delayed start as a relenting attempt of one firm that competitors do not immediately follow. False starts are defined as relenting attempts abandoned by the relenting firm altogether after the retailer had to wait too long in vain for competitors to follow. Noel (2008) motivates the case of asymmetric capacity constraints by the fact that independent fuel retailers have less overall capacity than majors. Majors are vertically integrated brands, especially Aral, Shel, ESSO, and Jet, in the Lueneburg market. In such a market, Noel's model predicts that the cycles become less asymmetric, more rapid, and smaller in amplitude (as observed in the German market for fuel retailing). For severe capacity restrictions, the shape of the cycles could be changed almost beyond recognition according to this pattern. Moreover, the unconstraint firm tends to be the one to relent first.

Our empirical analysis looks at competition between fuel retailers, focusing on the second phase of the Edgeworth cycle theory, namely the war of attrition or relenting phase. To connect our empirical approach with the theory, we look at how competition is modeled in the simplest form of the Edgeworth cycle theory for two firms. Maskin and Tirole (1988) formalize the reaction function of competitors in equation (23) as:

[6] Lewis (2012) argues that price cycles "are not explained by changes in wholesale prices," and Eibelshäuser and Wilhelm (2018) write that "the average volatility of retail gasoline prices in Germany far exceeds the volatility of the oil price," which we interpret as support for Lewis' argument. However, our analysis accounts for crude oil cost fluctuations.

$$R(p) = \begin{cases} \overline{p} \; for \; p > \overline{p}, \\ p - k \; for \; \overline{p} \geq p > \underline{p}, \\ c \; for \; \underline{p} \geq p > c, \\ \left.\begin{array}{c} c \; with \; probability \; \mu(\delta) \\ \overline{p} + k \; with \; probability \; 1 - \mu(\delta) \end{array}\right\} for \; p = c, \\ c \; for \; p < c, \end{cases} \quad (1)$$

where c is the marginal cost. $R(p)$ is the reaction function (or strategy), which depends on the price of the competitor p and is symmetric for both firms. In the equilibrium exist two prices, $\underline{p}$, and $\overline{p}$, with $\underline{p} < \overline{p}$. Beginning at $\overline{p}$, the price war leads to an intermediate price, $\underline{p}$, at which the firms undercut to the competitive price, with each firm trying to induce the opponent to relent first. Maskin and Tirole (1988) describe prices as belonging to the price grid, which is subdivided into equal intervals of size k, noting that this is not essential for their theory. We can think of k as restricting the price changes to 1 Eurocent per liter. The probability of continuing the war of attrition $\mu(\delta)$ is specified as a function of the discount factor δ. The discount factor is defined as $\delta \equiv \exp(-rT)$, with T being the time between consecutive periods and with firms discounting the future with the interest rate r.[7]

Our empirical analysis is dedicated to lines 4 and 5 of the right-hand side of the reaction function equation (1). However, instead of a duopoly, our local market consists of many gasoline stations with several different brands. We ask: What determines the probability of relenting first, $1 - \mu(\delta)$? Hence, what factors shape the mixed strategy equilibrium? We define various price variables to capture the effect of the price competition situation on whether to relent in the war of attrition phase, as outlined in section 5.

Maskin and Tirole (1988) discuss that at the cycle's trough, the competitors try to induce the opponent to relent first. Therefore, the duration of the war of attrition phase might play a role in explaining the probability of a retailer restoring the price level. Additionally, the spatial outlay of the market might play a role in each fuel retailer's decision to relent or not. Therefore, this spatial market outlay should be modeled from each gasoline station's perspective. We consider distance- and duration-weighted specifications of prices and use further local competition variables as outlined in Table 2. Finally, we add demand-side controls, brand affiliation, and station characteristics to determine why a retailer relents.

Moreover, we elaborate on line 5 on the right-hand side of the equation (1) for the reaction function by estimating what determines the magnitude of the price restoration. This focus is

[7] A full description can be found in Maskin and Tirole (1988).

relevant because the relenting retailer must decide whether and to what extent to raise the price when ending the war of attrition phase.

Wills-Johnson and Bloch (2010) show how Edgeworth cycles might arise in a spatially differentiated market. This is particularly relevant for markets characterized by strong spatial competition, such as retail gasoline markets. The authors demonstrate that no differences in costs or market shares are needed to provide an incentive to relent.

Eibelshäuser and Wilhelm (2018) extend the Edgeworth cycle theory by allowing for firm size heterogeneity, business hours, and product differentiation, holding marginal costs and demand fixed. They argue that price cycles[8] are more pronounced when there is mild local differentiation[9], less so with stronger differentiation, and that cycles disappear with very high differentiation. Their model predicts that firms keep their prices low before closing because relenting needs time to pay off. The authors relate the number of price cycles to the price adjustment costs, which, when they fall, lead to faster cyclical pricing patterns. They argue that larger firms with more capacity or retail facilities serve a more considerable fraction of customers at any price, ceteris paribus. If one firm is larger, it attracts more customers. Therefore, larger firms have greater incentives to set higher prices, and consequently, they lead the market in terms of price increases.

3.4 Data and Data Modification

Since August 2013 (Bundeskartellamt, 2021), all German gasoline stations have had to report gasoline price changes to the MTU. The data are available to certain registered information service providers and are made available to researchers by tankerkoenig.de. We prepared panel data for the three most common gasoline types, diesel, petrol E5 (with 5 percent ethanol, German *"Super E5")*, and petrol E10 (with 10 percent ethanol, German *"Super E10"*) for 2018 and 2019.[10] Previous research of the German retail fuel market reports from interviews with practitioners that retailers monitor nearby competitors and set their prices in response to their competitors' prices (Eibelshäuser and Wilhelm, 2018).

We limit our sample to one local German market – the town and area around Lueneburg – with 26 gasoline stations. Following existing literature, we differentiate between three brand categories: 1) oligopoly players (Aral, Shell, TOTAL, ESSO, and JET); 2) superregional

[8] The authors' proxy for price cycling behavior at the retailer level is the spread between minimum and maximum daily prices and the average number of hourly price adjustments.

[9] Eibelshäuser and Wilhelm (2018) argue that gasoline is a perfectly homogeneous good and that customers face different transportation costs when buying at different stations. High differentiation is defined as low station density and vice versa.

[10] Our data set includes all price changes from January 3, 2018, to December 31, 2019, as in Wein (2021). Thus, we have 728 days of price data for 26 retailers, visualized on a map by Wein (2021).

brands without upstream structure, which we call superregional non-oligopoly players, SRNOP (bft, HEM, Hoyer, LTG, Raiffeisen, Star); and 3) the independent local gasoline stations called regional non-oligopoly players, RNOP. We use single-brand dummies whenever possible; otherwise, we use these categories. There is no TOTAL brand gasoline station in Lueneburg, and only one ESSO station and one JET station, so we differentiate the brands as depicted in Table 1. We discuss the focus on a single local market in section eight.

Table 1: Brand and Categorization

Brand or category	Number of gasoline stations	Category
Aral	5	Oligopoly player
Shell	7	Oligopoly player
Esso	1	Oligopoly player
Jet	1	Oligopoly player
SRNOP	9	Superregional non-oligopoly players
RNOP	3	Regional non-oligopoly players
Σ	**26**	

Of the 26 stations in the Lueneburg area, 15 are located in the town, and the remaining 11 are in rural areas. The largest distance between two gasoline stations in our data set is just below 20km of driving distance. The driving distances between all retailers are estimated using Google Maps and are based on the average of driving in both directions. At the beginning of 2019, one gasoline station ceased operation – an Aral station in Brietlingen.

The data set is supplemented with information on services and gasoline station characteristics from the official service providers tankerkoenig.de and clevertanken.de. Moreover, we added information on services offered and characteristics from gasoline stations' websites and the authors' local site visits.

We define a relenting attempt as an increase in the price of more than 1 cpl above the average market price that occurs after at least five gasoline stations successively lowered prices in our market. If two or more gas stations increase their prices simultaneously, we identify them all as initiating the price increase. Thus, if two gasoline stations increase the price simultaneously, we count it as two "cycles" to keep all price-increasing gasoline stations in the data set. Randomly dropping some of the price increase initiators would distort the results, as we aim to explain why a particular gasoline station is the first to increase its price after a series of price decreases. Irrelevant price observations after relenting attempts are dropped because we focus on relenting attempts.

Additionally, the earliest possible relenting must occur at least one hour after the last retailer opens for the day. This ensures that the usual price corrections made at the opening to adapt to the current price level are not wrongly identified as relenting attempts. We add robustness checks without evening price observations as several gasoline stations close around 9 p.m. We modified the data to lead us to obtain panel data on price increases.

Figure 1: Average Market Price
November 19, 2019

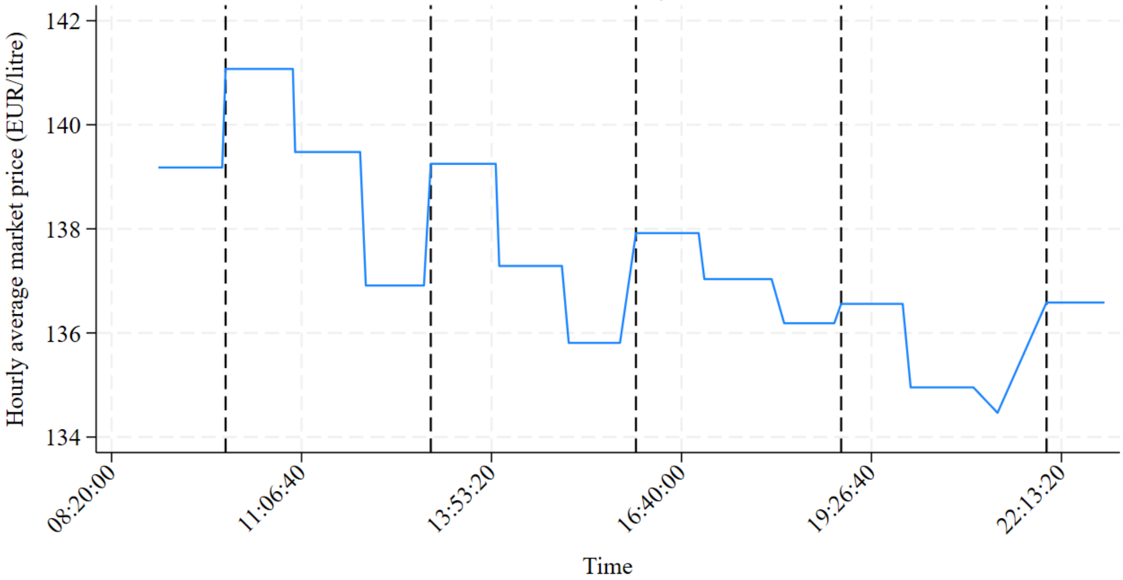


Figure 1 presents an example of petrol prices on a randomly chosen day, November 19, 2019. The example shows the gasoline petrol E5 prices at all gasoline stations in the Lueneburg area. We plot the hourly average market price to visualize the cyclical pattern. The dotted lines illustrate the exact relenting time. There were five cycles that day, all shown in Figure 1. Shell conducted all relenting attempts. The brand used three gasoline stations to simultaneously relent at 10 a.m., 1 p.m., 4 p.m., and 10 p.m. At 7 p.m., two gasoline stations were used to relent. There were no false or delayed starts that day.

Generally, in the Lueneburg market, at most ten gasoline stations are simultaneously initiating a new price cycle by raising prices. For each relenting retailer, we add a variable that indicates whether other gasoline stations initiated simultaneously – and if so, how many. Another variable indicates how many other gasoline stations of the same brand relented simultaneously.

We want to know how the price pattern in the market may influence a gasoline station's relenting decision. For each observation, we identify the competitors' latest prices. Then, we look at how many competitors were undercutting the gasoline station just before its price change. The price change can be a price reduction or an increase. We calculate the mean and median underbidding magnitude of the undercutting competitors. Moreover, we compute the competition's average and median price difference for each gasoline station right before it changes its price. Next, we define the average and median market price valid right before each price change in the data set.

We use crude oil prices to calculate a marginal cost proxy. We took the Brent spot prices in US dollars per barrel from the U.S. Energy Information Administration (2024). We converted them to euro per liter prices using exchange rates from the European Central Bank (2024).[11] Brent spot prices are commonly used as a proxy for the crude oil prices in the literature (among others by Kihm et al. (2016), Asane-Otoo and Dannemann (2022), Bakhat et al. (2022), and González and Moral (2023)). We use the price of the latest available date for the dates for which no crude oil prices are available.

Next, we calculate the smallest difference between the minimum daily price and the crude oil price for each gasoline station. This difference is the lowest "margin" ever accepted by that gasoline station in our data set. For each day, we synthesize a marginal cost proxy as the sum of the crude oil price of that day and the lowest margin ever accepted by that gas station. In fact, this marginal cost proxy is the lowest sum of marginal cost and profit margin ever accepted by that gas station.

We need this marginal cost (plus the lowest acceptable profit) proxy because it is important from a theoretical point of view. We use it to calculate the competitive pressure to which each gasoline station is exposed just before a price change. Specifically, we compute the difference between the average market price and the individual marginal cost proxy to measure individual competitive pressure for every observation just before a price change. The closer the market price moves towards a gasoline station's marginal cost, the more tempted it might be to relent.

Our empirical analysis focuses on the difference between the average market price and the individual marginal cost proxy. We call this variable "distance to marginal cost." The distance to marginal cost is calculated according to the following equation.

$$Distance\ to\ MC_{i,t} = \frac{1}{n}\sum_{j=0}^{N} p_{j,t} - MC_i, \forall\ i\ and\ j \in N, i \neq j, \forall\ t \in T \qquad (2)$$

With $Distance\ to\ MC_{i,t}$ reflecting the difference between the average market price and gasoline station i's marginal cost proxy at time t. The $p_{j,t}$ is the price that is valid for competitor j in period t. We take the average of all competitors' market prices and subtract

[11] For simplicity, we neglect the processing gain of the various refineries in the production of different fuels and divide the price per barrel by the number of liters to obtain a proxy for the crude oil price per liter. Byrne (2019) uses terminal gate prices for wholesale gasoline as a proxy for stations' marginal costs. Lewis (2009) uses rack price for unbranded gasoline as the wholesale price.

the marginal cost proxy MC_i of gasoline station i. This is done for all price changes of all gasoline stations in our local market.

Alternatively, we consider the variable "price pressure, undercutting," defined as the absolute value of the competitors' average underbidding of a retailer's former price. This variable is added to each observation and represents the average underbidding by the competitors. It is, by definition, positive as we take the absolute value to make interpretation easier. Alternative specifications include taking the median instead of the mean and all competitors' mean and median instead of restricting it to the underbidding competitors (which we refer to as "average price difference to rivals"). The "price pressure, undercutting" variable is calculated according to the following equation.

$$Price\ Pressure_{i,t} = \left| p_{i,t-1} - \frac{1}{n}\sum_{j=0}^{N} p_{j,t} \right|, \forall\ i\ and\ j \in N, i \neq j, \forall\ t \in T \qquad (3)$$

Equation (3) shows how the $price\ pressure_{i,t}$ for gasoline station i is calculated at time t. The expression $p_{i,t-1}$ represents retailer i's latest price before period t, hence, from the previous period $t-1$. The average market price is computed as shown in the above equation. Moreover, we consider the distance- and duration-weighted average market price. For duration-weighting, we calculate the time difference between each price change and all competitors' price changes before that one. Hence, it is the period a price was valid before a gasoline station decided to change its price. If a gasoline station reports the latest price change before it opens in the morning, then the duration is calculated as the difference between the opening time and the price change. We create a variable indicating the duration-weighted average market price and use it for the various price pressure variables.

The final price-related variable is the "number of underbidding competitors." It is simply a count of the number of competitors that underbid the latest price of a gas station right before it changed its price. It varies between 0 and 25.

Table 2: Variables Overview

Category	Variable
Dependent variables	***Increasing price observation**:* Dummy = 1 for increasing price observation and 0 for non-increasing price observation. ***Relenting magnitude***: Measures by how much the increasing gasoline station raises its price above the average market price, i.e., the difference between the relenter's new price and the average market price, in Eurocents per liter. **Successful relenting attempt**: Dummy = 1 for a successful price-increasing attempt and 0 if delayed or false.
Price competition	***Distance to marginal cost***: The difference between the average market price and a gasoline station's marginal cost proxy. ***Price pressure, undercutting***: The absolute value of a gasoline station's former price minus the competitors' average (mean or median) underbidding. ***Average price difference to rivals***: The value of a gasoline station's former price minus the competitors' average (mean or median) price. ***Average market price***: The average (or median) market price of a gasoline station's competitors. ***Average duration-weighted market price***: The average market price, but weighted by the duration for which each gasoline competitor's price was valid. ***Average distance-weighted market price***: The average market price, but each competitor's price is weighted by the driving distance to the gasoline station that is about to change its price. ***Number of undercutting rivals:*** The number of retailers underbidding the latest price of a gasoline station that is about to change its price. ***Number of retailers attempting to relent***: Number of retailers that simultaneously attempt to relent. ***Number of same-brand retailers that relent***: Number of same-brand retailers that simultaneously attempt to relent.
Local competition	***Distance***: Driving distances between gasoline stations are estimated using Google Maps and are based on the mean value of the distances in both driving directions. ***In sight?**:* Dummy = 1 if a competitor can be seen from the gasoline station and 0 otherwise. ***Located at Federal Road?***: Dummy = 1 if located at a federal road (German "Bundesstraße") and 0 otherwise. ***Located near Motorway?***: Dummy = 1 if located near the motorway (German "Autobahn") and 0 otherwise. ***Station in a rural area?***: Dummy = 1 if located outside of the town area of Lueneburg and 0 otherwise.
Demand-side controls	***Price observation occurred [day of the week]?***: Where [day of the week] = [Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday] and the day of the week of each observation is identified via dummy variables. ***Lower Saxony school holidays extended***: Dummy = 1 if public holiday or school holiday and 0 otherwise. ***Opening hours Monday to Friday?***: Number of hours a gasoline station is open on weekdays (in machine hours). ***Opening hours Saturday?***: Number of hours a gasoline station is open on a Saturday (in machine hours). ***Opening hours Sunday/Public Holiday?***: Number of hours a gasoline station is open on a Sunday or public holiday (in machine hours). ***Consumer satisfaction***: Corresponds to the consumer satisfaction rating of Google, with values from 1 = not satisfied to 5 = satisfied.
Brands and brand categories	***Aral***: Dummy = 1 if the gas station is of brand "Aral" and 0 otherwise. ***Shell***: Dummy = 1 if the gas station is of brand "Shell" and 0 otherwise. ***Esso***: Dummy = 1 if the gas station is of brand "Esso" and 0 otherwise. ***JET***: Dummy = 1 if the gas station is of brand "JET" and 0 otherwise. ***ESSO_JET***: Dummy = 1 if the brand is "ESSO" or "JET" and 0 otherwise. ***Hoyer***: Dummy = 1 if the gas station is of brand "Hoyer" and 0 otherwise. ***LTG***: Dummy = 1 if the gas station is of brand "LTG" and 0 otherwise. ***HEM***: Dummy = 1 if the gas station is of brand "HEM" and 0 otherwise. ***Raiffeisen***: Dummy = 1 if the gas station is of brand "Raiffeisen" and 0 otherwise. ***STAR***: Dummy = 1 if the gas station is of brand "STAR" and 0 otherwise. ***BFT***: Dummy = 1 if the gas station is of brand "BFT" and 0 otherwise. The abbreviation BFT stands for "Bundesverband freier und unabhängiger Tankstellen e.V.", which is association of small independent gasoline retailers. ***BLG***: Dummy = 1 if it is the regional gasoline station of the "Beckmann Lindemann GmbH" and 0 otherwise. ***FreiTS***: Dummy = 1 if it is the regional gasoline station of the "Freie Tankstelle Salewski" and 0 otherwise. ***FreieT***: Dummy = 1 if it is the regional gasoline station of the "Freie Tankstelle" and 0 otherwise. ***Oligopoly***: Dummy =1 if brand "Aral," "Shell," "ESSO," or "JET" and 0 otherwise. There is no gas station of the brand "TOTAL." It is not used in regression analysis because single brands are preferred. ***Superregional non-oligopoly player? (SRNOP)***: Dummy = 1 if the gasoline station of the brand "bft," "Hoyer," "LTG," "HEM," "Raiffeisen," or "STAR" and 0 otherwise. ***Regional non-oligopoly player? (RNOP)***: Dummy = 1 if gasoline station of brand "Beckmann Lindemann GmbH," "Freie Tankstelle Salewski," or "Freie Tankstelle" and 0 otherwise.
Station characteristics	***Self-service station?***: Dummy = 1 if the gasoline station is self-service and 0 otherwise. Thus, the gasoline station has an automated payment system without on-site staff. ***Shop or Rewe-shop?***: A measure that takes the value 1 if the gasoline station has a shop or kiosk (19 out of 26). It takes the value 2 if it is a small supermarket of the Rewe (2 out of 26) brand and 0 otherwise (5 out of 26). ***Bistro? Bakery?***: This is a measure of the gastronomic offer. It takes the value 1 if the gasoline station has a bistro or an in-store bakery (6 out of 26). It takes the value 2 if it has both (5 out of 26) and 0 otherwise (15 out of 26). ***Number of accepted credit cards*?**: Number of credit card types that are accepted for payment. ***ATM?***: Dummy = 1 if the gasoline station has a cash dispenser and 0 otherwise. ***Are restrooms available?***: Dummy = 1 if the gasoline station has restrooms and 0 otherwise. ***Car repair?***: Dummy = 1 if the gasoline station has a car repair on premises and 0 otherwise. ***Car wash? Vacuum cleaner?***: This is a measure of the car cleaning offer. It takes the value 1 if the gasoline station has a car wash or a vacuum cleaner. It takes on the value 2 if the retailer offers both and 0 otherwise. ***Number of Services?***: The number of services that a gasoline station offers. This is a simple count of all variables in this table's category "station characteristics," with the number of credit cards converted into a dummy variable = 1 if at least one type of credit card is accepted.

We differentiate between 12 services: self-service filling station, shop, Rewe's small supermarkets, bistros, backing stations, kiosks, credit card acceptance, ATMs, restrooms, car washes, car repair, and vacuum cleaners. Based on the services offered, we define a variable called the "service index," which is simply a count of the number of services offered, which we use only if estimation with single services is not feasible. Moreover, we create more meaningful measures for service categories, especially for shopping services offered, car-cleaning services offered, and gastronomical offers, as described in detail in Table 2. We present a detailed overview of all variables in Table 2. We show complete summary statistics in Appendix Table 1. We use all explanatory variables commonly used in previous research and more. Unfortunately, sufficient data on traffic intensity is not available.

3.5 Estimation Approaches

We examine what factors explain a gasoline station's willingness to be the first to increase its price after a series of price decreases and the magnitude by which it raises prices. Hence, we differentiate between the likelihood of being the first to raise the price and the strength of the price increase in Eurocent per liter (cpl). Moreover, we look at the factors affecting the probability that the market follows the relenting attempt.

3.5.1 Estimating Effects of Determinants of the Likelihood of Being the Price Increaser

First, we focus on the probability of a gasoline station initiating a new price cycle by increasing its price, that is, the relenting probability $1 - \mu(\delta)$ in the theoretical framework by Maskin and Tirole (1988). Consequently, we specify the dependent variable as a binary variable, taking the value one if the gasoline station increases its price more than 1 cpl above the average market price after a series of at least five price decreases and zero otherwise. According to the Edgeworth cycle theory, retailers play a mixed strategy, remaining at the cycle's trough with probability μ and relenting with probability $1 - \mu$.

According to the Edgeworth cycle theory, price is the decisive factor that causes cyclical pricing patterns. We look at different price variables. The distance to marginal cost variable captures the effect of competitors' prices being closer to a gasoline station's marginal cost on the likelihood of that station being the first to relent. The economic intuition behind this variable is that there is pressure from undercutting competitors on stations that cannot or do not want to lower their prices further in the cycle trough because the profit margin would be too small. Our distance to marginal cost variable captures the pressure on the relenting gasoline station just before the price increase, taking into account the opponents' prices and the individual costs. Moreover, we look at various measures of price competition, as discussed in the previous section.

The price variables change over time and with different entities. We use fixed effects estimation techniques to capture the impact of price difference variables, as done in previous publications (Wein, 2021). The fixed effects logit model of the binary dependent variable y_{it} can be expressed as:

$$Pr(y_{it} = 1|x_{it}, \alpha_i, \beta) = \frac{1}{1 + e^{-\alpha_i - x_{it}\beta}} \tag{4}$$

with $y_{it} = 1$ for relenting, and $y_{it} = 0$ otherwise. There are M regressors x_{it} with β representing the parameter vector $(M \times 1)$ to be estimated, and α_i is the fixed effect. Gasoline stations without varying y_{it} would not contribute to identification; however, all gasoline stations show variation with respect to the dependent variable, as shown in Table 4. The panel is small in terms of the number of gasoline stations (N=26), as we limit ourselves to one local market, and it is long in terms of periods (T=10,552 is the total number of price cycles over 728 days). Each relenting and the price valid just before it is regarded as a separate time unit because the prevailing market constellation could be why a gasoline station increases its price.

Finally, we are interested in station-specific factors: brand affiliation, location characteristics, and services offered. We use random effects logit estimation techniques to capture the effect of entity-specific variables.

3.5.2 Estimating Effects of Determinants of the Price Increase

Second, we look at the factors determining the strength of the price increase of each increasing entity and focus on the *magnitude of the price increase above the average market price* instead of the binary dependent variable used above. According to the Edgeworth cycle theory, in the decreasing phase of a price cycle, gasoline stations alternately and repeatedly undercut one another by infinitesimal amounts until prices fall near marginal costs. In this so-called war of attrition phase, firms can keep their prices low, or a gasoline station can relent by restoring its price to a higher level (Noel, 2018a). Since we define the dependent variable as the magnitude of the price increase, its distribution is a combination of a discrete distribution at zero and a continuous distribution above. Linear regression models may be used when assuming a continuous distribution of the dependent variable. The best achievable estimation approach for a censored distribution that is discrete at zero and continuous above is the fixed effects Poisson regression approach (FEP). Only weak assumptions must be satisfied; thus, the FEP is “fully robust in the sense that only the structural conditional means assumption . . . is needed for consistency and asymptotic normality” (Wooldridge, 1999). A FEP may well be applied here, even though the data at hand are non-count data (Wooldridge, 2002).

Again, the independent variable, the magnitude of the price increase, changes over time and between entities. We use fixed-effects Poisson estimation techniques to capture the effect of price difference variables and random-effects Poisson regression to capture the effect of entity-specific variables. Finally, we conduct several estimations based on various model specifications to check for robustness.

3.5.3 Estimating Factors Influencing the Success Probability of the Relenting Attempts

In our empirical analysis, we define a delayed start and a false start as follows:

Delayed start: An attempt to relent as defined previously but with at least five subsequent price decreases by competitors. Thus, competitors continue the undercutting at the cycle’s trough instead of increasing their prices to undercut the relenting retailer’s price. The relenting retailer does not try to take the price increase back in the following hour. The following price change should be negative but must not take back the initial price increase.

False start: An attempt to relent as defined previously but with at least five subsequent price decreases by competitors. The relenting retailer decreases its price within one hour after the attempt. The decrease must be as high in magnitude as the previous increase. Therefore, one can think of this decrease as taking back the previous increase.

This definition prevents us from falsely identifying a delayed start as a false start. The relenting station also lowered its price after a delayed start, but only after other gasoline stations raised prices with a delay, and the undercutting commenced again.

However, since the number of delayed starts (106) and false starts (33) is small, we defined a new variable that we use in our multivariate analysis. The binary dependent variable “success,” ξ, takes the value one for relenting attempts that are neither delayed nor false starts (and therefore labeled as successful) and zero otherwise. The random effects logit regression model can be written as:

$$\Pr(\xi_{it} = 1|x_{it}, \alpha_i, \beta) = \frac{1}{1 + e^{-\alpha_i - x_{it}\beta}} \quad (5)$$

analogously to equation (4). The vector of dependent variables x_{it} contains variables similar to the abovementioned estimation strategies. Therefore, station-specific variables, namely brand affiliation, location characteristics, services offered, and demand-side controls, enter the regression analysis. Moreover, the number of gasoline stations simultaneously attempting to relent and the number of same-brand retailers simultaneously attempting to relent enter the regression because the success probability might depend rather on the number of attempting retailers than the brand, as discussed in the theory section.

3.6 Descriptive Results

In our data set, we identified 10,552 price-increasing events, as seen in Table 3.[12] The table shows the rounded magnitude by which the new price exceeds the average market price when initiating a new price cycle and the frequency of these price increases. More than 60 percent of price increases exceed the average market price by 5 to 7 cpl.

Table 3: Frequency and Magnitude of Price Increase Above Average Market Price When Relenting

Relenting magnitude rounded	Freq.	Percent	Cum.
2	840	7.96	7.96
3	806	7.64	15.60
4	1099	10.42	26.01
5	1997	18.93	44.94
6	2527	23.95	68.89
7	1998	18.93	87.82
8	838	7.94	95.76
9	254	2.41	98.17
10	110	1.04	99.21
11	34	0.32	99.54
12	15	0.14	99.68
13	15	0.14	99.82
14	7	0.07	99.89
15	3	0.03	99.91
16	2	0.02	99.93
21	1	0.01	99.94
22	2	0.02	99.96
23	1	0.01	99.97
24	1	0.01	99.98
25	1	0.01	99.99
31	1	0.01	100.00
Total	10552	100.00	

Table 4 displays price increases by each gasoline station. Three stations dominate the pricing structure: Gasoline stations 1, 7, and 16. All three are Shell stations, the dominant brand on

[12] There are some negative price-increasing values. This occurs because the magnitude of the price increase is defined as the amount by which the relenting retailer raises its price above the average market price.

the market. Shell's market share is about 27 percent (7 gasoline stations out of 26); however, Shell accounts for about 55 percent of price-increasing events, as seen in Table 5. Similarly, Aral holds a market share of almost 20 percent and accounts for about 32 percent of price-increasing events. Table 5 shows the brand affiliation and the number of price-increasing events initiated by each brand.

Table 4: Price Increases by Gasoline Station, Petrol E5

Station numbers	**Brand or category**	Within one round: 1 = increasing price observ., 0= non-increasing price observ.		
		0	1	Total
1	Shell	8475	1949	10424
2	Aral	9847	705	10552
3	Aral	9780	772	10552
4	Aral	9725	826	10551
5	SRNOP	10537	0	10537
6	ESSO	10524	28	10552
7	Shell	8727	1812	10539
8	SRNOP	10551	1	10552
9	Aral	9764	777	10541
10	SRNOP	9623	8	9631
11	SRNOP	10540	4	10544
12	SRNOP	9996	524	10520
13	RNOP	9922	7	9929
14	Shell	10393	11	10404
15	RNOP	6622	86	6708
16	Shell	8509	2027	10536
17	RNOP	10371	52	10423
18	JET	10257	8	10265
19	Shell	10542	10	10552
20	SRNOP	9971	107	10078
21	Aral	4263	314	4577
22	Shell	10499	14	10513
23	SRNOP	9621	477	10098
24	Shell	10390	29	10419
25	SRNOP	10548	2	10550
26	SRNOP	9076	2	9078
Total		249073	10552	259625

Table 4 reveals that the two dominant brands work differently. Shell initiates price cycles through three out of seven gasoline stations. At the same time, Aral has a uniform distribution regarding the frequency of price-increasing events over its gasoline stations. In the section on multivariate results, we provide further evidence for the notion that Shell and Aral dominate the price cycle pattern.

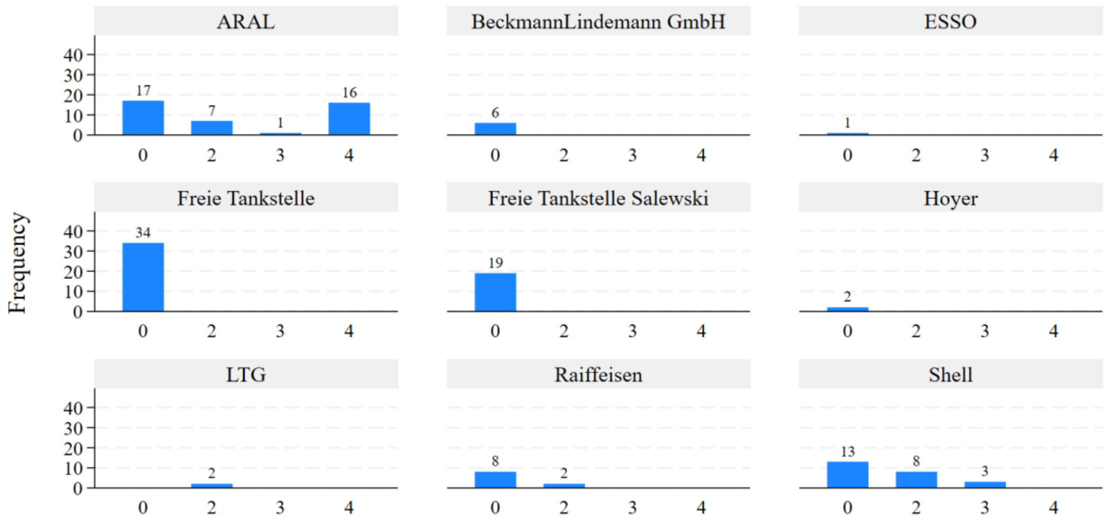
General descriptive statistics for the petrol E5 data set, including the number of observations, standard deviation, minimum, and maximum, are in Appendix Table 1. The average petrol E5 price is about 140 cpl over the observation period.

According to our definition of relenting, on average, 3.95 actual cycles per day between 8 a.m. and 10 p.m., with a standard deviation of 1.23 and a minimum of 2 and a maximum of 9 cycles per day. As mentioned earlier, many cycles are initiated by several gasoline stations raising prices simultaneously, so we act as if each of these increases is a period (cycle) of its own when analyzing why a gasoline station is the first to raise its price. Thus, according to this definition, there are about 10,553 cycles in the data set, with an average of 14.5 cycles per day (sd=6.1, min=4, max=36). We chose this definition because we do not want to exclude any stations that raised prices simultaneously with other stations. On average, there are slightly more daily cycles on weekdays compared to weekends and on public and school holidays compared to non-holidays.[13]

Table 5: Frequency of Price-increasing Events by Brand, Petrol E5

Brand	Within one round: 1 = increasing price observ., 0= non-increasing price observ.		
	0	1	Total
Aral	43379	3394	46773
BLG	9922	7	9929
ESSO	10524	28	10552
FreieT	6622	86	6708
FreieTS	10370	53	10423
HEM	10540	4	10544
Hoyer	9623	8	9631
JET	10257	8	10265
LTG	30161	4	30165
Raiffeisen	19592	584	20176
STAR	10551	1	10552
Shell	67535	5852	73387
BFT	9996	524	10520
Total	249072	10553	259625

Figure 2: Frequency of Failed Relenting Attempts by Brand and the Number of Retailers Involved in the Attempt



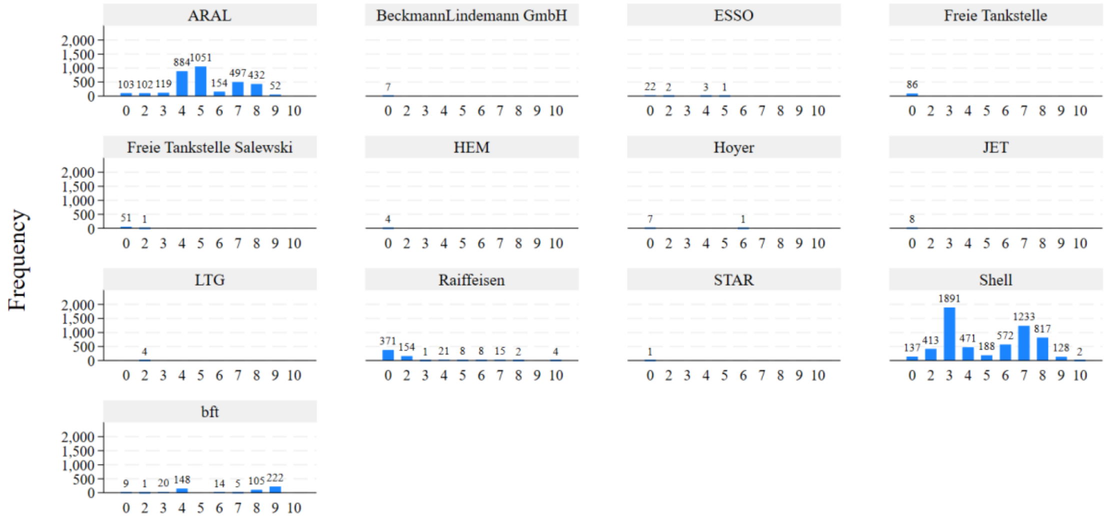
Note: The horizontal axis shows the number of retailers that have simultaneously attempted and failed to relent. For example, ARAL failed to relent five times with one of its stations alone and 12 times simultaneously with two other retailers of the same or another brand.

[13] According to the one-sided Z-test and T-test, the average number of cycles per day on weekdays is 4.00, which is higher than the mean of 3.83 on weekends (Saturday and Sunday). This difference is significant at the 5 percent confidence level. Similarly, the average number of cycles on public and school holidays is 4.13, which is higher compared to non-holidays (significant at the 1 percent confidence level).

Figure 2 shows the number of delayed or false starts by brand. Considering the frequency distribution of price-increasing events from Table 5, it is striking how often small retailers experience delayed or false starts. For example, retailers belonging to Aral experienced 41 false starts out of 3,394 price-increasing attempts. In contrast, the local retailer “Freie Tankstelle” failed 33 out of 86 relenting attempts. As shown in Table 5, the retailers BLG, HEM, Hoyer, JET, LTG, and STAR undertake only a few relenting attempts overall and, therefore, are less at risk of experiencing delayed or false starts, as visualized in Figure 2.

Relative to the overall number of relenting attempts, the dominant brands Aral and Shell seem to experience substantially fewer delayed or false starts than other retailers. Generally, there were relatively fewer failed relenting attempts when multiple retailers were involved, which is evident from Figure 3.

Figure 3: Frequency of Relenting Attempts by Brand and the Number of Retailers Involved in the Attempt



Note: The horizontal axis shows the number of retailers that have simultaneously attempted to relent. For example, ARAL attempted to relent 103 times with one of its stations alone and 102 times simultaneously with two other retailers of the same or another brand.

3.7 Regression Results and Discussion

First, we present estimation results on the factors determining the likelihood of the station initiating a price increase. Second, we present results on factors determining the strength of each relenting station's price increase. The third subsection looks at the probability of successful relenting attempts. We discuss our results in the last subsection.

3.7.1 Factors That Determine the Likelihood of Being the Price Increaser

We limit ourselves to one local market, so station characteristics and location parameters do not change in the data set. Table 6 shows the results for the fixed- and random-effects logit regression. We compared different model specifications and decided on a table entry based on Akaike's (AIC) and Schwarz's Bayesian (BIC) information criteria.[14] Furthermore, we report the number of observations.

In Table 6, several coefficients are statistically significant at the 0.1 percent confidence level. Next to the description at the left edge of Table 6 (column 1), we present coefficients of fixed-effects logit estimates for the first quarter of 2018 (column 2) along with standard errors (column 3) and marginal effects at means (column 4).[15] The three columns on the right-hand side of Table 6 contain coefficients, standard errors, and marginal effects at means for random-effects logit estimates.

The most appropriate model to estimate the effects of the price variables is to use a fixed-effects approach to account for all gasoline station heterogeneity. Therefore, we provide conditional fixed effects logit regression results. Due to limited calculation capacity,[16] we had to limit the time to two or three months and present results for the first quarter of 2018. There is a statistically significant effect of the distance to marginal cost, which is economically irrelevant in explaining why a gasoline station decides to relent. The Same is true for the number of undercutting opponents. The coefficients of weekdays and holidays are insignificant. The results are robust to replacing the distance to marginal cost variable with the average market price as well as duration or distance-weighted versions. Using the median instead of the average market price does not change the results either. Finally, the results do not change when altering the observational period.

Fixed-effects estimation results show that prices, weekdays, and holidays play a minor role in explaining why a gasoline station is the one to relent. Next, we employ a random-effects logit approach to examine the role of station characteristics, location, and brand affiliation. Looking at geographic effects, gasoline stations near motorways are 0.9 percentage points more likely to initiate a new price cycle, and gas stations in rural areas are 0.3 percentage points more likely. Similar to the fixed effects logit results, there are no significant day-of-the-week effects.

The consumer satisfaction effect is negative and statistically significant at the 1 percent confidence level. A one-star higher consumer satisfaction rating (1 = not satisfied to 5 =

[14] Similar to Asane-Otoo and Schneider (2015), who also refer to the AIC and the BIC.

[15] We limit the time to one quarter or two months because estimation for longer periods "results in numeric overflow" in Stata.

[16] Using all periods (January 2018 to December 2019) leads Stata to report the error (1400) that the "combinations result in numeric overflow; computation cannot proceed." As this error results most commonly when one attempts to estimate a model with too many effective observations, we limit the period to the first three months of each year and obtain similar results, respectively.

satisfied) is associated with a 0.6 percentage points lower probability of being the station to increase prices first.[17]

Table 6: Fixed- and Random-Effects Logit Estimation, Petrol E5

	FE Logit Q1 2018	FE Logit SE	FE Logit ME	RE Logit	RE Logit SE	RE Logit ME
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Distance to marginal cost	-0.186***	(0.0145)	|-0.000|	-0.0196	(0.0126)	|-0.000|
Num of undercutting rivals	-0.288***	(0.00849)	|-0.001|	-0.233***	(0.0268)	|-0.000|
In sight?				3.548	(.)	|0.007|
Located near a motorway				4.686***	(0.294)	|0.009|
Located near a federal road				-0.369	(0.243)	|-0.001|
Station in rural area?				1.426***	(0.265)	|0.003|
Tuesday	-0.176	(0.126)		-0.0163	(0.0483)	|-0.000|
Wednesday	-0.0995	(0.119)		-0.00391	(0.0646)	|-0.000|
Thursday	-0.00299	(0.117)		-0.0318	(0.0846)	|-0.000|
Friday	-0.0828	(0.121)		0.0171	(0.0268)	|0.000|
Saturday	0.102	(0.120)		0.0363	(0.0286)	|0.000|
Sunday	-0.0415	(0.122)		-0.0218	(0.0622)	|-0.000|
Lower Saxony holidays	-0.132	(0.0741)	|-0.000|	0.0201	(0.0770)	|0.000|
Aral				4.242***	(0.353)	|0.033|
ESSO				5.720	(.)	|0.130|
JET				1.336	(.)	|0.001|
SRNOP				-3.469***	(0.366)	|-0.000|
Shell				4.857***	(0.668)	|0.059|
Consumer satisfaction?				-2.965***	(0.0654)	|-0.006|
Shop? Rewe? Kiosk?				2.217***	(0.277)	|0.004|
Bistro? Bakery?				-0.168	(0.256)	|-0.000|
Car repair?				-3.617***	(0.170)	|-0.007|
Car wash? Vacuum cleaner?				-2.582***	(0.390)	|-0.005|
Self-service station?				-1.330	(.)	|-0.002|
Number of accepted credit cards?				-1.188***	(0.193)	|-0.002|
ATM?				3.034***	(0.311)	|0.006|
Are restrooms available?				-0.577*	(0.255)	|-0.001|
Constant				12.66	(.)	|.|
Observations	30088			244950		
AIC	6622.7			51822.9		
BIC	6697.5			52072.7		

Robust standard errors in parentheses for random-effects estimation (variance-covariance matrix type robust not allowed with fixed-effects logit estimation); * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP).

Most coefficients for services offered are statistically significant at the 0.1% confidence level. A retailer offering more shopping possibilities is 0.4 percentage points more likely to attempt relenting than one without a shop. Retailers with an ATM are 0.6 percentage points more likely to relent. All other services have a negative sign indicating that retailers relying more on service offers are less likely to relent. A retail site with a car repair is 0.7, with more car cleaning offers 0.5, and with a self-service installation 0.2 percentage points less likely

[17] Note that a reputation is built over the long run, and hence, causality likely runs in the other direction than could be wrongly assumed from looking only at these results.

to relent. Also, each additional credit card type accepted reduces a retailer's likelihood to relent by 0.2 percentage points.

Brand affiliation is relatively important in explaining a retailer's likelihood of attempting to relent. Gasoline stations belonging to the premium brand Aral are 3.3 percentage points more likely to raise their prices to initiate a new price cycle than regional non-oligopoly players (RNOP) - the baseline brand category. Shell gasoline stations are 5.9 percentage points more likely to initiate a new price cycle. These estimates are significant at the 1%confidence level. The estimates for brands ESSO and JET are statistically insignificant, and the marginal effect at means for superregional non-oligopoly players (SRNOP) is economically irrelevant.

The results of the fixed-effects logit regression and the random-effects logit regressions are similar. Even though fixed-effects estimation techniques are generally preferred over random-effects techniques, random-effects estimates for time-constant variables are the best we can do given the data.

The results based on the alternative price pressure variables are similar overall, as shown in Appendix Table 2. The price variables play no role in the decision of whether a retailer is the first to relent. Estimates for location and service characteristics are similar to those in Table 6. The results for brand affiliation are more pronounced for Aral, whose retailers are 3.5 to 5.4 percentage points more likely to relent. The respective estimates for Shell are more heterogeneous and lie between 2.1 and 10.9 percentage points. For all four alternative price variables, the estimates for ESSO are statistically significant at the 0.1% confidence level and indicate that the retailer is between 13.3 and 22.6 percentage points more likely to relent.

The results for the other fuel types, petrol E10 and diesel, are very similar, as shown in Appendix Tables 3 and 4. While there are no surprises with respect to fixed-effects estimates, there are slight differences with respect to the random-effects estimates. A retailer near a motorway is 0.7 to 1 percentage point more likely to relent for diesel and petrol E10 respectively. This effect is statistically significant at the 0.1% confidence level. Location on a federal road does not influence the likelihood of relenting in the diesel market but increases the probability by 0.4 percentage points in the petrol E10 market.

The brand affiliation estimates for diesel are very similar to the ones for petrol E5. Retailers belonging to Aral are 2.7 percentage points more likely to relent, and those belonging to Shell are 5.6 percentage points more likely. For petrol E10, in contrast, retailers belonging to Aral are 7.6 percentage points more likely to relent, and those belonging to Shell are 2.1 percentage points more likely. Coefficients for services offered are very similar for all fuel types.

Overall, price-related variables play a minor role in explaining why a gasoline station attempts to relent. Location and the services offered are more important. Brand is the most important determinant of the likelihood that a particular retailer is the one to relent.

3.7.2 Factors That Determine the Strength of the Price Increase of the Price Increaser

Next, we present the results of random-, and fixed-effects Poisson estimates in Table 7. There are 10,552 price cycles over the two years from 2018 to 2019. On average, gasoline stations initiating a new cycle increase the price by 5.56 cpl (Std. Dev. 1.94). Examining the magnitude of price jumps helps to identify which factors determine the size of the cycle. The cycle size matters to customers who lose consumer surplus in longer and higher cycles. In this part of our research, we identify which factors lead to higher or lower price cycles. We focus on the *magnitude of the price increase* as the dependent variable (instead of the Bernoulli variable of a price increase); hence, the coefficients and marginal effects may not be compared to those above.

Again, all coefficients of the fixed-effects Poisson (FE Poisson) regression are statistically insignificant, except the distance to marginal cost and the number of undercutting rivals coefficient. The price coefficients still show no economically relevant effect. If the average market price gets 1 cpl closer to a relenting retailer's marginal cost proxy, then the relenting magnitude exceeds the average market price by an additional 0.003 cpl. For each additional competitor that undercuts the latest price of a relenting gasoline station before its relenting attempt, the relenting magnitude is 0.03 cpl greater.

The price variable coefficients for the random-effects Poisson regression are very similar. The relenting magnitude is almost 2 cpl higher if the relenting gasoline station belongs to the brand Aral, and it is nearly 1 cpl higher if it belongs to Shell. Retailers belonging to superregional noon-oligopoly players (SRNOP) relent by 0.9 cpl more than regional non-oligopoly players (RNOP). These coefficients are statistically significant at the 5% confidence level. Self-service stations relent my 0.5 cpl more than others. Other location and retailer characteristics do not influence the relenting magnitude significantly.

We present estimation results corresponding to Table 7 for the other fuel types in Appendix Tables 5 and 6. Fixed-effects estimates for the petrol E10 market are similar and confirm the results for petrol E5 from Table 7. The fixed-effects estimate for the distance to marginal cost is statistically insignificant for diesel, while the effect of one additional undercutting opponent is the same. For the diesel market, relenting attempts are significantly larger on Saturdays than on Mondays; however, the economic effect is negligible.

Table 7: Fixed- and Random-Effects Poisson Estimation, Petrol E5

	RE Poisson		FE Poisson	
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e., the difference between new and old prices, in euro cents per liter (cpl).				
Distance to marginal cost	0.00515***	(0.000942)	0.00537***	(0.000938)
Num of undercutting rivals	0.0310***	(0.00221)	0.0308***	(0.00221)
In sight?	-0.222	(0.433)		
Located near a motorway	-0.346	(0.241)		
Located near a federal road	-0.273	(0.296)		
Station in rural area?	0.260	(0.252)		
Tuesday			0.0109	(0.0146)
Wednesday			-0.00501	(0.0126)
Thursday			-0.00679	(0.00758)
Friday	0.0106	(0.00831)	0.0108	(0.00880)
Saturday	-0.00218	(0.0133)	-0.00290	(0.00911)
Sunday	0.0112	(0.00588)	0.00946	(0.00834)
Lower Saxony holidays	0.00241	(0.00512)	0.00317	(0.00502)
Aral	1.948*	(0.849)		
ESSO	0.418	(0.637)		
JET	-0.204	(0.293)		
SRNOP	0.888*	(0.393)		
Shell	0.981*	(0.458)		
Consumer satisfaction?	-0.578	(0.380)		
Shop? Rewe? Kiosk?	-0.745**	(0.233)		
Bistro? Bakery?	-0.0598	(0.0893)		
Car repair?	0.184	(0.298)		
Car wash? Vacuum cleaner?	0.424	(0.279)		
Self-service station?	0.481*	(0.244)		
Number of accepted credit cards?	-0.112	(0.0897)		
ATM?	0.442	(0.269)		
Are restrooms available?	-0.0715	(0.140)		
Constant	3.046	(1.967)		
Observations	9762		9761	
AIC	38038.7		37803.1	
BIC	38211.2		37867.8	

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Weekday base is Monday for the FE Poisson and Monday to Thursday for the RE Poisson; Brand category base is the group of regional non-oligopoly players (RNOP).

Random-effects estimates for petrol E10 are again similar to the results presented for the petrol E5 market in Table 7. In support of our findings from analyzing the petrol E5 market, results for Aral and Shell are statistically significant at the 0.1% confidence level with very similar estimates. Also, results for ESSO and SRNOP are significant and comparable to the petrol E5 results. Moreover, the station and location characteristics results are statistically significant and in line with our above finding. Results for the diesel market are less pronounced, with no significant brand affiliation effects. However, retailers near a federal road raise prices by 0.7 cpl less.

Again, brand affiliation plays a relatively important role in explaining the magnitude of price increases. The oligopoly players Aral and Shell appear to make a decisive contribution to higher price cycles in the market. Price dynamics play a minor role in explaining the strength of price increases.

3.7.3 Factors That Determine the Success Probability of the Relenting Attempts

Finally, we present the results of our analysis regarding successful relenting attempts in Table 8. We label all relenting attempts that are not delayed or false starts as successful. A more extensive database may allow future research to elaborate on the difference between delayed and false starts.

Our local market example shows that the number of gasoline stations attempting to relent prices simultaneously has a positive and statistically significant effect on the probability of success. The economic effects of our estimates are relatively small. If a relenting attempt includes one more gasoline retailer in the local market, it is 0.1 percentage points more likely to be successful.

Though not statistically significant, the signs of the relenting magnitude and the in-sight coefficients are consistent with economic intuition. The probability of success decreases with the relenting magnitude because competitors face a higher risk following the relenting retailer. The likelihood of an attempt being successful decreases if competitors are in sight.[18] Retailers near the motorway or federal roads are more likely to succeed, though only the latter coefficient is statistically significant at the 1% confidence level. Retailers in rural areas are 0.3 percentage points less likely to be successful in their relenting attempts. Overall, the local effects are of minor economic relevance as changes in success probability are at or below 0.3 percentage points. Also of minor economic relevance are the day of the week and public holiday estimates.

The relatively most important factor influencing the probability of success is the brand affiliation of the retailer attempting to relent. The probability of success differs greatly for major brands, such as Aral, Shell, and Esso, compared to others, as Noel's (2008) triopoly Edgeworth cycle theory extension predicted. Aral, Shell, and Esso retailers are 2.3 to 3.3 percentage points more likely to succeed in their relenting attempts than the baseline of regional non-oligopoly players. The coefficient for Aral is statistically insignificant, and the coefficients for ESSO and Shell are statistically significant at the 0.1% confidence level. JET was omitted because it had no false or delayed start, according to our definition.[19] The superregional non-oligopoly players (bft, Hoyer, LTG, HEM, and STAR) are about 3.1

[18] Future research may show how the probability of success changes if a competitor "in sight" does or does not participate in the relenting attempt.
[19] There are several brands with few relenting attempts and no failed ones; see Figures 2 and 3.

percentage points more likely to be successful in their relenting attempts. However, this coefficient is only statistically significant at the 5% confidence level.[20]

Table 8: Fixed- and Random-Effects Logit Estimation, Petrol E5

	RE Logit	SE	ME
Dependent variable: Successful relenting attempt: Dummy = 1 for a successful price-increasing attempt and 0 for a delayed or false start.			
Relenting magnitude	-0.0262	(0.0831)	|-0.000|
Num retailers attempting relent	0.819^{***}	(0.0975)	|0.001|
Num same-brand retailers relent	0.0284	(0.343)	|0.000|
In sight?	-1.331	(0.682)	|-0.001|
Located near a motorway	0.974	(0.633)	|0.001|
Located near a federal road	1.848^{**}	(0.597)	|0.001|
Station in rural area?	-3.286^{***}	(0.687)	|-0.003|
Tuesday	-0.302	(0.395)	|-0.000|
Wednesday	-0.575	(0.362)	|-0.000|
Thursday	1.083^{***}	(0.316)	|0.000|
Friday	-0.901	(0.549)	|-0.001|
Saturday	-0.891	(0.676)	|-0.001|
Sunday	-0.227	(0.628)	|-0.000|
Lower Saxony holidays	-0.212	(0.256)	|-0.000|
Aral	1.154	(2.408)	|0.023|
ESSO	4.996^{***}	(1.270)	|0.033|
SRNOP	2.720^{*}	(1.248)	|0.031|
Shell	5.349^{***}	(1.458)	|0.033|
Consumer satisfaction?	0.978^{*}	(0.406)	|0.001|
Shop? Rewe? Kiosk?	0.969^{*}	(0.407)	|0.001|
Bistro? Bakery?	0.721^{***}	(0.172)	|0.001|
Car repair?	-0.793^{*}	(0.359)	|-0.001|
Car wash? Vacuum cleaner?	-1.218^{***}	(0.265)	|-0.001|
Self-service station?	-2.954^{***}	(0.299)	|-0.002|
Number of accepted credit cards?	-0.570^{**}	(0.206)	|-0.000|
ATM?	-0.0339	(0.355)	|-0.000|
Are restrooms available?	-0.834	(0.555)	|-0.001|
Constant	-0.885	(2.087)	|.|
Observations	9753		
AIC	773.1		
BIC	931.2		

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP). JET was omitted because it had no delayed or false start in the time considered.

Results for diesel are more pronounced, as shown in Appendix Table 7. Aral, Esso, JET, SRNOP, and Shell retailers are 15.6 to 16 percentage points more likely to succeed in their relenting attempts than the baseline of RNOP. All brand affiliation coefficients except Aral and SRNOP are significant at the 0.1% confidence level. The Aral coefficient is insignificant, and the SRNOP coefficient is significant at the 5% confidence level. The coefficient for the number of simultaneously relenting retailers is insignificant, as is the one for retailers located near motorways or federal roads. The small negative effect on the

[20] Clearly, data for many different local retail markets would yield a better estimate of the effects. These results here, for just one local market, should be considered as the first contributions that can give an idea of how the market mechanisms work. Further research is needed.

probability of success in relenting for retailers located in rural areas is the same as for petrol E5. Most service coefficients are insignificant, and those that significantly influence the probability of success are similar to the ones for petrol E5.

The results for petrol E10 are very similar to the ones for petrol E5 with respect to the relenting magnitude, the number of simultaneously relenting retailers, and location parameters (see Appendix Table 7). The number of retailers involved in the relenting attempt significantly increases the success probability of the relenting attempt but is economically negligible. The brand affiliation coefficients are either statistically insignificant or have no economic effect on the success probability of relenting retailers. There are no surprises when it comes to the role that services offered play in the success probability of relenting in the petrol E10 market compared to the petrol E5 market.

3.7.4 Discussion of Results

Overall, we provide evidence that the dominant brands are more likely to attempt relenting and do so with stronger price increases than RNOP. Moreover, we show that: 1) the probability of successful restoration of the price level increases in the number of coordinated gasoline stations; however, this increase is only marginal, 2) the probability of success strongly depends on the brand affiliation, and 3) it depends a little on the location of the retailer as well as the services offered. How are our results related to market power?

Market power is the ability of single players to influence the market price. This ability depends on the brand, according to our results. Large vertically integrated brands with several gasoline stations in the local market, namely Aral (BP) and Shell, act as price leaders (as known from the existing literature), less so, Esso (Exxon Mobil) and Jet (Philips 66). We show this by providing empirical evidence that, especially for Aral and Shell, 1) they are more likely to restore the price level to end the war of attrition phase, and 2) they exert more influence on the market price by typically having price level restorations of higher magnitude.

To stress the point that it is not the number of gasoline stations coordinated by one brand but rather the brand itself that determines when to restore the price level, we estimate the likelihood of successful price restoration, taking into account the number of gasoline stations used. We find that the brand affiliation is relatively important. Factors explaining the importance of brand affiliation might be price elasticities resulting from perceived product differentiation and capacity differences, as discussed by Noel (2008).

Major brands might be less motivated to engage in aggressive undercutting due to the inelastic demand they face, e.g., from business consumers. Moreover, brands operating multiple sites in one local market profit relatively more from higher price levels than brands with only a few sites and, therefore, have a higher incentive to restore the price level. In contrast, for small firms with sufficient capacity, it is profitable to charge somewhat lower prices to capture some market share, as discussed by Eckert (2003).

Maskin and Tirole (1988) show that cycles can also exist under capacity constraints. As in the Edgeworth cycle theory extension to a triopoly by Noel (2008), we take the capacity as exogenously given. While Noel defines capacity constraints in terms of the maximum output of a firm, Eibelshäuser and Wilhelm (2018) focus on the number of retail outlets operated by the firm. The (potential) capacity to supply a local market is likely to depend on the level of vertical integration and the number of retail outlets in local markets. In the short run, both are constant. In the long run, the number of brands operated by a single brand in a specific local market and likely, to a lesser extent, the level of vertical integration is endogenous because each brand chooses both.

A specific pricing pattern may influence a chain's decision of how many gasoline stations to operate in a local market. At the same time, the number of sites run by specific firms influences the pricing pattern, as we show in our empirical analysis. The ability to influence both is likely path-dependent because small brands are less capable of changing these factors than major brands. It may predominantly be the choice of major brands, how many stations to run in a single local market, and how to influence the pricing pattern. Our results show that the number of gasoline stations coordinated in relenting attempts and, even more, the brand affiliation affect the probability of successful relenting. Major brands' ability to influence the price significantly more is, by definition, market power.

3.8 Robustness Checks and Threats to Validity

Our results are similar for the different fuel types and identical in terms of market mechanisms. The following subsection provides several robustness checks and their discussion. In the second subsection, we discuss threats to validity.

3.8.1 Robustness Checks

As mentioned, one Aral gasoline station ceased operations in 2019. We present robustness checks that exclude this station from the data set in Appendix Table 8. There are no notable changes compared to the reference model from Table 6.

Generally, the first round of price increases each day could be distorted because the pricing policy is based on the price level of the previous evening and not on the prices of competitors who open earlier. We dealt with this issue by only considering price increases that occurred at least one hour after the last gasoline station opened. Thus, by definition, the first price increase we look at must be after 8 a.m. on weekdays.

Observations of price changes in the late evening hours may distort results because competition patterns change as gasoline stations close (Eibelshäuser and Wilhelm, 2018). We include a robustness check excluding observations after 9 p.m.[21] and one limited to the first 25 cycles of each day. The robustness checks in Appendix Table 8 show no notable differences if the number of cycles is limited to the first 25 cycles of each day. Minor changes occur if only observations until 9 p.m. are taken into account. There is a small positive effect on the likelihood of relenting if gasoline stations are located near a federal road, and there is no effect for retailers in rural areas. The brand affiliation coefficient for Aral becomes insignificant, and minor differences concerning services offered occur.

We focus on the gasoline market in Lueneburg and the surrounding area and use geographic characteristics to define the market, considering commuter routes and the proximity to the motorway. The estimation models contain variables to account for location, as listed in Table 2, and we use driving distance instead of distance as the crow flies for location variables. In Appendix Table 8, we present robustness checks for gasoline stations within the town of Lueneburg. We base this latter market definition on the historically evolved delineation of the town. This drastically limits the number of gasoline stations to 15. Therefore, it is no surprise that estimation results are somewhat different. Many station characteristics would have been excluded due to collinearity. We use a count of the number of services offered with respect to shopping, gastronomical and car maintenance offers, and the availability of restrooms and ATMs. Notable changes compared to the base model from Table 6 occur concerning the effects of brand affiliation. Retailers belonging to Aral are 9.5 percent more likely to relent, and those belonging to Shell are even 20.4 percent more likely to relent than RNOP.

Another concern is that we exaggerated the assumed rationality of gasoline stations and that gasoline stations do not react by the second but rather on a minute basis. Thus, instead of allowing a station to react to a competitor's price decrease with a price jump within a few seconds, we rule out such reaction speed by requiring the latest price decrease to lie at least five minutes before the price jump, similar to Wein (2021). This new identification mechanism accounts for the fact that gasoline stations only have to transmit price changes

[21] On weekdays, the first three gasoline stations close at 7 p.m., 8 p.m., and 8:30 p.m.

to the MTU within five minutes. The new estimates are similar to the ones of the reference model, as shown in Appendix Table 8.

The estimates seem somewhat sensitive to how we define the relenting attempt. We present estimation results of two alternative versions that reveal small differences regarding the estimates. The alternative definitions of a relenting attempt require the relenting magnitude to be at least 2 cpl or 0 cpl above the average market price, respectively (in contrast to the base model for which we set this threshold value to 1 cpl). There are no changes with respect to the estimated effect of price-related variables. Also, the location estimates are very similar to the ones of the base model. The brand affiliation estimates are similar but sometimes not statistically significant and slightly stronger or weaker in magnitude. The same is true for the station characteristics. Overall, the estimates are similar.

So far, we have used the distance to marginal cost proxy and price pressure measures, which we developed to capture the influence of the pricing situation just before each relenting attempt. Now, we use the average market price instead of the distance to the marginal cost proxy. Coefficients hardly change.[22] Using the median market price instead yields coefficients similar to those of the base model, which are significant for SRNOP and Shell. We also compute the average market price based on prices weighted by the time they were valid before the relenting attempt and present the results in Appendix Table 8. Results are very similar to the base model from Table 6.

Prices of competitors located near the initiating station may play a decisive role in explaining why the particular retailer is first to increase prices. We present results of estimates using the average market price, based on distance-weighted price differences between the relenting retailer and the competitors in Appendix Table 8. Again, there are only minor changes. Aral's brand affiliation coefficient is smaller, and Shell's is larger. Estimates of location and station characteristics remain similar to the base model.

Overall, the results of our robustness checks are consistent with the estimates discussed above. Price plays a minor role in gasoline stations' decisions on whether to be the first to raise prices and initiate a new price cycle. The results of similar robustness checks as those conducted in Appendix Table 8, but of Poisson estimates, are in Appendix Table 9. The Poisson results are similar to previous results and robust with respect to different model specifications and for other fuel types.

---

[22] Standard errors were not estimable when using the average, median, or distance-weighted prices. Thus, evaluating the statistical significance of the brand affiliation estimates for these specifications is impossible.

3.8.2 Threats to Validity

The overall research goal of this article is to identify the relevant determinants that cause price cycles. Price cycles occur in some form worldwide in the gasoline retail market. Why do we focus on a single local market? Are our results externally valid?

We limit ourselves to the market around one town, Lueneburg, because revising the data set is very complex and time-consuming. In other markets, the results could change – especially in markets under regulation or that differ with respect to gasoline station composition. We use the same market definition as Wein (2021), who argues that local knowledge is important to answer the crucial question of market definition. Thus, commuter routes can be identified, and it is possible to decide if gasoline stations on the edge still belong to the market.

Narrowing the data set to Lueneburg comes at the cost of limited power in interpreting gasoline stations and market characteristics due to low to no change in respective variables. Daily recording of the service variables would require a lot of effort, and locational changes and brand changes are rare in the German gasoline retail market (Wein, 2021).

This results in limited external validity for this study. However, we expect cyclical price patterns of markets similar to Lueneburg to follow the same mechanics identified here because similar cyclical pricing patterns are observed all over the world. Comprehensive estimation approaches allowed us to estimate the effects of a variety of factors for the market chosen without limitation to internal validity. Fixed effects approaches ensure that we do not fear threats to internal validity from omitted variables. We present the results of appropriate estimation techniques to capture the functional form. As complete data were available from the MTU and all prices of gasoline stations of the Lueneburg market were entered into the analysis, there was no problem with imprecise measurement or sample selection. Simultaneous causality is no issue in our short-run analysis.

Finally, we discuss starting points for further empirical research beyond our empirical analysis of delayed and false starts along two dimensions (space and time). Not least to reveal weaknesses in our study due to our limited database.

First, our data regarding timing are very accurate, which allows differentiation between delayed and false starts. However, the number of cases of delayed and false starts is limited. Therefore, we abstain from differentiating between delayed and false starts in our empirical analysis, although we deem such differences worthy of examination. Since both are a form of relenting failure, we focus on analyzing this failure. Our estimates show what factors determine the likelihood of success (or failure) of retailers' relenting attempts.

Second, we introduce a variable capturing the change in the success probability of simultaneously relenting with several retail sites (differentiating between the overall number of stations and the same-brand number of stations). In our data set, we have no brand affiliation variation and little chain size variation as we focus on a single local market. Brand or chain size can be measured as the number of retail sites belonging to a brand or by looking at the capacity; see Eibelshäuser and Wilhelm (2018) and Noel (2008) for theoretical discussions. In our data set, for example, the number of sites Shell operates does not change over time. Our results suggest that brand affiliation is relatively important in explaining the probability of successful relenting attempts. A larger data set covering several local markets and sufficient time are required to explain why brand affiliation is more important. Notably, the motivation for certain brands likely depends on the number of stations they operate in a local market. This number of sites is endogenous in the long run. Further factors explaining the importance of brand affiliation might be capacity differences and different price elasticities resulting from perceived product differentiation, as discussed by Noel (2008).

3.9 Summary and Conclusion

Since August 2013, the retail fuel prices of all German retailers have been available and accessible to everyone via websites or phone applications virtually in real time. Utilizing these services, consumers can easily choose the cheapest gasoline station within a certain driving distance around their location. The information is also useful to retailers themselves, for whom it becomes much easier to monitor local competitor prices. From an economic perspective, one would expect gasoline stations to react quickly to competitors' price changes.

As Wein (2021) described, gasoline prices in Germany fluctuate a lot over the day and follow a relatively fixed ritual. Prices rise in the late evening or at night, fall sharply in the early morning, and go up and down in between. The literature describes the cycles as corresponding to the well-known Edgeworth cycles. These Edgeworth cycles are said to appear because gasoline stations undercut each other until a price close to the marginal costs is reached. Then, one or more retailers raise their prices, initiating a new price cycle, and others follow. Then, undercutting begins again. We identified the gasoline station which was the first to increase its price after the underbidding. Economically speaking, the increaser is giving up on competing via the price in the local market and hopes that competitors respond by increasing prices by just undercutting the new price of the initiating station. Then, the retailer relenting initially can respond by undercutting the competition again and obtaining consumer surplus over the course of the price cycle.

Microeconomic considerations of profit maximization lead the gasoline station to increase its price only if sales gained from starting a new cycle – minus the loss of sales that occurs in the short-run during higher prices, exceed the sale losses that would arise if the gasoline station endured the trough of the cycle to continue the war of attrition. Those retailers that compete primarily over the price, for example, because they are located in unfavorable locations, tend to increase prices less often. Similarly, gasoline stations are less inclined to raise prices if they rely more on services such as car repair or car wash to generate sales.

To show why retailers are the first to raise prices to reach a higher price level, the "paradise", we use publicly accessible data and revise them massively, similar to Wein (2021). We use data for the same local market, the region of Lueneburg, covering the years 2018 to 2019. Focusing on one region allows us to assume that the retailers compete with each other. After identifying the first price increase after a series of five price decreases, we added all competitors' prices, valid immediately before the price increase. Similar to Wein (2021), we build on the basic assumption that all retailers were facing the same price level one second before the price increase, but only one of them decided to increase its price. We format a panel unit that contains both the old and new prices of the relenting retailer and all competitors' prices that were valid directly before the price increase. Such accurate price cycle identification is only possible due to the data's time precision. We used a variety of regression approaches, such as conditional fixed effects logit, random effects logit, and fixed effects Poisson approaches, to test what distinguishes the relenting retailer from the non-price increasers.

Even though most coefficients produced by our estimation approaches are highly statistically significant, the economic significance of the effects is sometimes low. At the same time, estimation results show that some service variables, location parameters, and brand affiliations have a significant economic effect on a gasoline station's pricing decisions. As we limit ourselves to one local market, gas station characteristics, location parameters, and brands' market power do not change notably in the data set.

The Edgeworth cycle theory assumes that cyclical price patterns in the gasoline market result exclusively from price competition. Our estimation results show that the price variables play a minor role in retailers' decisions on whether to be the first to raise the price. In contrast, market structural factors play a relatively more important role. We used fixed effects regression to identify the effects of price variables. The statistically significant variables for price pressure show a vanishingly small economic effect on the likelihood of a gasoline station relenting. According to the estimates for petrol E5 data, if the average market price moves 1 cent per liter closer to a retailer's marginal cost, its relenting probability does not change. Using the average market price, median market price and distance- or duration-weighted average market price does not change this result.

In contrast, estimates from the random logit approaches show that location parameters play a slightly larger role in explaining why a retailer is the one to relent. Results show that a gasoline station near a motorway is about 1 percentage point more likely to initiate a new price cycle, and a gasoline station in a rural area is about 0.3 percentage points less likely. There are no significant day-of-the-week effects. Though economically small, positive effects on the relenting probability are associated with shopping offers and having an ATM. Negative effects on the relenting probability are associated with services such as car repair, car wash availability of restrooms, and the number of accepted credit cards.

A relatively important role in explaining the relenting probability plays the brand affiliation of a retailer. Depending on the fuel type and model specification, the dominant premium brands, Aral and Shell, are up to 10.9 percentage points more likely to initiate a new price cycle than regional non-oligopoly players (RNOP), the baseline brand category. Though rarely statistically significant, the third premium brand, ESSO, might also be more likely to relent. Furthermore, Poisson estimation results show that Aral and Shell, who jointly account for more than 80 percent of price increases in this market, are also the major drivers of the size of the price cycles. For petrol E5 and E10, they increase the price by 1 to 2 cpl more on average than RNOP. Only some superregional non-oligopoly players seem to mimic this behavior. There are no significant differences in the diesel market.

Results of our delayed and false start analysis show that the probability of successful price restoration increases marginally in the number of coordinated gasoline stations and depends to a small extent on the retailer's location. In contrast, the likelihood of success depends relatively strongly on a retailer's brand affiliation. It differs greatly between the major brands Aral, Shell, and Esso, compared to others, as predicted by Noel's (2008) triopoly Edgeworth cycle theory extension. In the petrol E5 market, Aral, Shell, and Esso retailers are 2.3 to 3.3 percentage points more likely to succeed in their relenting attempts than the baseline RNOP. Superregional non-oligopoly players (bft, Hoyer, LTG, HEM, and STAR) are about 3.1 percentage points more likely to be successful in relenting. There are no statistically significant effects in the petrol E10 market. In the diesel market, Aral, ESSO, JET, SRNOP, and Shell are between 15.6 and 16 percentage points more likely to be successful in their relenting attempt, though the coefficient for Aral is insignificant.

Overall, price considerations play a minor role in explaining why a gasoline station is the first to increase its price. Station characteristics and location parameters play a slightly more prominent role, but brand affiliation plays a relatively important role. These parameters do not seem to be decisive either; however, these factors are much more important when it comes to a station's decision to be the first to increase prices than price considerations alone. This result is consistent with the findings of previous research (e.g., Lewis (2012)) that show that dominant retail chains act as price leaders by leading price restorations in markets exhibiting price cycles. Together, the strong results for oligopoly players Aral and Shell suggest that market power is the major driver of the cyclical pricing pattern in the gasoline market. The results are robust with respect to markets for different fuel types. Throughout the article, we present the often less pronounced results of the petrol E5 market. Estimation results for brand-specific effects are often larger when focusing on the diesel or petrol E10 market. Moreover, the results are robust to various alternative model specifications, as demonstrated by numerous robustness checks.

There is a risk of being the first to increase gasoline prices. If a station increases its price and no one follows, it bears the cost of foregone sales until it lowers the price again. There is a similar risk of being the first gasoline station to follow the increaser. How many false starts on new price cycles existed in the Lueneburg market from 2018 to 2019? If we define a false price increase as one in which none of the five subsequent price changes at any gasoline station is positive, 139 of 10,552 price-increasing events are false price increases. A brand with several gasoline stations in the market can jointly coordinate its stations to increase prices. This reduces their risk of a false start because competitors face a lower risk of falling for a false start if half the market already demands higher prices. Thus, suppliers with market power should have a higher incentive to induce a new price cycle.

The data set we used here is very similar to the one used by Wein (2021), and the results should be treated with the same caution. We show that all retailers influence the price; however, some dominant brands (especially ARAL and Shell) influence the price significantly more, both in terms of the frequency and magnitude of their price increases, which indicates the existence of market power. Further research should continue to focus on what drives cyclical pricing patterns in the retail gasoline market. Further research is needed to elaborate on what happens shortly after a relenting attempt, on the role of brand affiliation, and false and delayed starts.

3.10 Appendix

Appendix Table 1: Descriptive Statistics, Petrol E5

Variable	Obs	Mean	Std. Dev.	Min	Max
Price	259625	140.134	6.054	122.9	167.9
Relenting attempt	259625	.041	.197	0	1
Relenting magnitude	10552	5.559	1.944	.593	30.815
Num retailers attempting relent	259625	.197	1.074	0	10
Num same-brand retailers relent	259224	.15	.827	0	9
Distance to marginal cost	259625	16.044	5.933	-1.44	35.649
Distance to mc, median	259625	16.044	5.933	-1.44	35.649
Average market price	259625	141.328	5.752	126.196	159.752
Median market price	259625	141.174	5.914	124.9	161.9
Price pressure, undercutting	255162	2.961	1.707	.3	20
Median price pressure, undercutting	255162	2.732	1.83	.1	20
Duration-weighted price press	248093	-2.505	2.584	-64.594	-.016
Distance-weighted price press	255162	-1.335	.817	-11.56	0
Average price diff to rivals	259625	-.999	2.15	-18.077	14.5
Median price diff to rivals	259625	-1.154	2.272	-20	15
Crude oil price, Brent	259625	.369	.034	.278	.471
Num of undercutting rivals	259625	14.061	7.14	0	25
Aral	259625	.18	.384	0	1
ESSO	259625	.041	.197	0	1
JET	259625	.04	.195	0	1
Shell	259625	.283	.45	0	1
SRNOP	259625	.353	.478	0	1
RNOP	259625	.104	.306	0	1
Consumer satisfaction?	244950	4.073	.346	3.4	4.8
Shop? Rewe? Kiosk?	259625	.903	.501	0	2
Bistro? Bakery?	259625	.621	.8	0	2
Car repair?	259625	.317	.465	0	1
Car wash? Vacuum cleaner?	259625	.762	.513	0	2
Self-service station?	259625	.22	.414	0	1
Number of accepted credit cards?	244950	3.615	1.92	0	5
ATM?	259625	.162	.368	0	1
Are restrooms available?	259625	.556	.497	0	1
In sight?	259625	.081	.273	0	1
Located near a motorway	259625	.078	.268	0	1
Located near a federal road	259625	.241	.428	0	1
Station in rural area?	259625	.412	.492	0	1
Price obs. occurred on Monday	259625	.15	.357	0	1
Price obs. occurred on Tuesday	259625	.143	.35	0	1
Price obs. occurred on Wednesday	259625	.147	.355	0	1
Price obs. occurred on Thursday	259625	.149	.356	0	1
Price obs. occurred on Friday	259625	.145	.352	0	1
Price obs. occurred on Saturday	259625	.137	.344	0	1
Price obs. occurred on Sunday	259625	.13	.336	0	1
Opening hours Monday to Friday?	259625	20.698	4.065	12	24
Opening hours Saturday?	259625	20.338	4.841	6	24
Opening hours Sunday/Public Holi	259625	19.909	5.891	0	24
Lower Saxony holidays	259625	.322	.467	0	1
False start	10552	.003	.056	0	1
Delayed start	10552	.01	.1	0	1
Delayed or false start	10552	.013	.114	0	1

Appendix Table 2: Random-Effects Logit, Petrol E5

	RE Logit with "Price pressure, undercutting"	RE Logit with "Median price pressure, undercutting"	RE Logit with "Average price difference to rivals"	RE Logit with "Median price difference to rivals"
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.				
Relenting attempt				
Price pressure, undercutting	-0.774***			
	(0.016)			
	|-0.001|			
Median price pressure, undercutting		-0.639***		
		(0.015)		
		|-0.001|		
Average price diff to rivals			0.673***	
			(0.014)	
			|0.000|	
Median price diff to rivals				0.114***
				(0.011)
				|0.000|
Num of undercutting rivals	-0.154***	-0.158***	-0.059***	-0.203***
	(0.003)	(0.003)	(0.004)	(0.004)
	|-0.000|	|-0.000|	|-0.000|	|-0.000|
In sight?	4.510***	4.523***	4.115***	3.565***
	(0.565)	(0.564)	(0.610)	(0.524)
	|0.006|	|0.007|	|0.003|	|0.006|
Located near a motorway	4.306***	4.575***	4.759***	4.718***
	(0.502)	(0.500)	(0.508)	(0.433)
	|0.006|	|0.007|	|0.004|	|0.009|
Located near a federal road	-1.121**	-1.044**	-0.690	-0.401
	(0.371)	(0.373)	(0.399)	(0.346)
	|-0.002|	|-0.002|	|-0.001|	|-0.001|
Station in rural area?	2.041***	2.008***	1.446***	1.426***
	(0.345)	(0.346)	(0.352)	(0.307)
	|0.003|	|0.003|	|0.001|	|0.003|
Tuesday	0.008			
	(0.045)			
	|0.000|			
Wednesday	0.029			
	(0.045)			
	|0.000|			
Thursday	0.007			
	(0.045)			
	|0.000|			
Friday	0.033	0.024	0.042	0.031
	(0.045)	(0.036)	(0.035)	(0.035)
	|0.000|	|0.000|	|0.000|	|0.000|
Saturday	0.158***	0.134***	0.065	0.051
	(0.046)	(0.036)	(0.036)	(0.035)
	|0.000|	|0.000|	|0.000|	|0.000|
Sunday	0.200***	0.124***	0.025	-0.007
	(0.046)	(0.037)	(0.036)	(0.035)
	|0.000|	|0.000|	|0.000|	|-0.000|
Lower Saxony holidays	0.116***	0.062*	0.025	0.002

Appendix Table 2: Random-Effects Logit, Petrol E5

<table>
<tr><th></th><th>RE Logit with “Price pressure, undercutting”</th><th>RE Logit with “Median price pressure, undercutting”</th><th>RE Logit with “Average price difference to rivals”</th><th>RE Logit with “Median price difference to rivals”</th></tr>
<tr><td></td><td>(0.026)</td><td>(0.026)</td><td>(0.026)</td><td>(0.025)</td></tr>
<tr><td></td><td>|0.000|</td><td>|0.000|</td><td>|0.000|</td><td>|0.000|</td></tr>
<tr><td>Aral</td><td>4.647**</td><td>4.152**</td><td>8.645***</td><td>4.527***</td></tr>
<tr><td></td><td>(1.497)</td><td>(1.482)</td><td>(1.415)</td><td>(1.209)</td></tr>
<tr><td></td><td>|0.054|</td><td>|0.045|</td><td>|0.052|</td><td>|0.035|</td></tr>
<tr><td>ESSO</td><td>6.271***</td><td>5.943***</td><td>10.206***</td><td>5.978***</td></tr>
<tr><td></td><td>(1.085)</td><td>(1.074)</td><td>(0.986)</td><td>(0.870)</td></tr>
<tr><td></td><td>|0.226|</td><td>|0.224|</td><td>|0.207|</td><td>|0.133|</td></tr>
<tr><td>JET</td><td>1.309*</td><td>1.293*</td><td>5.094***</td><td>1.658***</td></tr>
<tr><td></td><td>(0.594)</td><td>(0.591)</td><td>(0.527)</td><td>(0.494)</td></tr>
<tr><td></td><td>|0.001|</td><td>|0.002|</td><td>|0.002|</td><td>|0.002|</td></tr>
<tr><td>SRNOP</td><td>-4.155***</td><td>-4.463***</td><td>-1.888**</td><td>-3.305***</td></tr>
<tr><td></td><td>(0.651)</td><td>(0.648)</td><td>(0.670)</td><td>(0.586)</td></tr>
<tr><td></td><td>|-0.001|</td><td>|-0.000|</td><td>|-0.000|</td><td>|-0.000|</td></tr>
<tr><td>Shell</td><td>3.679***</td><td>3.540***</td><td>9.441***</td><td>5.095***</td></tr>
<tr><td></td><td>(0.750)</td><td>(0.742)</td><td>(0.704)</td><td>(0.586)</td></tr>
<tr><td></td><td>|0.021|</td><td>|0.025|</td><td>|0.109|</td><td>|0.060|</td></tr>
<tr><td>Consumer satisfaction?</td><td>-1.480*</td><td>-1.588*</td><td>-2.935***</td><td>-2.943***</td></tr>
<tr><td></td><td>(0.695)</td><td>(0.701)</td><td>(0.732)</td><td>(0.611)</td></tr>
<tr><td></td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.005|</td></tr>
<tr><td>Shop? Rewe? Kiosk?</td><td>2.897***</td><td>3.082***</td><td>2.419***</td><td>2.275***</td></tr>
<tr><td></td><td>(0.315)</td><td>(0.319)</td><td>(0.313)</td><td>(0.289)</td></tr>
<tr><td></td><td>|0.004|</td><td>|0.004|</td><td>|0.002|</td><td>|0.004|</td></tr>
<tr><td>Bistro? Bakery?</td><td>-0.073</td><td>-0.029</td><td>-0.020</td><td>-0.144</td></tr>
<tr><td></td><td>(0.131)</td><td>(0.131)</td><td>(0.134)</td><td>(0.128)</td></tr>
<tr><td></td><td>|-0.000|</td><td>|-0.000|</td><td>|-0.000|</td><td>|-0.000|</td></tr>
<tr><td>Car repair?</td><td>-2.830***</td><td>-2.957***</td><td>-3.809***</td><td>-3.593***</td></tr>
<tr><td></td><td>(0.619)</td><td>(0.618)</td><td>(0.636)</td><td>(0.532)</td></tr>
<tr><td></td><td>|-0.004|</td><td>|-0.004|</td><td>|-0.003|</td><td>|-0.006|</td></tr>
<tr><td>Car wash? Vacuum cleaner?</td><td>-2.605***</td><td>-2.609***</td><td>-2.777***</td><td>-2.585***</td></tr>
<tr><td></td><td>(0.412)</td><td>(0.415)</td><td>(0.442)</td><td>(0.368)</td></tr>
<tr><td></td><td>|-0.004|</td><td>|-0.004|</td><td>|-0.002|</td><td>|-0.005|</td></tr>
<tr><td>Self-service station?</td><td>-0.340</td><td>-0.499</td><td>-1.160**</td><td>-1.304***</td></tr>
<tr><td></td><td>(0.371)</td><td>(0.370)</td><td>(0.403)</td><td>(0.343)</td></tr>
<tr><td></td><td>|-0.000|</td><td>|-0.001|</td><td>|-0.001|</td><td>|-0.002|</td></tr>
<tr><td>Number of accepted credit cards?</td><td>-1.283***</td><td>-1.285***</td><td>-1.785***</td><td>-1.208***</td></tr>
<tr><td></td><td>(0.153)</td><td>(0.152)</td><td>(0.143)</td><td>(0.116)</td></tr>
<tr><td></td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.001|</td><td>|-0.002|</td></tr>
<tr><td>ATM?</td><td>4.236***</td><td>4.165***</td><td>3.062***</td><td>3.088***</td></tr>
<tr><td></td><td>(0.507)</td><td>(0.503)</td><td>(0.477)</td><td>(0.429)</td></tr>
<tr><td></td><td>|0.006|</td><td>|0.006|</td><td>|0.002|</td><td>|0.006|</td></tr>
<tr><td>Are restrooms available?</td><td>-0.262</td><td>-0.468*</td><td>-0.669**</td><td>-0.625**</td></tr>
<tr><td></td><td>(0.205)</td><td>(0.206)</td><td>(0.233)</td><td>(0.204)</td></tr>
<tr><td></td><td>|-0.000|</td><td>|-0.001|</td><td>|-0.000|</td><td>|-0.001|</td></tr>
<tr><td>Constant</td><td>6.324</td><td>6.614</td><td>8.639*</td><td>11.745***</td></tr>
<tr><td></td><td>(3.594)</td><td>(3.622)</td><td>(3.817)</td><td>(3.169)</td></tr>
<tr><td>Observations</td><td>240746</td><td>240746</td><td>244950</td><td>244950</td></tr>
<tr><td>AIC</td><td>46885.332</td><td>47559.858</td><td>49236.966</td><td>51813.353</td></tr>
<tr><td>BIC</td><td>47186.685</td><td>47830.037</td><td>49507.595</td><td>52083.982</td></tr>
</table>

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP).

Appendix Table 3: Fixed-Effects Logit Estimation, Diesel, and Petrol E10

	FE Diesel Q1 2018	FE Diesel SE	FE Diesel ME	FE E10 Q1 2018	FE E10 SE	FE E10 ME
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Distance to marginal cost	-0.169^{***}	(0.0147)	|-0.000|	-0.172^{***}	(0.0147)	|-0.000|
Num of undercutting rivals	-0.313^{***}	(0.00956)	|-0.001|	-0.332^{***}	(0.00966)	|-0.001|
Tuesday	-0.317^{*}	(0.130)		-0.142	(0.127)	
Wednesday	-0.333^{**}	(0.121)		-0.0152	(0.122)	
Thursday	-0.185	(0.121)		0.000132	(0.119)	
Friday	-0.0310	(0.121)		-0.0232	(0.123)	
Saturday	-0.318^{**}	(0.122)		0.261^{*}	(0.118)	
Sunday	-0.311^{*}	(0.123)		0.196	(0.121)	
Lower Saxony holidays	0.0726	(0.0735)	|0.000|	0.0414	(0.0737)	|0.000|
Observations	28324			29177		
AIC	6467.3			6384.0		
BIC	6541.6			6458.5		

Standard errors in parentheses (variance-covariance matrix type robust not allowed with fixed-effects logit estimation); * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday.

Appendix Table 4: Random-Effects Logit Estimation, Diesel, and Petrol E10

	RE Diesel	RE Diesel SE	RE Diesel ME	RE E10	RE E10 SE	RE E10 ME
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Distance to marginal cost	-0.0537***	(0.0151)	|-0.000|	-0.0236	(0.0139)	|-0.000|
Num of undercutting rivals	-0.261***	(0.0314)	|-0.000|	-0.135***	(0.00899)	|-0.000|
In sight?	1.791*	(0.731)	|0.003|	0.827	(.)	|0.003|
Located near a motorway	3.833***	(0.240)	|0.007|	3.085***	(0.278)	|0.010|
Located near a federal road	0.881	(0.660)	|0.002|	1.146***	(0.265)	|0.004|
Station in rural area?	0.153	(0.871)	|0.000|	0.451	(0.247)	|0.001|
Tuesday	-0.0102	(0.0509)	|-0.000|	0.0331	(0.0889)	|0.000|
Wednesday	-0.0407	(0.0452)	|-0.000|	0.0602	(0.0484)	|0.000|
Thursday	-0.0562	(0.0790)	|-0.000|	0.0295	(0.0661)	|0.000|
Friday	0.0118	(0.0592)	|0.000|	0.0494	(0.0411)	|0.000|
Saturday	-0.0479	(0.0350)	|-0.000|	0.0970	(0.0586)	|0.000|
Sunday	-0.0766	(0.0514)	|-0.000|	0.0690*	(0.0338)	|0.000|
Lower Saxony holidays	0.0190	(0.0678)	|0.000|	0.0377	(0.0842)	|0.000|
Aral	4.163***	(1.001)	|0.027|	5.811***	(0.545)	|0.076|
ESSO	4.148	(.)	|0.026|	5.213	(.)	|0.043|
JET	0.879	(.)	|0.001|	1.109	(.)	|0.001|
SRNOP	-3.103	(.)	-|0.000|	-0.220	(0.508)	|-0.000|
Shell	4.926***	(1.359)	|0.056|	4.476***	(0.519)	|0.021|
Consumer satisfaction?	-1.862***	(0.0761)	|-0.003|	-2.269***	(0.0916)	|-0.007|
Shop? Rewe? Kiosk?	3.037***	(0.272)	|0.005|	1.247***	(0.303)	|0.004|
Bistro? Bakery?	-0.483	(0.399)	|-0.001|	-0.951***	(0.281)	|-0.003|
Car repair?	-2.421***	(0.241)	|-0.004|	-2.329***	(0.243)	|-0.007|
Car wash? Vacuum cleaner?	-1.185	(0.890)	|-0.002|	-1.159***	(0.267)	|-0.004|
Self-service station?	-1.150***	(0.334)	|-0.002|	-0.498*	(0.248)	|-0.002|
Number of accepted credit cards?	-1.160***	(0.347)	|-0.002|	-1.020***	(0.143)	|-0.003|
ATM?	2.544***	(0.432)	|0.004|	2.771***	(0.489)	|0.009|
Are restrooms available?	-0.512	(0.382)	|-0.001|	0.329	(0.280)	|0.001|
Constant	7.133	(.)		6.692	(.)	
Observations	243493			238992		
AIC	49360.1			54062.7		
BIC	49609.7			54311.9		

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP).

Appendix Table 5: Fixed-Effects Poisson Estimation of the Relenting Magnitude, Diesel, and Petrol E10

	FE Poisson Diesel		FE Poisson E10	
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e., the difference between new and old prices, in euro cents per liter (cpl).				
Distance to marginal cost	0.00214	(0.00236)	0.00516***	(0.00157)
Num of undercutting rivals	0.0316***	(0.00165)	0.0332***	(0.00321)
Tuesday	-0.00342	(0.0131)	-0.00331	(0.0111)
Wednesday	0.00288	(0.00972)	0.000413	(0.0117)
Thursday	0.00693	(0.00966)	0.00494	(0.0119)
Friday	-0.00118	(0.0103)	-0.0117	(0.0142)
Saturday	0.0214***	(0.00631)	0.0109	(0.0159)
Sunday	0.00759	(0.0105)	0.00330	(0.0103)
Lower Saxony holidays	-0.000716	(0.00804)	0.000650	(0.00719)
Observations	0.00214		9486	
AIC	0.0316***		37112.4	
BIC	-0.00342		37176.9	

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP).

Appendix Table 6: Random-Effects Poisson Estimation of the Relenting Magnitude, Diesel, and Petrol E10

	RE Poisson Diesel		RE Poisson E10	
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e., the difference between new and old prices, in euro cents per liter (cpl).				
Distance to marginal cost	0.00200	(0.00236)	0.00517***	(0.00156)
Num of undercutting rivals	0.0316***	(0.00166)	0.0333***	(0.00321)
In sight?	0.450	(0.363)	0.0247	(0.305)
Located near a motorway	-0.0244	(0.163)	-0.250*	(0.125)
Located near a federal road	-0.696**	(0.251)	-0.426*	(0.200)
Station in rural area?	0.470*	(0.229)	0.331	(0.185)
Friday	-0.00298	(0.00960)	-0.0127	(0.00865)
Saturday	0.0204***	(0.00587)	0.0102	(0.0102)
Sunday	0.00666	(0.00806)	0.00311	(0.00645)
Lower Saxony holidays	-0.00187	(0.00807)	0.000107	(0.00712)
Aral	0.994	(0.547)	1.808***	(0.407)
ESSO	0.123	(0.444)	0.596*	(0.265)
JET	0.0405	(0.255)	-0.0289	(0.148)
SRNOP	0.244	(0.279)	0.671**	(0.242)
Shell	0.541	(0.327)	0.961***	(0.260)
Consumer satisfaction?	-0.771**	(0.261)	-0.495*	(0.214)
Shop? Rewe? Kiosk?	-0.591**	(0.190)	-0.598***	(0.173)
Bistro? Bakery?	0.122*	(0.0617)	0.0109	(0.0441)
Car repair?	-0.205	(0.195)	0.106	(0.143)
Car wash? Vacuum cleaner?	0.0582	(0.243)	0.269	(0.197)
Self-service station?	0.0687	(0.170)	0.421**	(0.146)
Number of accepted credit cards?	-0.0545	(0.0598)	-0.122*	(0.0493)
ATM?	0.426*	(0.214)	0.488***	(0.123)
Are restrooms available?	-0.286***	(0.0796)	-0.106	(0.0619)
Constant	4.484***	(1.335)	2.774**	(1.064)
Observations	9665		9488	
AIC	37812.1		37327.3	
BIC	37984.3		37499.1	

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Weekday base is Monday, Tuesday, Wednesday, and Thursday because maximum likelihood estimation including all days of the week (but Monday) was not achievable; Brand category base is the group of regional non-oligopoly players (RNOP).

Appendix Table 7: Random-Effects Logit Estimation of Success, Diesel, and Petrol E10

	RE Diesel	RE Diesel SE	RE Diesel ME	RE E10	RE E10 SE	RE E10 ME
Dependent variable: Successful relenting attempt: Dummy = 1 for a successful price-increasing attempt and 0 for a delayed or false start.						
Relenting magnitude	0.122	(0.129)	|0.000|	0.00300	(0.129)	|0.000|
Num retailers attempting relent	0.271	(0.199)	|0.000|	0.985***	(0.126)	|0.001|
Num same-brand retailers relent	0.384	(0.395)	|0.001|	-0.0272	(0.365)	|-0.000|
In sight?	-0.500	(1.226)	|-0.001|	0.999	(0.749)	|0.001|
Located near a motorway	0.158	(0.971)	|0.000|	1.028*	(0.523)	|0.001|
Located near a federal road	0.388	(1.006)	|0.001|	0.470	(0.641)	|0.000|
Station in rural area?	-1.955**	(0.758)	|-0.003|	-1.508*	(0.647)	|-0.001|
Tuesday	-1.764***	(0.409)	|-0.003|	-0.143	(0.336)	|-0.000|
Wednesday	-1.059*	(0.473)	|-0.001|	-0.561	(0.338)	|-0.000|
Thursday	-1.310*	(0.517)	|-0.001|	0.109	(0.504)	|0.000|
Friday	-1.337**	(0.409)	|-0.002|	-0.791	(0.537)	|-0.001|
Saturday	-1.748**	(0.560)	|-0.003|	-0.990	(0.567)	|-0.001|
Sunday	-0.366	(0.471)	|-0.000|	-0.299	(0.699)	|-0.000|
Lower Saxony holidays	0.338	(0.226)	|0.001|	-0.274	(0.270)	|-0.000|
Aral	4.011	(2.679)	|0.157|	-4.124	(2.628)	|-0.016|
ESSO	6.642***	(1.418)	|0.160|	1.778	(1.513)	|0.000|
JET	5.608***	(0.630)	|0.160|	4.203***	(0.772)	|0.000|
SRNOP	3.786*	(1.535)	|0.156|	-0.698	(1.277)	|-0.000|
Shell	5.373***	(1.178)	|0.160|	0.460	(1.665)	|0.000|
Consumer satisfaction?	-2.280	(1.259)	|-0.005|	0.341	(0.358)	|0.000|
Shop? Rewe? Kiosk?	-1.266	(1.421)	|-0.002|	2.120***	(0.617)	|0.002|
Bistro? Bakery?	-0.799	(0.433)	|-0.001|	0.426	(0.319)	|0.000|
Car repair?	-1.729	(1.138)	|-0.003|	-1.081*	(0.459)	|-0.001|
Car wash? Vacuum cleaner?	-1.941**	(0.646)	|-0.003|	-1.713***	(0.258)	|-0.001|
Self-service station?	-1.150	(0.712)	|-0.002|	-2.060***	(0.473)	|-0.002|
Number of accepted credit cards?	-0.657*	(0.299)	|-0.001|	0.0589	(0.249)	|0.000|
ATM?	1.483	(1.688)	|0.002|	-0.196	(0.525)	|-0.000|
Are restrooms available?	1.107	(0.713)	|0.002|	-0.540	(0.694)	|-0.000|
Constant	13.77*	(6.608)		1.626	(2.003)	
Observations	9665			9488		
AIC	787.5			745.1		
BIC	959.8			916.8		

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP).

Appendix Table 8: Robustness Checks – Random Effects Logit Estimation, Petrol E5

<table>
<tr><th></th><th>Base model as in Table 6</th><th>Excluding the exiting retailer</th><th>Only time before 9 p.m.</th><th>Only the first 25 cycles</th><th>Only town of Lueneburg</th><th>Last price drop 5 min before relenting</th><th>Relenting of at least 2 cpl</th><th>Relenting of at least 0 cpl</th><th>Average market price</th><th>Average duration-weighted price</th><th>Average distance-weighted price</th><th>Median market price</th></tr>
<tr><td colspan="13">Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.</td></tr>
<tr><td>Distance to marginal cost</td><td>-0.020</td><td>-0.017</td><td>-0.011</td><td>-0.020</td><td>-0.024*</td><td>-0.019</td><td>-0.019</td><td>-0.021</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>(0.013)
|-0.000|</td><td>(0.013)
|-0.000|</td><td>(0.011)
|-0.000|</td><td>(0.013)
|-0.000|</td><td>(0.010)
|-0.000|</td><td>(0.013)
|-0.000|</td><td>(0.013)
|-0.000|</td><td>(0.012)
|-0.000|</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average market price</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-0.019</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>(0.016)
|-0.000|</td><td></td><td></td><td></td></tr>
<tr><td>Average duration-weighted market price</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>0.007***</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>(0.000)
|0.000|</td><td></td><td></td></tr>
<tr><td>Average distance-weighted market price</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-0.024</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>(0.032)
|-0.000|</td><td></td></tr>
<tr><td>Median market price</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>-0.031*</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>(0.015)
|-0.000|</td></tr>
<tr><td>Num of undercutting rivals</td><td>-0.233***</td><td>-0.233***</td><td>-0.222***</td><td>-0.230***</td><td>-0.435***</td><td>-0.233***</td><td>-0.224***</td><td>-0.233***</td><td>-0.233***</td><td>-0.227***</td><td>-0.233***</td><td>-0.232***</td></tr>
<tr><td></td><td>(0.027)
|-0.000|</td><td>(0.027)
|-0.000|</td><td>(0.024)
|-0.000|</td><td>(0.026)
|-0.000|</td><td>(0.058)
|-0.003|</td><td>(0.027)
|-0.000|</td><td>(0.027)
|-0.000|</td><td>(0.026)
|-0.001|</td><td>(0.028)
|-0.000|</td><td>(0.003)
|-0.000|</td><td>(0.027)
|-0.000|</td><td>(0.026)
|-0.000|</td></tr>
<tr><td>In sight?</td><td>3.548</td><td>3.595</td><td>2.562***</td><td>3.508</td><td>0.505</td><td>3.509***</td><td>3.689***</td><td>3.372</td><td>3.688***</td><td>3.246***</td><td>4.138</td><td>3.737***</td></tr>
<tr><td></td><td>(.)
|0.007|</td><td>(.)
|0.007|</td><td>(0.424)
|0.004|</td><td>(.)
|0.007|</td><td>(0.691)
|0.003|</td><td>(0.262)
|0.007|</td><td>(0.847)
|0.006|</td><td>(.)
|0.009|</td><td>(0.824)
|0.007|</td><td>(0.535)
|0.005|</td><td>(.)
|0.007|</td><td>(0.254)
|0.007|</td></tr>
<tr><td>Located near a motorway</td><td>4.686***</td><td>4.713***</td><td>4.483***</td><td>4.616***</td><td>3.042</td><td>4.664***</td><td>4.452***</td><td>4.367***</td><td>4.728***</td><td>4.746***</td><td>5.540***</td><td>4.702***</td></tr>
</table>

Appendix Table 8: Robustness Checks – Random Effects Logit Estimation, Petrol E5

	Base model as in Table 6	Excluding the exiting retailer	Only time before 9 p.m.	Only the first 25 cycles	Only town of Lueneburg	Last price drop 5 min before relenting	Relenting of at least 2 cpl	Relenting of at least 0 cpl	Average market price	Average duration-weighted price	Average distance-weighted price	Median market price
	(0.294)	(0.292)	(0.342)	(0.302)	(2.339)	(0.315)	(0.852)	(1.286)	(0.280)	(0.440)	(0.375)	(0.343)
	|0.009|	|0.009|	|0.007|	|0.009|	|0.021|	|0.009|	|0.007|	|0.011|	|0.009|	|0.007|	|0.010|	|0.009|
Located near a federal road	-0.369	-0.409	1.328**	-0.365		-0.344	-1.145*	-0.035	-0.499	-0.195	-0.823**	-0.545*
	(0.243)	(0.239)	(0.437)	(0.260)		(0.273)	(0.549)	(1.218)	(0.770)	(0.352)	(0.303)	(0.273)
	|-0.001|	|-0.001|	|0.002|	|-0.001|		|-0.001|	|-0.002|	|-0.000|	|-0.001|	||-0.000	|-0.001|	|-0.001|
Station in rural area?	1.426***	1.462***	-0.265	1.407***		1.398***	2.270	1.163	1.530*	1.133***	1.518*	1.563***
	(0.265)	(0.257)	(0.410)	(0.292)		(0.348)	(1.196)	(1.499)	(0.707)	(0.309)	(0.616)	(0.370)
	|0.003|	|0.003|	|-0.000|	|0.003|		|0.003|	|0.003|	|0.003|	|0.003|	|0.002|	|0.003|	|0.003|
Tuesday	-0.016	-0.017	-0.006	-0.022	-0.085*	-0.025	-0.022	-0.015	-0.016	0.018	-0.015	
	(0.048)	(0.048)	(0.056)	(0.045)	(0.035)	(0.049)	(0.038)	(0.044)	(0.050)	(0.045)	(0.051)	
	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.001|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|0.000|	|-0.000|	
Wednesday	-0.004	-0.007	0.001	-0.003	-0.031	-0.009	-0.003	-0.006	-0.004	0.032	-0.003	
	(0.065)	(0.066)	(0.070)	(0.051)	(0.050)	(0.065)	(0.068)	(0.059)	(0.065)	(0.045)	(0.065)	
	|-0.000|	|-0.000|	|0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|0.000|	|-0.000|	
Thursday	-0.032	-0.025	-0.026	-0.035	-0.053	-0.035	-0.022	-0.030	-0.032	0.012	-0.031	
	(0.085)	(0.084)	(0.091)	(0.077)	(0.041)	(0.084)	(0.081)	(0.078)	(0.085)	(0.045)	(0.086)	
	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|0.000|	|-0.000|	
Friday	0.017	0.018	0.013	0.005	-0.017	0.023	0.014	0.013	0.017	0.051	0.017	0.031
	(0.027)	(0.027)	(0.028)	(0.024)	(0.026)	(0.032)	(0.026)	(0.028)	(0.028)	(0.045)	(0.031)	(0.030)
	|0.000|	|0.000|	|0.000|	|0.000|	|-0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|
Saturday	0.036	0.033	0.036	0.027	0.080	0.035	0.025	0.038	0.036	-0.113*	0.034	0.052
	(0.029)	(0.028)	(0.030)	(0.030)	(0.074)	(0.027)	(0.034)	(0.033)	(0.028)	(0.046)	(0.028)	(0.058)
	|0.000|	|0.000|	|0.000|	|0.000|	|0.001|	|0.000|	|0.000|	|0.000|	|0.000|	|-0.000|	|0.000|	|0.000|
Sunday	-0.022	-0.017	-0.016	-0.021	0.039	-0.035	-0.033	-0.017	-0.022	-0.114*	-0.024	-0.005
	(0.062)	(0.063)	(0.057)	(0.058)	(0.090)	(0.063)	(0.067)	(0.060)	(0.063)	(0.045)	(0.063)	(0.068)
	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.000|
Lower Saxony holidays	0.020	0.024	-0.004	0.021	0.035	0.020	0.010	0.019	0.020	0.022	0.014	0.033
	(0.077)	(0.077)	(0.073)	(0.078)	(0.109)	(0.077)	(0.086)	(0.072)	(0.078)	(0.026)	(0.079)	(0.075)
	|0.000|	|0.000|	|-0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|

Appendix Table 8: Robustness Checks – Random Effects Logit Estimation, Petrol E5

	Base model as in Table 6	Excluding the exiting retailer	Only time before 9 p.m.	Only the first 25 cycles	Only town of Lueneburg	Last price drop 5 min before relenting	Relenting of at least 2 cpl	Relenting of at least 0 cpl	Average market price	Average duration-weighted price	Average distance-weighted price	Median market price
Aral	4.242***	4.214***	2.004	4.253***	5.286**	4.269	5.620*	3.071***	4.324	4.441***	2.698	4.355
	(0.353)	(0.337)	(.)	(0.515)	(1.816)	(.)	(2.577)	(0.281)	(.)	(1.229)	(.)	(.)
	|0.033|	|0.033|	|0.009|	|0.034|	|0.095|	|0.033|	|0.071|	|0.028|	|0.035|	|0.028|	|0.015|	|0.036|
ESSO	5.720	5.725	3.789	5.642	1.185	5.734	5.038	5.071	5.880	5.482***	4.622	5.931
	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(.)	(0.880)	(.)	(.)
	|0.130|	|0.130|	|0.058|	|0.125|	|0.001|	|0.130|	|0.041|	|0.182|	|0.149|	|0.076|	|0.097|	|0.156|
JET	1.336	1.348	1.627	1.327		1.346	0.398	0.506	1.376	1.468**	1.372	1.369
	(.)	(.)	(.)	(.)		(.)	(3.395)	(0.827)	(.)	(0.493)	(.)	(.)
	|0.001|	|0.001|	|0.006|	|0.001|		|0.001|	|0.000|	|0.001|	|0.001|	|0.001|	|0.003|	|0.001|
SRNOP	-3.469***	-3.509***	-4.776***	-3.418***	-0.894	-3.425***	-2.957	-3.947*	-3.528	-3.350***	-4.659	-3.527***
	(0.366)	(0.327)	(0.499)	(0.727)	(.)	(0.476)	(.)	(1.651)	(.)	(0.599)	(.)	(0.464)
	|-0.000|	|-0.000|	|-0.001|	|-0.000|	|-0.000|	|-0.000|	|-0.000|	|-0.001|	|-0.000|	|-0.000|	|-0.001|	|-0.000|
Shell	4.857***	4.845***	3.693***	4.817***	6.243***	4.881***	4.950	3.786	4.834	5.112***	4.395***	4.813***
	(0.668)	(0.635)	(0.556)	(0.854)	(1.660)	(0.624)	(2.824)	(3.182)	(.)	(0.593)	(1.267)	(0.691)
	|0.059|	|0.059|	|0.053|	|0.059|	|0.204|	|0.059|	|0.037|	|0.057|	|0.058|	|0.053|	|0.079|	|0.056|
Consumer satisfaction?	-2.965***	-2.997***	-0.816***	-2.931***	-3.854	-2.945***	-3.965***	-1.881***	-2.951***	-3.135***	-3.689***	-2.912***
	(0.065)	(0.057)	(0.050)	(0.144)	(2.644)	(0.066)	(0.178)	(0.114)	(0.453)	(0.626)	(0.421)	(0.403)
	|-0.006|	|-0.006|	|-0.001|	|-0.006|	|-0.027|	|-0.006|	|-0.006|	|-0.005|	|-0.005|	|-0.005|	|-0.006|	|-0.005|
Shop? Rewe? Kiosk?	2.217***	2.226***	3.754***	2.192***		2.209***	1.188	2.790*	2.271***	2.102***	2.292***	2.277***
	(0.277)	(0.272)	(0.342)	(0.333)		(0.304)	(0.721)	(1.340)	(0.171)	(0.298)	(0.347)	(0.246)
	|0.004|	|0.004|	|0.006|	|0.004|		|0.004|	|0.002|	|0.007|	|0.004|	|0.003|	|0.004|	|0.004|
Bistro? Bakery?	-0.168	-0.163	-0.159	-0.178		-0.175	-0.275	-0.259	-0.161	-0.155	-0.010	-0.164
	(0.256)	(0.254)	(0.159)	(0.267)		(0.267)	(1.091)	(0.414)	(0.187)	(0.129)	(0.301)	(0.295)
	|-0.000|	|-0.000|	|-0.000|	|-0.000|		|-0.000|	|-0.000|	|-0.001|	|-0.000|	|-0.000|	|-0.000|	|-0.000|
Car repair?	-3.617***	-3.641***	-3.131***	-3.583***		-3.600***	-3.591***	-3.145**	-3.617***	-3.646***	-4.471***	-3.599***
	(0.170)	(0.167)	(0.173)	(0.173)		(0.146)	(0.838)	(1.137)	(0.297)	(0.542)	(0.244)	(0.253)
	|-0.007|	|-0.007|	|-0.005|	|-0.007|		|-0.007|	|-0.005|	|-0.008|	|-0.007|	|-0.005|	|-0.008|	|-0.007|
Car wash? Vacuum cleaner?	-2.582***	-2.610***	-2.674***	-2.581**		-2.573***	-2.360*	-2.194	-2.630***	-2.327***	-2.916***	-2.639***
	(0.390)	(0.343)	(0.224)	(0.806)		(0.304)	(1.143)	(1.532)	(0.452)	(0.374)	(0.814)	(0.322)

Appendix Table 8: Robustness Checks – Random Effects Logit Estimation, Petrol E5

<table>
<tr><th></th><th>Base model as in Table 6</th><th>Excluding the exiting retailer</th><th>Only time before 9 p.m.</th><th>Only the first 25 cycles</th><th>Only town of Lueneburg</th><th>Last price drop 5 min before relenting</th><th>Relenting of at least 2 cpl</th><th>Relenting of at least 0 cpl</th><th>Average market price</th><th>Average duration-weighted price</th><th>Average distance-weighted price</th><th>Median market price</th></tr>
<tr><td></td><td>|-0.005|</td><td>|-0.005|</td><td>|-0.004|</td><td>|-0.005|</td><td></td><td>|-0.005|</td><td>|-0.004|</td><td>|-0.006|</td><td>|-0.005|</td><td>|-0.003|</td><td>|-0.005|</td><td>|-0.005|</td></tr>
<tr><td>Self-service station?</td><td>-1.330</td><td>-1.331</td><td>-1.902***</td><td>-1.325</td><td>-1.997</td><td>-1.340***</td><td>-0.744</td><td>-1.105</td><td>-1.266</td><td>-1.535***</td><td>-1.866</td><td>-1.228***</td></tr>
<tr><td></td><td>(.)</td><td>(.)</td><td>(0.167)</td><td>(.)</td><td>(.)</td><td>(0.260)</td><td>(1.242)</td><td>(0.732)</td><td>(.)</td><td>(0.352)</td><td>(.)</td><td>(0.332)</td></tr>
<tr><td></td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.003|</td><td>|-0.003|</td><td>|-0.014|</td><td>|-0.003|</td><td>|-0.001|</td><td>|-0.003|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.003|</td><td>|-0.002|</td></tr>
<tr><td>Number of accepted credit cards?</td><td>-1.188***</td><td>-1.185***</td><td>-0.980***</td><td>-1.180**</td><td>-0.319</td><td>-1.186***</td><td>-1.103</td><td>-1.113</td><td>-1.199***</td><td>-1.225***</td><td>-1.123***</td><td>-1.203***</td></tr>
<tr><td></td><td>(0.193)</td><td>(0.163)</td><td>(0.148)</td><td>(0.432)</td><td>(0.369)</td><td>(0.147)</td><td>(0.581)</td><td>(0.857)</td><td>(0.182)</td><td>(0.118)</td><td>(0.261)</td><td>(0.153)</td></tr>
<tr><td></td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.003|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td><td>|-0.002|</td></tr>
<tr><td>ATM?</td><td>3.034***</td><td>3.050***</td><td>2.199***</td><td>3.004***</td><td></td><td>3.034***</td><td>3.775***</td><td>2.766</td><td>3.132***</td><td>2.830***</td><td>2.813***</td><td>3.165***</td></tr>
<tr><td></td><td>(0.311)</td><td>(0.309)</td><td>(0.311)</td><td>(0.305)</td><td></td><td>(0.388)</td><td>(0.538)</td><td>(1.734)</td><td>(0.174)</td><td>(0.433)</td><td>(0.642)</td><td>(0.412)</td></tr>
<tr><td></td><td>|0.006|</td><td>|0.006|</td><td>|0.003|</td><td>|0.006|</td><td></td><td>|0.006|</td><td>|0.006|</td><td>|0.007|</td><td>|0.006|</td><td>|0.004|</td><td>|0.005|</td><td>|0.006|</td></tr>
<tr><td>Are restrooms available?</td><td>-0.577*</td><td>-0.604*</td><td>-0.165</td><td>-0.546*</td><td></td><td>-0.567*</td><td>-0.667</td><td>-0.255</td><td>-0.581**</td><td>-0.621**</td><td>-1.051*</td><td>-0.558</td></tr>
<tr><td></td><td>(0.255)</td><td>(0.253)</td><td>(0.174)</td><td>(0.262)</td><td></td><td>(0.262)</td><td>(1.031)</td><td>(0.442)</td><td>(0.194)</td><td>(0.210)</td><td>(0.422)</td><td>(0.319)</td></tr>
<tr><td></td><td>|-0.001|</td><td>|-0.001|</td><td>|-0.000|</td><td>|-0.001|</td><td></td><td>|-0.001|</td><td>|-0.001|</td><td>|-0.001|</td><td>|-0.001|</td><td>|-0.001|</td><td>|-0.002|</td><td>|-0.001|</td></tr>
<tr><td>Number of services offered</td><td></td><td></td><td></td><td></td><td>-1.020</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>(0.926)</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>|-0.007|</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Constant</td><td>12.663</td><td>12.816</td><td>2.816</td><td>12.530</td><td>16.207</td><td>12.570</td><td>16.223</td><td>8.005</td><td>14.965</td><td>11.784***</td><td>18.391</td><td>16.490</td></tr>
<tr><td></td><td>(.)</td><td>(.)</td><td>(.)</td><td>(.)</td><td>(12.633)</td><td>(.)</td><td>(.)</td><td>(.)</td><td>(.)</td><td>(3.250)</td><td>(.)</td><td>(.)</td></tr>
<tr><td>Observations</td><td>244950</td><td>237784</td><td>240751</td><td>239195</td><td>128238</td><td>240214</td><td>225360</td><td>255093</td><td>244950</td><td>244950</td><td>244950</td><td>244950</td></tr>
<tr><td>AIC</td><td>51822.899</td><td>51277.487</td><td>48184.333</td><td>50945.389</td><td>40263.629</td><td>51501.199</td><td>46566.117</td><td>55244.337</td><td>51822.252</td><td>49242.775</td><td>51861.394</td><td>51668.871</td></tr>
<tr><td>BIC</td><td>52072.710</td><td>51526.585</td><td>48433.729</td><td>51194.630</td><td>40410.054</td><td>51740.152</td><td>46813.928</td><td>55495.122</td><td>52051.246</td><td>49544.630</td><td>52079.979</td><td>51887.456</td></tr>
</table>

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Weekday base is Monday; Brand category base is the group of regional non-oligopoly players (RNOP). For “Only town of Lueneburg,” services were combined to a service count, when possible, due to collinearity.

Appendix Table 9: Robustness Checks – Random Effects Poisson Estimation, Petrol E5

	Base model as in Table 6	Excluding the exiting retailer	Only time before 9 p.m.	Only the first 25 cycles	Only town of Lueneburg	Last price drop 5 min before relenting	Relenting of at least 2 cpl	Relenting of at least 0 cpl	Average market price	Average duration-weighted price	Average distance-weighted price	Median market price
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e., the difference between new and old prices, in euro cents per liter (cpl).												
Distance to marginal cost	-0.015	-0.013	-0.009	-0.015	0.002	-0.014	-0.014	-0.016				
	(0.010)	(0.010)	(0.009)	(0.010)	(0.001)	(0.010)	(0.342)	(0.010)				
Average market price									-0.014			
									(0.010)			
Average duration-weighted market price										0.004***		
										(0.001)		
Average distance-weighted market price											-0.018	
											(0.016)	
Median market price												-0.024*
												(0.009)
Num of undercutting rivals	-0.171***	-0.170***	-0.168***	-0.170***	0.056***	-0.170***	-0.163	-0.173***	-0.171***	-0.158***	-0.171***	-0.170***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.007)	(0.013)	(0.328)	(0.014)	(0.014)	(0.012)	(0.013)	(0.013)
In sight?	3.121***	3.152***	2.113***	3.094***	0.290***	3.080***	2.333	2.977***	3.230***	2.880***	3.530***	3.262***
	(0.818)	(0.825)	(0.592)	(0.809)	(0.012)	(0.806)	(2489.869)	(0.875)	(0.852)	(0.779)	(0.917)	(0.860)
Located near a motorway	3.898***	3.905***	3.766***	3.849***	0.121***	3.872***	3.178	3.678***	3.932***	3.792***	4.504***	3.906***
	(0.621)	(0.625)	(0.473)	(0.614)	(0.015)	(0.614)	(3077.238)	(0.822)	(0.638)	(0.594)	(0.802)	(0.641)
Located near a federal road	-0.467	-0.501	1.236*	-0.460		-0.444	0.075	-0.159	-0.568	-0.416	-0.795	-0.600

Appendix Table 9: Robustness Checks – Random Effects Poisson Estimation, Petrol E5

	Base model as in Table 6	Excluding the exiting retailer	Only time before 9 p.m.	Only the first 25 cycles	Only town of Lueneburg	Last price drop 5 min before relenting	Relenting of at least 2 cpl	Relenting of at least 0 cpl	Average market price	Average duration-weighted price	Average distance-weighted price	Median market price
	(0.570)	(0.575)	(0.502)	(0.563)		(0.561)	(2534.775)	(0.508)	(0.595)	(0.536)	(0.669)	(0.600)
Station in rural area?	1.298*	1.325*	-0.345	1.283*		1.273*	1.039	1.085**	1.379*	1.150	1.358	1.398*
	(0.644)	(0.651)	(0.393)	(0.635)		(0.632)	(2317.565)	(0.393)	(0.673)	(0.597)	(0.704)	(0.680)
Tuesday	-0.023		-0.011	-0.027		-0.028	-0.028				-0.021	
	(0.034)		(0.041)	(0.031)		(0.035)	(0.238)				(0.034)	
Wednesday	-0.011		-0.007	-0.010		-0.015	-0.011				-0.010	
	(0.053)		(0.058)	(0.043)		(0.053)	(0.401)				(0.052)	
Thursday	-0.038		-0.032	-0.039		-0.039	-0.029				-0.037	
	(0.068)		(0.075)	(0.063)		(0.067)	(0.207)				(0.068)	
Friday	0.012	0.029	0.007	0.004	0.011	0.016	0.007	0.020		0.039	0.013	0.030
	(0.020)	(0.026)	(0.023)	(0.019)	(0.012)	(0.023)	(0.792)	(0.023)		(0.030)	(0.020)	(0.027)
Saturday	0.024	0.039	0.024	0.018	0.015	0.024	0.014	0.044	0.036	-0.098	0.024	0.043
	(0.022)	(0.047)	(0.025)	(0.023)	(0.009)	(0.020)	(0.312)	(0.047)	(0.043)	(0.054)	(0.022)	(0.047)
Sunday	-0.020	-0.000	-0.019	-0.020	0.000	-0.029	-0.026	0.001	-0.008	-0.052	-0.021	0.000
	(0.046)	(0.058)	(0.045)	(0.045)	(0.004)	(0.045)	(1.278)	(0.057)	(0.055)	(0.045)	(0.046)	(0.057)
Lower Saxony holidays	0.016	0.018	-0.003	0.016	0.004	0.016	0.009	0.011	0.016	0.014	0.011	0.025
	(0.055)	(0.055)	(0.055)	(0.055)	(0.003)	(0.055)	(0.489)	(0.051)	(0.055)	(0.046)	(0.055)	(0.054)
Aral	4.022**	3.994**	1.991	4.038***	-0.272***	4.036***	5.235	2.702	4.076**	4.153***	2.964	4.107**
	(1.228)	(1.238)	(1.151)	(1.224)	(0.059)	(1.213)	(1572.174)	(2.075)	(1.256)	(1.178)	(1.714)	(1.266)
ESSO	5.269***	5.267***	3.503***	5.205***	-0.800***	5.269***	4.361	4.520***	5.386***	5.146***	4.512***	5.426***
	(0.863)	(0.873)	(0.692)	(0.870)	(0.042)	(0.851)	(1091.996)	(1.284)	(0.868)	(0.812)	(1.304)	(0.875)
JET	1.261**	1.274**	1.501***	1.259**		1.267**	0.554	0.360	1.292**	1.306***	1.307*	1.295**
	(0.427)	(0.434)	(0.232)	(0.433)		(0.418)	(835.949)	(0.291)	(0.434)	(0.396)	(0.555)	(0.438)
SRNOP	-2.874***	-2.898***	-4.099***	-2.840***	-0.469***	-2.831***	-1.996	-3.386**	-2.923***	-2.650***	-3.725***	-2.914***
	(0.638)	(0.642)	(0.713)	(0.633)	(0.023)	(0.633)	(2697.109)	(1.055)	(0.654)	(0.626)	(0.970)	(0.658)
Shell	4.386***	4.364***	3.332***	4.363***	-0.270***	4.395***	4.565	3.244***	4.365***	4.433***	4.080***	4.350***
	(0.683)	(0.691)	(0.406)	(0.678)	(0.016)	(0.670)	(231.561)	(0.780)	(0.712)	(0.632)	(0.850)	(0.719)
Consumer satisfaction?	-2.461**	-2.471**	-0.503	-2.426**	0.075***	-2.438**	-2.167	-1.574	-2.450**	-2.500**	-2.966**	-2.412*
	(0.914)	(0.920)	(0.796)	(0.901)	(0.013)	(0.904)	(2947.938)	(1.057)	(0.939)	(0.868)	(1.038)	(0.940)

Appendix Table 9: Robustness Checks – Random Effects Poisson Estimation, Petrol E5

	Base model as in Table 6	Excluding the exiting retailer	Only time before 9 p.m.	Only the first 25 cycles	Only town of Lueneburg	Last price drop 5 min before relenting	Relenting of at least 2 cpl	Relenting of at least 0 cpl	Average market price	Average duration-weighted price	Average distance-weighted price	Median market price
Shop? Rewe? Kiosk?	1.861***	1.866***	3.310***	1.853***	0.262***	1.852***	1.525	2.368***	1.905***	1.717***	1.914***	1.908***
	(0.318)	(0.320)	(0.443)	(0.317)	(0.022)	(0.315)	(266.143)	(0.168)	(0.324)	(0.306)	(0.358)	(0.324)
Bistro? Bakery?	-0.252	-0.249	-0.278	-0.258	0.024***	-0.260	-0.317	-0.354	-0.246	-0.265	-0.136	-0.246
	(0.205)	(0.206)	(0.163)	(0.203)	(0.003)	(0.201)	(624.063)	(0.206)	(0.210)	(0.192)	(0.249)	(0.212)
Car repair?	-3.241***	-3.251***	-2.791***	-3.213***	-0.162***	-3.222***	-2.608	-2.882**	-3.243***	-3.154***	-3.841***	-3.221***
	(0.778)	(0.783)	(0.586)	(0.768)	(0.019)	(0.769)	(1699.067)	(1.022)	(0.801)	(0.745)	(0.968)	(0.805)
Car wash? Vacuum cleaner?	-2.469***	-2.488***	-2.586***	-2.465***	0.224***	-2.460***	-1.679	-2.147***	-2.507***	-2.323***	-2.701***	-2.511***
	(0.720)	(0.726)	(0.320)	(0.708)	(0.015)	(0.707)	(616.651)	(0.578)	(0.750)	(0.671)	(0.801)	(0.756)
Self-service station?	-1.166***	-1.164***	-1.687***	-1.160***	-0.096***	-1.173***	-0.834	-0.991	-1.120**	-1.182***	-1.545**	-1.090**
	(0.336)	(0.337)	(0.401)	(0.333)	(0.015)	(0.335)	(549.715)	(0.653)	(0.344)	(0.334)	(0.472)	(0.345)
Number of accepted credit cards?	-1.084***	-1.081***	-0.887***	-1.081***	-0.004	-1.082***	-1.089	-0.983***	-1.093***	-1.086***	-1.045***	-1.096***
	(0.130)	(0.131)	(0.085)	(0.128)	(0.003)	(0.127)	(3.412)	(0.169)	(0.135)	(0.120)	(0.156)	(0.136)
ATM?	2.682***	2.691***	1.929***	2.663***	0.123***	2.676***	2.727	2.370***	2.755***	2.541***	2.549***	2.779***
	(0.561)	(0.565)	(0.437)	(0.561)	(0.034)	(0.555)	(1893.820)	(0.692)	(0.566)	(0.539)	(0.651)	(0.568)
Are restrooms available?	-0.368	-0.384	0.042	-0.345	0.000	-0.357	0.146	-0.078	-0.372	-0.337	-0.714	-0.352
	(0.276)	(0.277)	(0.292)	(0.274)	(.)	(0.274)	(2900.924)	(0.383)	(0.279)	(0.268)	(0.392)	(0.279)
Constant	9.859*	9.894*	0.919	9.723*	0.530***	9.751*	7.237	6.144	11.597*	8.955*	13.956*	12.680**
	(4.642)	(4.675)	(4.041)	(4.577)	(0.089)	(4.595)	(14105.405)	(5.684)	(4.846)	(4.441)	(5.997)	(4.862)
Observations	244950	237784	240751	239195	8825	240214	225360	255093	244950	244950	244950	244950
AIC	55107.699	54631.194	50675.731	54084.619	34297.943	54834.363	49603.225	58543.035	55110.264	53557.099	55142.000	54998.293
BIC	55357.510	54869.914	50925.128	54333.860	34397.137	55083.706	49851.036	58793.820	55349.666	53806.910	55391.811	55237.695

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; Weekday base is usually Monday, and otherwise Monday to Thursday/Friday; Brand category base is the group of regional non-oligopoly players (RNOP).

4 Cross-Border Competition in the Gasoline Retail Market: Impact of Proximity at the German-Polish Border

Mats Petter Kahl*

2024

Abstract

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.

Keywords: fuel tourism, gas price differentials, market transparency, gasoline taxes

JEL classification: L13, L41, L92

Statements and Declarations: none

---

* Mats Petter Kahl, Leuphana University Lueneburg, Institute of Economics, Universitaetsallee 1, 21335 Lueneburg, Germany, email: mats.kahl@leuphana.de, ORCID: 0000-0003-3387-6386

I am grateful to Thomas Wein and Boris Hirsch for their valuable comments and support.

The author has no relevant financial or non-financial interests to disclose.

4.1 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 Prague 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.

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, 2018c). 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, 2023; Seiler and Stöckmann, 2023). In fact, Rietveld and van Woudenberg (2005) argue "that the most important source of variation in fuel prices must be taxed." 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 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.

4.2 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. (2016) 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 (2016b) 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]

[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

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.

(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.

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.

4.3 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 Figure 1.

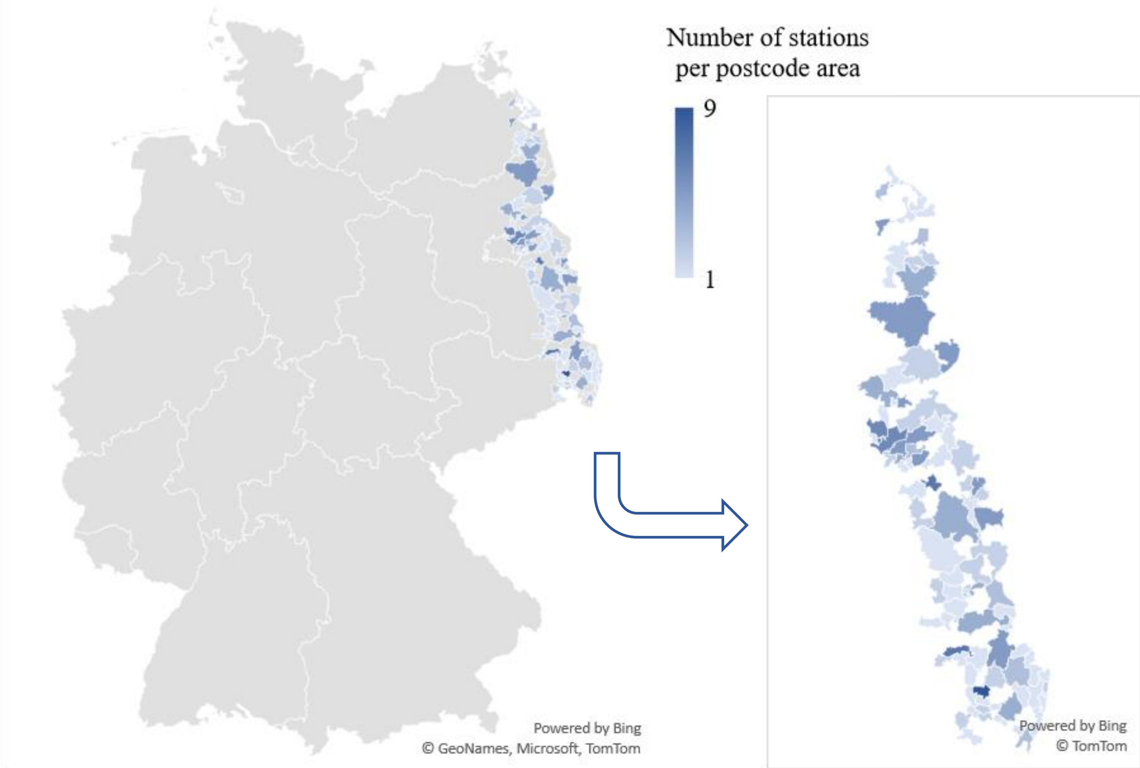
The price difference results from differences in fuel taxes (Rietveld and van Woudenberg, 2005), illustrated in Appendix Figure 2. Taxes are about 65 Eurocents per liter (cpl) for petrol and about 47 cpl for diesel in Germany (European Commission, 2022) and remained constant over time (Bundesministerium 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

[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).

Poland, Appendix Figure 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).

FIGURE 1: OVERVIEW OF THE NUMBER OF GERMAN GASOLINE STATIONS PER POSTCODE AREA ALONG THE GERMAN-POLISH BORDER



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 Figure 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

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

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.

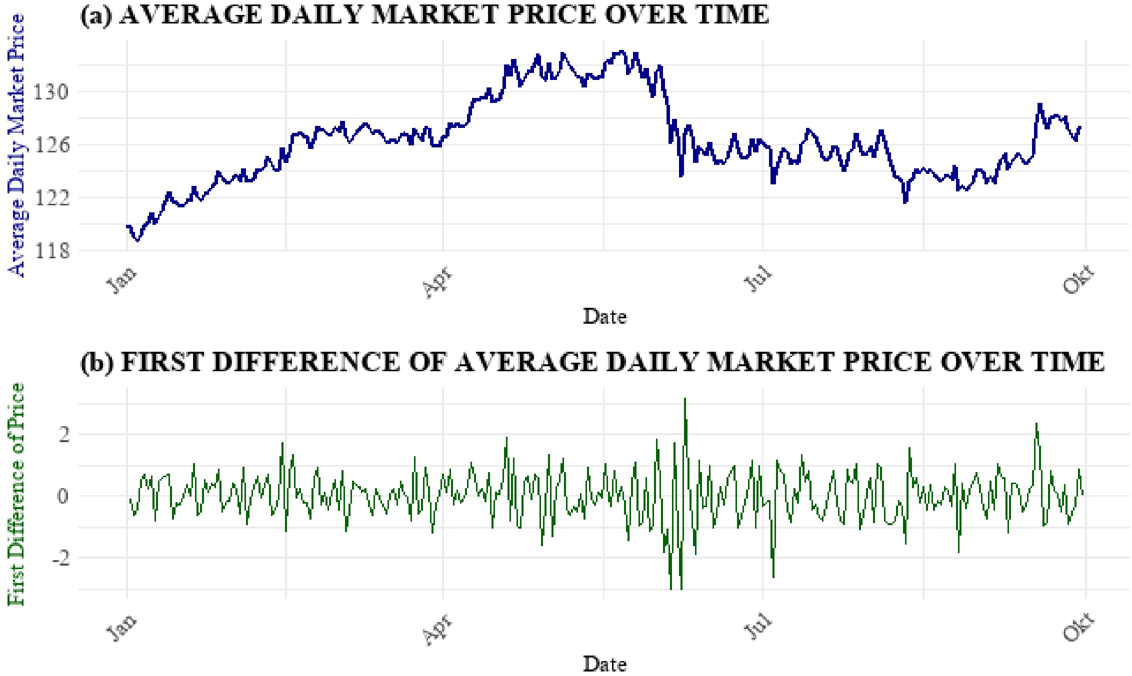
Further, local competition variables enter the regression. I estimate all driving distances between all German gasoline stations in order to identify the nearest German competitor and the number of German competitors in a predefined surrounding area. Similar to Haucap et al. (2015, p. 21), I experimented with different critical values (10km, 5km, 2km, and 1km) 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.

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.

FIGURE 2:

(a) AVERAGE DAILY MARKET PRICE OVER TIME

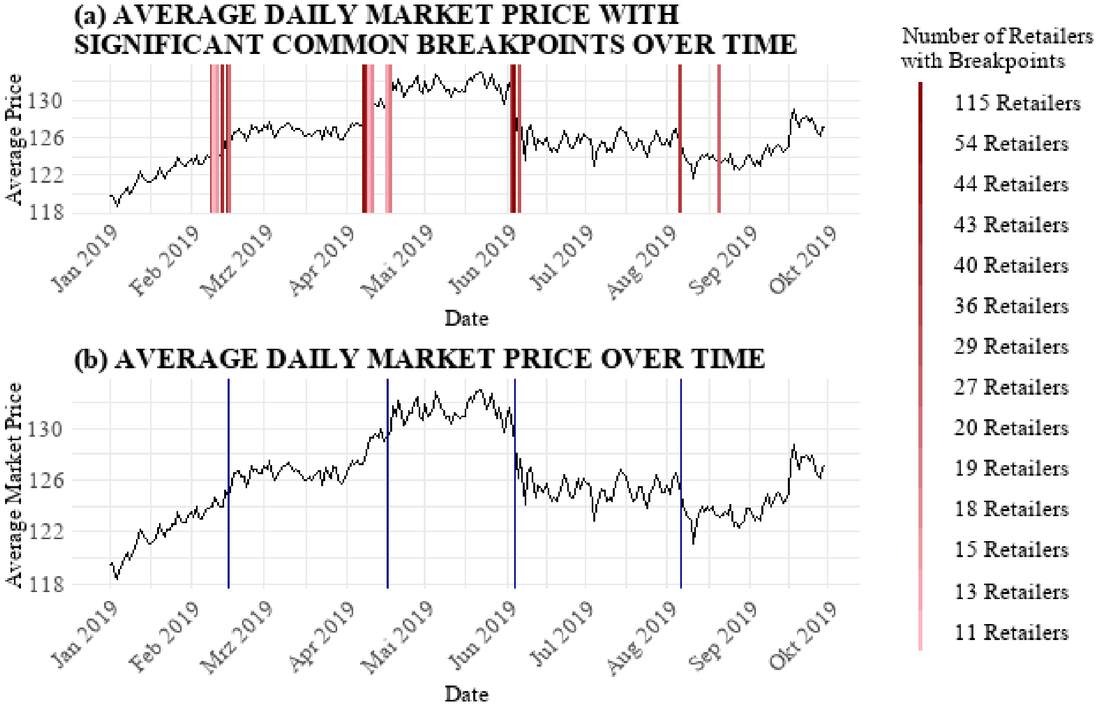
(b) FIRST DIFFERENCE OF AVERAGE DAILY MARKET PRICE OVER TIME



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]

FIGURE 3:
(a) AVERAGE DAILY MARKET PRICE WITH SIGNIFICANT COMMON BREAKPOINTS OVER TIME



Since the time series likely has a unit root (is non-stationary), a first-differencing regression methodology is appropriate. Figure 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. Figure 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

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

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:

$$p_{it} = \beta_0 + \beta_1 DIS_i + \beta_2 PAP_t + \beta_3 CO_t + \beta_4 x_i + \beta_5 WEH_t + \beta_6 S_t + \varepsilon_{it} \qquad (2)$$

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:

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

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 equation (2) yields:

$$\begin{aligned}\Delta p_{it} = {} & \beta_1 \Delta PAP_t + \beta_2 \Delta PAP_{t-k} + \beta_3 \Delta CO_t + \beta_4 \Delta CO_{t-k} \\ & + \beta_5 \Delta WEH_t + \beta_6 \Delta S_t + \Delta u_{it}\end{aligned} \qquad (3)$$

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).

FIGURE 4: CRUDE OIL PRICE AND STRUCTURAL BREAKS OVER TIME

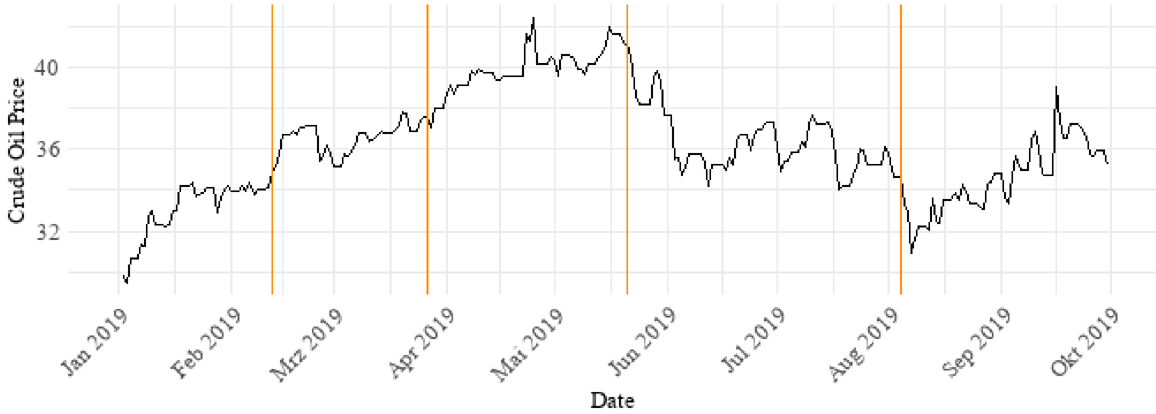
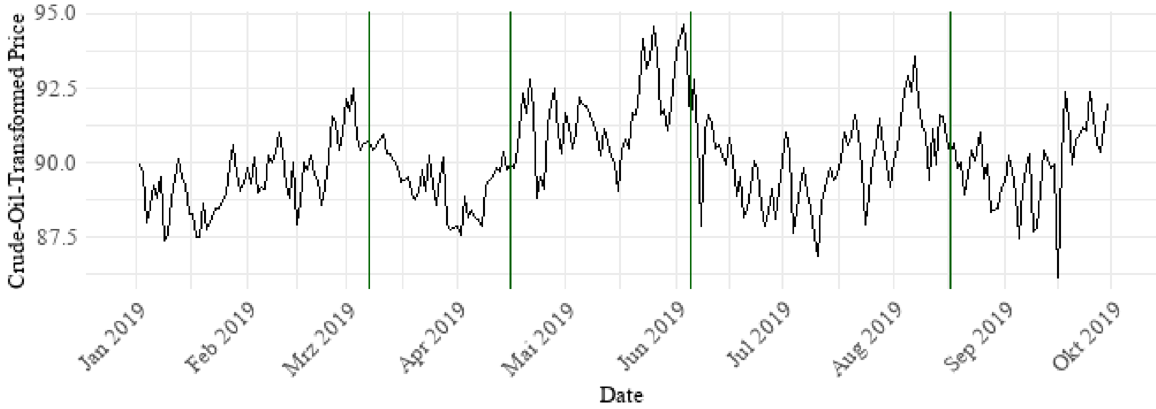


FIGURE 5:
CRUDE-OIL-TRANSFORMED AVERAGE DAILY MARKET PRICE OVER TIME



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 Figure 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 Figure 5.

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

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

where:

$$\alpha_i = \alpha + \eta_i \quad (5)$$

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 $\hat{\beta}$ denote the fixed effects estimator of β, and let $\bar{p}_i$ result from averaging across t; then, the γ can be estimated by the regression of $\bar{p}_i - \hat{\beta}\bar{x}_i$ on z_i and an intercept. The resulting estimator is denoted $\hat{\gamma}_{FEF}$ 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]:

$$p_{it} = \hat{\beta}' x_{it} + \hat{u}_{it} \quad (6)$$

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

$$\hat{u}_{it} = p_{it} - \hat{\beta}' x_{it}. \quad (7)$$

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

$$\bar{\hat{u}}_i = \frac{1}{T}\sum_{t=1}^{T} \hat{u}_{it}. \quad (8)$$

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

$$\hat{\gamma}_{FEF} = \left[\sum_{i=1}^{N}(z_i - \bar{z})(z_i - \bar{z})'\right]^{-1} \sum_{i=1}^{N}(z_i - \bar{z})(\bar{\hat{u}}_{it} - \bar{\hat{u}}), \quad (9)$$

[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.

and

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

where:

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

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-hour 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 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.,

---

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

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

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 15km to the nearest Polish competitor; zone B includes all stations with a driving distance of more than 15km but no more than 30km to the closest Polish competitor. Analogously, zone C contains the stations with a 30-45km distance, and zone D includes the remaining stations with a distance of up to 60km 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.

4.4 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-hour day cycle.

[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.

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 15km away from their nearest Polish competitor; zone B includes all stations more than 15km and up to 30km away; zone C consists of all stations more than 30km and up to 45km away; and zone D all stations between 45km and 60km 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.

TABLE 1: FEF REGRESSION, 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 10km	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)

TABLE 1: FEF REGRESSION, DIESEL

	Dependent variable: Residuals of the FE Stage				
	FEF - All Zones	FEF – Zone A	Zone B	Zone C	Zone D
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.

For zone A, there is a small economic effect of 1 cpl higher prices for retailers located 1 kilometer 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 ($n_{highway} = 8$). 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

[12] The results are robust to changing the first-stage model to a first-difference approach rather than fixed effects.
[13] Changing the critical value of the perimeter from 10km to 5km, or 2km, 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.

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.

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.

[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.

TABLE 2: FD REGRESSION OF AVERAGE DAILY PRICE (24h), 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	9,498	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.

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-hour 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-hour 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-hour 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.

[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.

TABLE 3: FD REGRESSION OF AVERAGE DAILY PRICE (24h), 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	7,945	12,875	9,698	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.

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.

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 5km	3.154	2.889	3.576	3.455
No. of German competitors within 10km	4.359	3.972	6.441	5.883

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

[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.

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 Figure 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 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 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

[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.

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

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.

4.5 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

[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.

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 hours and 13 hours).

Moreover, I divide the border region into four 15km 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 15km 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.

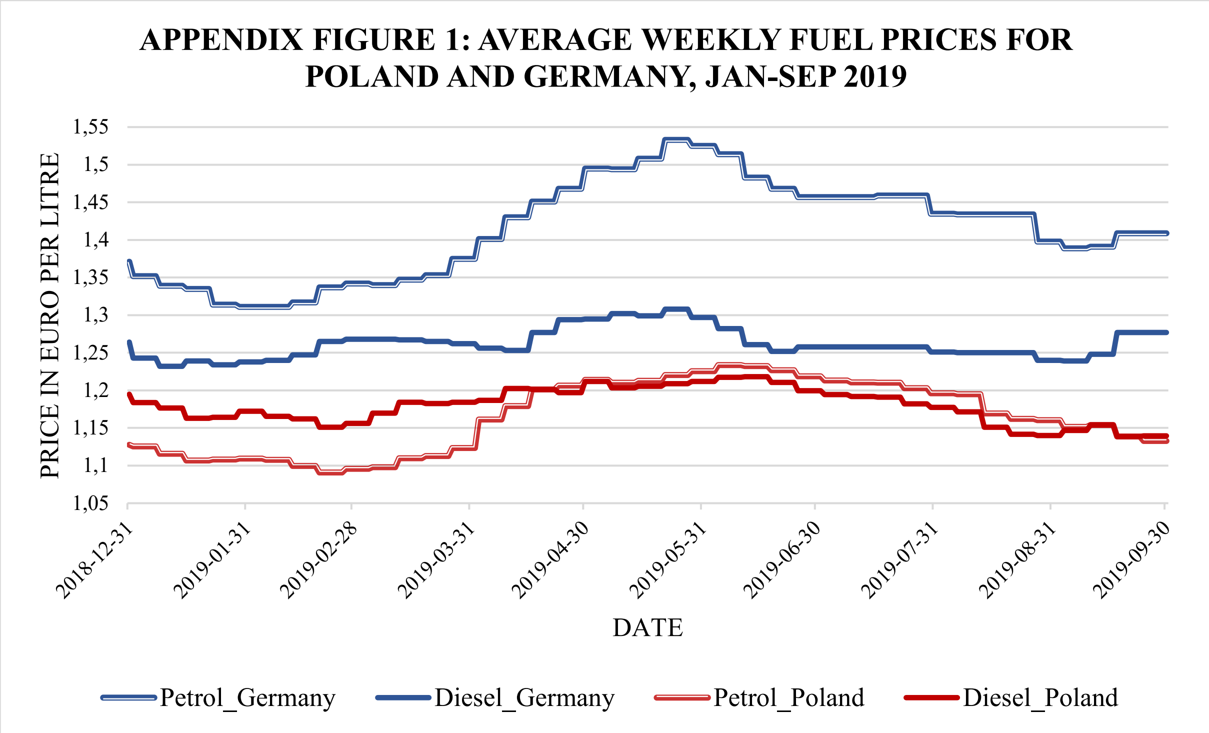
Furthermore, I find a higher share of premium brands in proximity to the Polish border. The percentage of premium brands decreases with distance from the Polish border, from about 51% in the zone closest to the border to between 41% and 47% in regions further inland. An economic explanation may include 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.

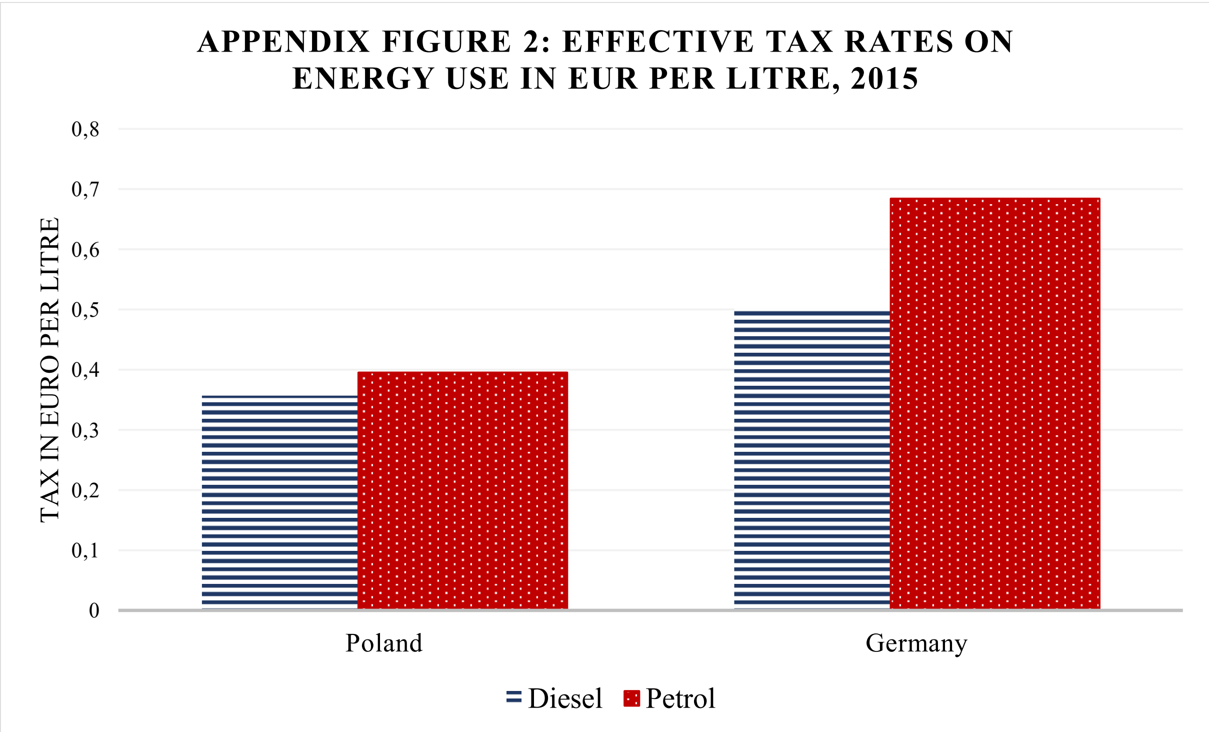
Future research may use long-run data on gasoline station infrastructure to casually analyze the effect of tax and price differentials on the retailer infrastructure in border regions. Moreover, research on the extent of fuel tourism and its welfare implications is required. Finally, the question arises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

4.6 Appendix

4.6.1 Figures



23



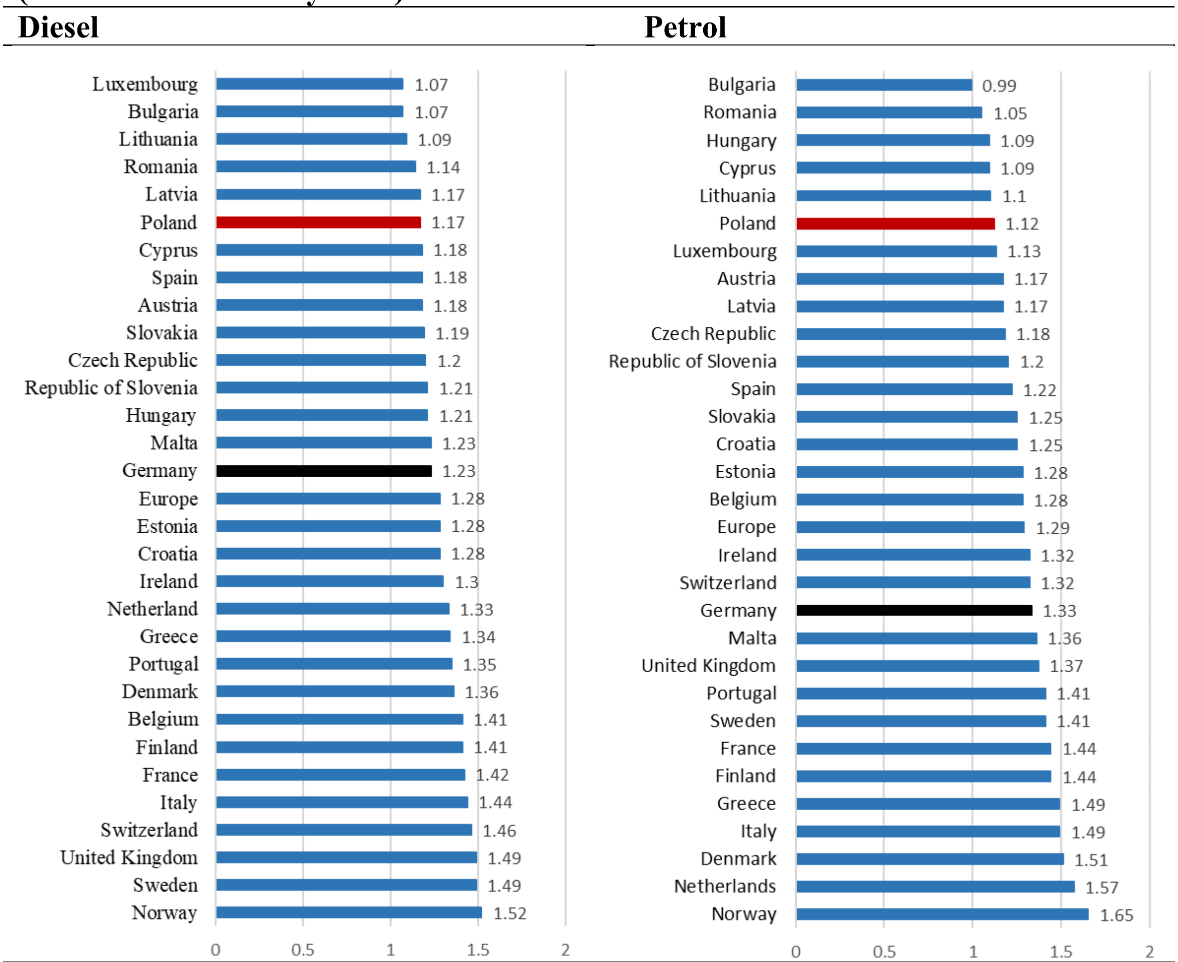
24

---

23 Appendix Figure 1 is based on data from globalpetrolprices.com (2019).

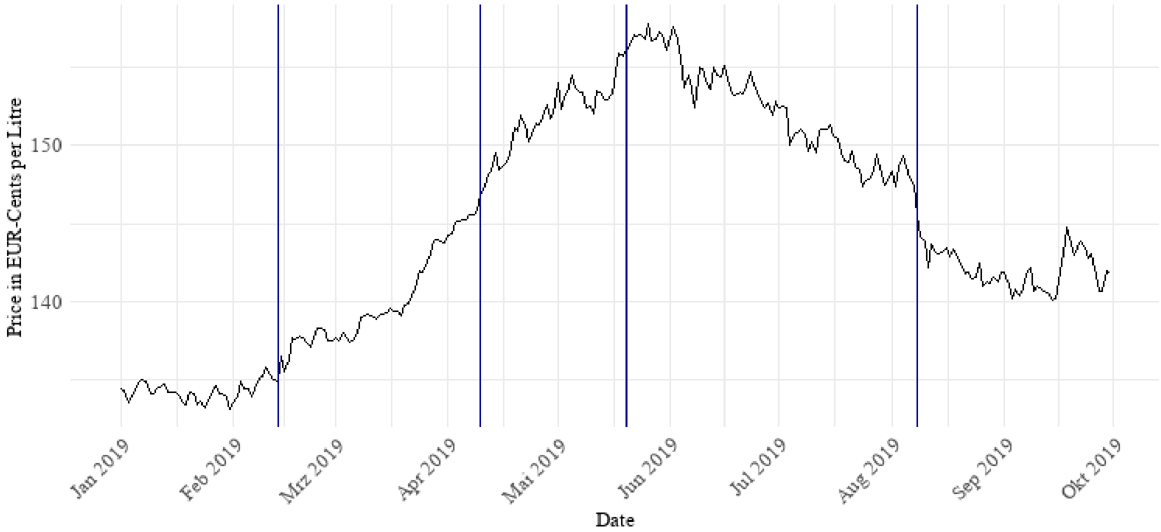
24 Appendix Figure 2 is based on data from the OECD (2018b); (2018c).

APPENDIX FIGURE 3: DIESEL PRICES IN EUROS PER LITRE FOR EUROPE (effective 15th January 2019)

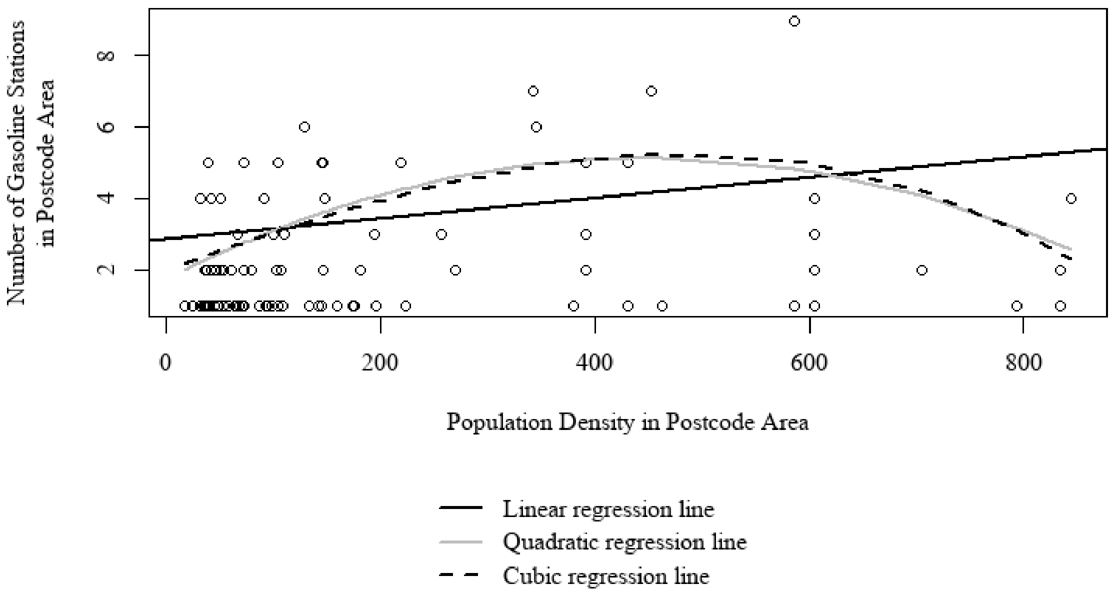


Note: This Figure is based on data from infoRoad GmbH (2019).

APPENDIX FIGURE 4: AVERAGE DAILY MARKET PRICE OVER TIME AND STRUCTURAL BREAKS, PETROL



APPENDIX FIGURE 5: NUMBER OF GASOLINE STATIONS AND POPULATION DENSITY



4.6.2 Tables

APPENDIX TABLE 1: VARIABLES

Category	Variable
Dependent variables	Average daily price, minimum daily price, maximum daily price (day of 24 hours or day of 16 hours); 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 5km
	No. German competitors in 5min
	No. German competitors in 10min
	No. German competitors in 15min
	No. German competitors in 20min
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

APPENDIX TABLE 2: 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

APPENDIX TABLE 3: UNIT-ROOT TESTS, 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

APPENDIX TABLE 4: UNIT-ROOT TESTS, DIESEL

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

APPENDIX TABLE 5: STRUCTURAL BREAK TEST RESULTS, 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.

APPENDIX TABLE 6: 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.5km	1	3.377	3	11	2.150	2	5
No.German.competitors.in.10km	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
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 hours	0	0.362	0	1	0.480	0	1

APPENDIX TABLE 7: DESCRIPTIVE STATISTICS, 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 5km	1	3.139	3	7	1.746	1	5
No. German competitors in 10km	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 hours	0	0.337	0	1	0.473	0	1

APPENDIX TABLE 8: DESCRIPTIVE STATISTICS, ZONE B (N=9,658)

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 5km	1	2.874	3	10	1.752	1	4
No. German competitors in 10km	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 hours	0	0.314	0	1	0.464	0	1

APPENDIX TABLE 9: DESCRIPTIVE STATISTICS, 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 5km	1	3.758	3	11	2.364	2	6
No. German competitors in 10km	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
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 hours	0	0.401	0	1	0.490	0	1

APPENDIX TABLE 10: DESCRIPTIVE STATISTICS, 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 5km	1	3.467	3	10	2.287	2	5
No. German competitors in 10km	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
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 hours	0	0.368	0	1	0.482	0	1

APPENDIX TABLE 11: FE REGRESSION UNDERLYING TABLE 1, AVERAGE DAILY DIESEL PRICE (24h)

	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	9,534	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.

APPENDIX TABLE 12: FEF ROBUSTNESS CHECKS, DIESEL

	Dependent variable: Residuals of the FE Stage		
	FEF Min Price (24h)	FEF Max Price (24h)	FEF Mean Price (13h)
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)
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 10km	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.

APPENDIX TABLE 13: FD ROBUSTNESS CHECKS, DIESEL

	Dependent variable: Daily Average Price		
	FD - Min Price (24h)	FD - Max Price (24h)	FD - Mean Price (13h)
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 (24h) are "2019-02-13," "2019-04-08," "2019-06-03," and "2019-08-06"; for the maximum daily price (24h) are "2019-02-14," "2019-04-19," "2019-06-05," and "2019-08-08"; and for the average daily price (13h) are "2019-02-14," "2019-04-18," "2019-06-05," and "2019-08-07".

APPENDIX TABLE 14: STATISTICAL TESTS FOR DIESEL DATA (MEAN 24h)

Test	Test statistic	df	p-value	Alternative hypothesis	Result
Breusch-Pagan test for heteroskedasticity	BP = 18807	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 = 1005600	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 = 646714	df = 22155	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 = 1297857	df = 20910	p-value < 0.0000	cross-sectional dependence	There is cross-sectional dependence.
Breusch-Pagan LM test for cross-sectional dependence in panels – RE	chisq = 1297951	df = 20910	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 = 31835	df = 54	p-value < 0.0000		
Breusch-Godfrey/Wooldridge test for serial correlation in panel models (order 1-3) - FE	Different values > 28800		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 (up to order 3) – pooled OLS	Different values > 38900		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 > 30900		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.

APPENDIX TABLE 15: FEF REGRESSION, 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 10km	-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)
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.

APPENDIX TABLE 16: FE REGRESSION UNDERLYING APPENDIX TABLE 15, AVERAGE DAILY PETROL PRICE (24h)

	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	9,893	9,516	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.

APPENDIX TABLE 17: FD REGRESSION OF AVERAGE DAILY PRICE (24h), PETROL

	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)
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	9,855	9,480	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".

APPENDIX TABLE 18: FD REGRESSION OF AVERAGE DAILY PRICE (24h), PETROL

	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	7,772	11,312	8,035	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.

References

Agrawal, D.R., 2015. The Tax Gradient: Spatial Aspects of Fiscal Competition. American Economic Journal: Economic Policy 7, 1–29. https://doi.org/10.1257/pol.20120360.

Alberini, A., Horvath, M., Vance, C., 2022. Drive less, drive better, or both? Behavioral adjustments to fuel price changes in Germany. Resource and Energy Economics 68, 101292. https://doi.org/10.1016/j.reseneeco.2022.101292.

Asane-Otoo, E., Dannemann, B.C., 2022. Rockets and Feathers Revisited: Asymmetric Retail Gasoline Pricing in the Era of Market Transparency. EJ 43, 103–122. https://doi.org/10.5547/01956574.43.6.easa.

Asane-Otoo, E., Schneider, J., 2015. Retail fuel price adjustment in Germany: A threshold cointegration approach. Energy Policy 78, 1–10. https://doi.org/10.1016/j.enpol.2014.12.013.

Atkinson, B., 2008. On Retail Gasoline Pricing Websites: Potential Sample Selection Biases and Their Implications for Empirical Research. Rev Ind Organ 33, 161–175. https://doi.org/10.1007/s11151-008-9187-7.

Atkinson, B., 2009. Retail Gasoline Price Cycles: Evidence from Guelph, Ontario Using Bi-Hourly, Station-Specific Retail Price Data. The Energy Journal 30, 86–109.

Atkinson, B., Eckert, A., West, D.S., 2009. PRICE MATCHING AND THE DOMINO EFFECT IN A RETAIL GASOLINE MARKET. Economic Inquiry 47, 568–588. https://doi.org/10.1111/j.1465-7295.2008.00149.x.

Atkinson, B., Eckert, A., West, D.S., 2014. Daily Price Cycles and Constant Margins: Recent Events in Canadian Gasoline Retailing. EJ 35. https://doi.org/10.5547/01956574.35.3.3.

Augusti, A., 2022. Vacances scolaires par zones. https://www.data.gouv.fr/fr/datasets/vacances-scolaires-par-zones/ (accessed 19 November 2022).

Bach, S., Isaak, N., Kemfert, C., Kunert, U., Schill, W.-P., Schmalz, S., Wägner, N., Zaklan, A., 2019. CO2-Bepreisung im Wärme- und Verkehrssektor: Diskussion von Wirkungen und alternativen Entlastungsoptionen : Endbericht des gleichnamigen Forschungsvorhabens im Auftrag des Bundesministeriums für Umwelt, Naturschutz und nukleare Sicherheit (BMU). DIW Berlin Deutsches Institut für Wirtschaftsforschung, Berlin, 1150 pp.

Bacon, R.W., 1991. Rockets and Feathers: The Asymmetric Speed of Adjustment of UK Retail Gasoline Prices to Cost Changes. Energy Economics 13, 211–218. https://doi.org/10.1016/0140-9883(91)90022-R.

Badaoui, M., 2022. Communes de france - Base des codes postaux. https://www.data.gouv.fr/fr/datasets/communes-de-france-base-des-codes-postaux/ (accessed 19 November 2022).

Bai, J., Perron, P., 2003. Computation and analysis of multiple structural change models. J. Appl. Econ. 18, 1–22. https://doi.org/10.1002/jae.659.

Bakhat, M., Rosselló, J., Sansó, A., 2022. Price transmission between oil and gasoline and diesel: A new measure for evaluating time asymmetries. Energy Economics 106, 105766. https://doi.org/10.1016/j.eneco.2021.105766.

Banfi, S., Filippini, M., Hunt, L.C., 2005. Fuel tourism in border regions: The case of Switzerland. Energy Economics 27, 689–707. https://doi.org/10.1016/j.eneco.2005.04.006.

Benedek, D., Mooij, R.A. de, Wingender, P., 2015. Estimating VAT Pass Through. International Monetary Fund, Washington, D.C, 41 pp.

Benzarti, Y., Carloni, D., 2019. Who Really Benefits from Consumption Tax Cuts? Evidence from a Large VAT Reform in France. American Economic Journal: Economic Policy 11, 38–63. https://doi.org/10.1257/pol.20170504.

Bernhardt, L., Breiderhoff, X., Dewenter, R., 2023. The Impact of the Tax Reduction on Fuel Prices in Germany – A Synthetic Difference-in-Differences Approach. Review of Economics 74, 141–160. https://doi.org/10.1515/roe-2023-0014.

Bertrand, J., 1883. Théorie Mathématique de la Richesse Sociale. Journal des savants 67, 499–508.

Besley, T.J., Rosen, H.S., 1999. Sales Taxes and Prices: An Empirical Analysis. National Tax Journal 52, 157–178. https://doi.org/10.1086/NTJ41789387.

Bloch, H., Wills-Johnson, N., 2010a. Gasoline Price Cycle Drivers: An Australian Case Study. SSRN Journal. https://doi.org/10.2139/ssrn.1558766.

Bloch, H., Wills-Johnson, N., 2010b. The Shape and Frequency of Edgeworth Price Cycles in an Australian Retail Gasoline Market. SSRN Journal. https://doi.org/10.2139/ssrn.1558747.

Boehnke, J., 2017. Pricing Strategies and Competition: Evidence from the Austrian and German Retail Gasoline Markets.

Borenstein, S., 1991. Selling Costs and Switching Costs: Explaining Retail Gasoline Margins. The RAND Journal of Economics 22, 354–369.

Bown, C.P., 2022. Russia's war on Ukraine: A sanctions timeline. Peterson Institute for International Economics. https://www.piie.com/blogs/realtime-economics/russias-war-ukraine-sanctions-timeline (accessed 30 January 2023).

Bragoudakis, Z., Degiannakis, S., Filis, G., 2020. Oil and pump prices: Testing their asymmetric relationship in a robust way. Energy Economics, 104755. https://doi.org/10.1016/j.eneco.2020.104755.

Brinkman, J., Mok-Lamme, D., 2019. Not in my backyard? Not so fast. The effect of marijuana legalization on neighborhood crime. Regional Science and Urban Economics 78, 103460. https://doi.org/10.1016/j.regsciurbeco.2019.103460.

Buettner, T., Madzharova, B., 2021. Unit Sales and Price Effects of Preannounced Consumption Tax Reforms: Micro-level Evidence from European VAT. American Economic Journal: Economic Policy 13, 103–134. https://doi.org/10.1257/pol.20170708.

Bundesinstitut für Bau-, Stadt- und Raumforschung, 2023. Laufende Raumbeobachtung des BBSR. Bundesamt für Bauwesen und Raumordnung. https://www.bbsr.bund.de/BBSR/DE/forschung/raumbeobachtung/downloads/download-referenzen.html;jsessionid=F868030FF0C41F44CEB52921C9EE51FD.live21303 (accessed April 2024).

Bundeskartellamt, 2011a. Fuel Sector Inquiry: Final Report in accordance with § 32e GWB - May 2011 - Summary. Bundeskartellamt, 31 pp. https://www.bundeskartellamt.de/SharedDocs/Publikation/EN/Sector%20Inquiries/Fuel%20Sector%20Inquiry%20-%20Final%20Report.pdf?__blob=publicationFile&v=14.

Bundeskartellamt, 2011b. Sektoruntersuchung Kraftstoffe. Bundeskartellamt, 287 pp. https://www.bundeskartellamt.de/SharedDocs/Publikation/DE/Sektoruntersuchungen/Sektoruntersuchung%20Kraftstoffe%20-%20Abschlussbericht.pdf?__blob=publicationFile&v=5 (accessed Februray 2018).

Bundeskartellamt, 2018. Market Transparency Unit for Fuels: The Market Transparency Unit for Fuels is intended to enable consumers to gain information on current fuel prices in Germany. https://www.bundeskartellamt.de/EN/Economicsectors/MineralOil/MTU-Fuels/mtufuels_node.html;jsessionid=980D78C08F3A988A02647AC9C725591C.2_cid378 (accessed May 2018).

Bundeskartellamt, 2021. Markttransparenzstelle für Kraftstoffe: Verbraucher. Zugelassene Verbraucher-Informationsdienste. Bundeskartellamt.

https://www.bundeskartellamt.de/DE/Wirtschaftsbereiche/Mineral%C3%B6l/MTS-Kraftstoffe/Verbraucher/verbraucher_node.html (accessed August 2021).

Bundeskartellamt, 2023. Market Transparency Unit for Fuels. Bundeskartellamt. https://www.bundeskartellamt.de/EN/Economicsectors/MineralOil/MTU-Fuels/mtufuels_node.html (accessed 31 January 2023).

Bundesministerium der Finanzen, 2018. Grundlagenwissen zum Benzinpreis und seiner Entwicklung. https://www.bundesfinanzministerium.de/Content/DE/Standardartikel/Service/Einfach_erklaert/2018-01-11-grundlagen-benzinpreis.html;jsessionid=70B286AC1058EDFCAB6241B0C98E2DFC?nn=12148&view=pdf.

Bundesministerium für Digitales und Verkehr, 2022. Verkehr in Zahlen 2022/2023. https://bmdv.bund.de/SharedDocs/DE/Publikationen/G/verkehr-in-zahlen-2022-2023-pdf.pdf?__blob=publicationFile (accessed 27 January 2023).

Bundesministeriums für Wirtschaft und Energie, 2020. gwb-digitalisierungsgesetz-referentenentwurf: Entwurf eines Zehnten Gesetzes zur Änderung des Gesetzes gegen Wettbewerbsbeschränkungen für ein fokussiertes, proaktives und digitales Wettbewerbsrecht 4.0 (GWB-Digitalisierung). Referentenentwurf des Bundesministeriums für Wirtschaft und Energie, 157 pp. https://www.bmwi.de/Redaktion/DE/Downloads/G/gwb-digitalisierungsgesetz-referentenentwurf.pdf?__blob=publicationFile&v=10.

Bundesregierung, 2022. Fragen und Antworten zum „Tankrabatt“. https://www.bundesregierung.de/breg-de/suche/faq-energiesteuersenkung-2049702.

Byrne, D.P., 2012. Petrol Price Cycles. Australian Economic Review 45, 497–506. https://doi.org/10.1111/j.1467-8462.2012.00702.x.

Byrne, D.P., 2019. Gasoline Pricing in the Country and the City. Rev Ind Organ 55, 209–235. https://doi.org/10.1007/s11151-018-9660-x.

Byrne, D.P., Leslie, G.W., Ware, R., 2015. How do Consumers Respond to Gasoline Price Cycles? EJ 36. https://doi.org/10.5547/01956574.36.1.5.

Cabral, L., Dürr, N.S., Schober, D., Woll, O., 2018. Learning Collusion: Theory and Evidence from the Shell Price Matching Guarantee. https://www.cresse.info/wp-content/uploads/2020/02/2018_ps11_pa2_Learning-Collusion.pdf (accessed 3 December 2023).

Calendarpedia, 2022. Termine der Schulferien in Deutschland. https://www.kalenderpedia.de/ferien/ferien-2023.html (accessed 19 November 2022).

Carare, A., Danninger, S., 2008. Inflation Smoothing and the Modest Effect of VAT in Germany. IMF Working Papers 2008, 1. https://doi.org/10.5089/9781451870336.001.

Carbonnier, C., 2007. Who pays sales taxes? Evidence from French VAT reforms, 1987–1999. Journal of Public Economics 91, 1219–1229. https://doi.org/10.1016/j.jpubeco.2006.12.004.

Castanias, R., Johnson, H., 1993. Gas Wars: Retail Gasoline Price Fluctuations. The Review of Economics and Statistics 75, 171. https://doi.org/10.2307/2109643.

Chirakijja, J., O'Dea, C., Crossley, T.F., Lührmann, M., 2009. The Stimulus Effect of the 2008 U.K. Temporary VAT Cut. Proceedings. Annual Conference on Taxation and Minutes of the Annual Meeting of the National Tax Association 102, 15–21.

Choi, I., 2001. Unit root tests for panel data. Journal of International Money and Finance 20, 249–272. https://doi.org/10.1016/S0261-5606(00)00048-6.

Clemenz, G., Gugler, K., 2006. Locational Choice and Price Competition: Some Empirical Results for the Austrian Retail Gasoline market. Empirical Economics 31, 291–312. https://doi.org/10.1007/s00181-005-0016-7.

Crossley, T.F., Low, H.W., Sleeman, C., 2014. Using a temporary indirect tax cut as a fiscal stimulus: evidence from the UK. IFS Working Papers W14/16.

Cui, J., Yang, H., Wang, Y., Yang, C., 2023. Dynamics of the gas retail market under China's price cap regulation. Energy Policy 174, 113424. https://doi.org/10.1016/j.enpol.2023.113424.

Dovern, J., Frank, J., Glas, A., Müller, L.S., Perico Ortiz, D., 2023. Estimating pass-through rates for the 2022 tax reduction on fuel prices in Germany. Energy Economics 126, 106948. https://doi.org/10.1016/j.eneco.2023.106948.

Doyle, J., Muehlegger, E., Samphantharak, K., 2010. Edgeworth Cycles Revisited. Energy Economics 32, 651–660. https://doi.org/10.1016/j.eneco.2009.09.001.

Dreher, A., Krieger, T., 2010. Diesel price convergence and mineral oil taxation in Europe. Applied Economics 42, 1955–1961. https://doi.org/10.1080/00036840701749076.

Driscoll, J.C., Kraay, A.C., 1998. Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data. Review of Economics and Statistics 80, 549–560. https://doi.org/10.1162/003465398557825.

Drolsbach, C.P., Gail, M.M., Klotz, P.-A., 2023. Pass-through of temporary fuel tax reductions: Evidence from Europe. Energy Policy 183, 113833. https://doi.org/10.1016/j.enpol.2023.113833.

Eckert, A., 2002. Retail price cycles and response asymmetry. Canadian Journal of Economics 35, 52–77. https://doi.org/10.1111/1540-5982.00120.

Eckert, A., 2003. Retail Price Cycles and the Presence of Small Firms. International Journal of Industrial Organization 21, 151–170. https://doi.org/10.1016/S0167-7187(02)00038-3.

Eckert, A., 2013. Empirical Studies of Gasoline Retailing: A Guide to the Literature. Journal of Economic Surveys 27, 140–166. https://doi.org/10.1111/j.1467-6419.2011.00698.x.

Eckert, A., West, D.S., 2004. Retail Gasoline Price Cycles across Spatially Dispersed Gasoline Stations. The Journal of Law and Economics 47, 245–273. https://doi.org/10.1086/380474.

Edgeworth, F.Y., 1925. The Pure Theory of Monopoly. Papers relating to political economy 1, 111–142.

Eibelshäuser, S., Wilhelm, S., 2017. Markets Take Breaks: Dynamic Price Competition with Opening Hours. Jahrestagung des Vereins für Socialpolitik 2017: Alternative Geld- und Finanzarchitekturen, 64 pp.

Eibelshäuser, S., Wilhelm, S., 2018. High-Frequency Price Fluctuations in Brick-and-Mortar Retailing, 59 pp.

European Central Bank, 2024. Euro foreign exchange reference rates. https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html (accessed 2 March 2024).

European Commission, 2022. Weekly Oil Bulletin. https://energy.ec.europa.eu/data-and-analysis/weekly-oil-bulletin_en (accessed 14 December 2022).

finanzen.net GmbH, 2022. Ölpreise in EUR (Brent) - Historische Kurse. https://www.finanzen.net/rohstoffe/oelpreis/historisch/euro?type=Brent (accessed 5 November 2022).

Foros, Ø., Steen, F., 2013. Vertical Control and Price Cycles in Gasoline Retailing. Scand. J. of Economics 115, 640–661. https://doi.org/10.1111/sjoe.12024.

Freitas, D., Syga, S., 2022. 35 Cent weniger für Benzin und 17 Cent weniger für Diesel – Der Tankrabatt ist angekommen. ifo Dresden berichtet 5, 6 pp.

Frondel, M., Vance, C., 2014. More Pain at the Diesel Pump?: An Econometric Comparison of Diesel and Petrol Price Elasticities. Journal of Transport Economics and Policy 48, 449–463.

Frondel, M., Vance, C., Kihm, A., 2016. Time lags in the pass-through of crude oil prices: big data evidence from the German gasoline market. Applied Economics Letters 23, 713–717. https://doi.org/10.1080/13504851.2015.1102836.

Fuest, C., Neumeier, F., Stöhlker, D., 2022. Der Tankrabatt: Haben die Mineralölkonzerne die Steuersenkung an die Kunden weitergegeben? Perspektiven der Wirtschaftspolitik 23, 74–80. https://doi.org/10.1515/pwp-2022-0024.

Gaus, D., Murray, N., Link, H., 2023. 9-Euro-Ticket: Niedrigere Preise allein stärken Alltagsmobilität mit öffentlichen Verkehrsmitteln nicht. DIW Wochenbericht 14/15. DIW, Berlin. https://www.diw.de/documents/publikationen/73/diw_01.c.869739.de/23-14-1.pdf (accessed May 2023).

Gautier, E., Le Saout, R., 2015. The Dynamics of Gasoline Prices: Evidence from Daily French Micro Data. Journal of Money, Credit and Banking 47, 1063–1089.

Genakos, C., Dimitrakopoulou, L., Kampouris, T., Papadokonstantaki, S., 2023. Vat Pass-Through and Competition: Evidence from the Greek Islands.

globalpetrolprices.com, 2019. Download Fuel Price Data. https://www.globalpetrolprices.com/data_download.php (accessed 3 December 2019).

González, J., Hurtado, C., 2019. Pricing Strategy Heterogeneity in Retail Gasoline Markets, 58 pp. https://facultystaff.richmond.edu/~churtado/Research/PricingStrategyHeterogeneity/PricingStrategyHeterogeneity.pdf.

González, J., Hurtado, C., 2021. Price Differences Within Retail Gasoline Markets. SSRN Journal. https://doi.org/10.2139/ssrn.3901166.

González, X., Moral, M.J., 2023. Competition and Competitors: Evidence from the Retail Fuel Market. EJ 44, 163–188. https://doi.org/10.5547/01956574.44.6.xgon.

Gurgur, T., Kilinc, Z., 2016. Crude Oil Price and Retail Price of Gasoline: An Empirical Analysis of Asymmetric Relationship. SSRN Journal. https://doi.org/10.2139/ssrn.2882091.

Haas, S. de, 2019. Do Pump Prices Really Follow Edgeworth Cycles? Evidence from the German Retail Fuel Market. MAGKS Joint Discussion Paper Series in Economics. 13-2019, 13 pp.

Hadri, K., 2000. Testing for stationarity in heterogeneous panel data. The Econometrics Journal 3, 148–161. https://doi.org/10.1111/1368-423X.00043.

Haucap, J., Heimeshoff, U., Siekmann, M., 2015. Price Dispersion and Station Heterogeneity on German Retail Gasoline Markets. DICE discussion paper 171. Düsseldorf Institute for Competition Economics, Düsseldorf, 34 pp. https://www.econstor.eu/handle/10419/106709.

Haucap, J., Heimeshoff, U., Siekmann, M., 2016. Selling gasoline as a by-product: The impact of market structure on local prices. düsseldorf university press, Düsseldorf, Germany, 143 pp.

Haucap, J., Heimeshoff, U., Siekmann, M., 2017. Fuel Prices and Station Heterogeneity on Retail Gasoline Markets. The Energy Journal 38. https://doi.org/10.5547/01956574.38.6.jhau.

Haucap, J., Müller, H.C., 2012. The Effects of Gasoline Price Regulations: Experimental Evidence. DICE discussion paper 47. Düsseldorf Institute for Competition Economics, Düsseldorf, Online-Ressource. http://www.worldcat.org/title/effects-of-gasoline-price-regulations-experimental-evidence/oclc/863978888?ap=citavi.

Hausman, J.A., Taylor, W.E., 1981. Panel Data and Unobservable Individual Effects. Econometrica 49, 1377. https://doi.org/10.2307/1911406.

Hosken, D.S., McMillan, R.S., Taylor, C.T., 2008. Retail Gasoline Pricing: What do We Know? International Journal of Industrial Organization 26, 1425–1436. https://doi.org/10.1016/j.ijindorg.2008.02.003.

Im, K.S., Pesaran, M., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. Journal of Econometrics 115, 53–74. https://doi.org/10.1016/S0304-4076(03)00092-7.

infoRoad GmbH, 2019. clever-tanken.de. https://www.clever-tanken.de/ (accessed 2019).

Kahl, M.P., 2020. Impact of cross-border competition on the German retail gasoline market - German-Polish border. Working Paper Series in Economics 392. Lüneburg: Leuphana Universität Lüneburg, Institut für Volkswirtschaftslehre. https://www.econstor.eu/bitstream/10419/234581/1/wp-392-upload.pdf.

Kahl, M.P., 2023. Was the German fuel discount passed on to consumers? Working Paper Series in Economics 419. Lüneburg: Leuphana Universität Lüneburg, Institut für Volkswirtschaftslehre. https://www.econstor.eu/bitstream/10419/278435/1/1844478483.pdf.

Kahl, M.P., Wein, T., 2022. How to reach the land of Cockaigne? Edgeworth cycle theory and why a gasoline station is the first to raise its price. Working Paper Series in

Economics 411. Lüneburg: Leuphana Universität Lüneburg, Institut für Volkswirtschaftslehre. https://www.econstor.eu/bitstream/10419/273136/1/1799714748.pdf.

Kihm, A., Ritter, N., Vance, C., 2016. Is the German Retail Gasoline Market Competitive? A Spatial-Temporal Analysis Using Quantile Regression. Land Economics 92, 718–736. https://doi.org/10.3368/le.92.4.718.

Kleineberg, C., 2020. Market definition of the German retail gasoline industry on highways and those in the immediate vicinity. University of Lüneburg Working Paper Series in Economics 388. Institute of Economics, Lüneburg. https://www.leuphana.de/fileadmin/user_upload/Forschungseinrichtungen/ifvwl/WorkingPapers/wp_388_Upload.pdf.

Kolay, S., Tyagi, R.K., 2018. Product Similarity and Cross-Price Elasticity. Rev Ind Organ 52, 85–100. https://doi.org/10.1007/s11151-017-9578-8.

Levin, A., Lin, C.-F., James Chu, C.-S., 2002. Unit root tests in panel data: asymptotic and finite-sample properties. Journal of Econometrics 108, 1–24. https://doi.org/10.1016/S0304-4076(01)00098-7.

Lewis, M.S., 2009. Temporary Wholesale Gasoline Price Spikes Have Long-Lasting Retail Effects: The Aftermath of Hurricane Rita. The Journal of Law and Economics 52, 581–605. https://doi.org/10.1086/592056.

Lewis, M.S., 2012. Price leadership and coordination in retail gasoline markets with price cycles. International Journal of Industrial Organization 30, 342–351. https://doi.org/10.1016/j.ijindorg.2011.12.002.

Lewis, M.S., Noel, M.D., 2011. The Speed of Gasoline Price Response in Markets With and Without Edgeworth Cycles. The Review of Economics and Statistics 93, 672–682. https://doi.org/10.2139/ssrn.2653067.

Linder, M., 2018. Price Cycles in the German Retail Gasoline Market - Competition or Collusion? Economics Bulletin 38, 593–602.

Livingston, S.M., Levitt, T., 1959. Competition and Retail Gasoline Prices. The Review of Economics and Statistics 41, 119–132.

Maddala, G.S., Wu, S., 1999. A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. Oxf Bull Econ Stat 61, 631–652. https://doi.org/10.1111/1468-0084.0610s1631.

Marco Schwochow, 2023. PLZ Download. suche-postleitzahl.org. https://www.suche-postleitzahl.org/ (accessed April 2024).

Maskin, E., Tirole, J., 1988. A Theory of Dynamic Oligopoly, II: Price Competition, Kinked Demand Curves, and Edgeworth Cycles. Econometrica 56, 571–599. https://doi.org/10.2307/1911701.

Michaelis, P., 2003. Tanktourismus : eine Szenario-Analyse. Volkswirtschaftliche Diskussionsreihe 249. Augsburg: Universität Augsburg, Institut für Volkswirtschaftslehre. https://www.econstor.eu/bitstream/10419/22772/1/249.pdf.

Ministère de la Transition Énergétique, 2022. Décret no 2022-1168 du 22 août 2022 modifiant le décret no 2022-423 du 25 mars 2022 relatif à l'aide exceptionnelle à l'acquisition de carburants, 3 pp.

Ministère de l'Économie, des Finances et de la Souveraineté industrielle, 2022. Le prix des carburants. https://www.prix-carburants.gouv.fr/rubrique/opendata/ (accessed 27 October 2022).

Montag, F., Mamrak, R., Sagimuldina, A., Schnitzer, M., 2023. Imperfect Price Information, Market Power, and Tax Pass-Through 414. CRC TRR 190 Rationality and Competition.

Montag, F., Sagimuldina, A., Schnitzer, M., 2020. Are temporary value-added tax reductions passed on to consumers? Evidence from Germany's stimulus, 24 pp.

Neukirch, A., Wein, T., 2016a. Collusive upward gasoline price movements in medium-sized German cities. University of Lüneburg Working Paper Series in Economics 363. Leuphana University of Lueneburg, 37 pp.

Neukirch, A., Wein, T., 2016b. Das Auf und Ab der Tankstellenpreise – Die Rolle des Binnen- und Außenwettbewerbs. List Forum 42, 195–245. https://doi.org/10.1007/s41025-016-0044-4.

Neukirch, A., Wein, T., 2019. Price Gouging at the Pump? The Lerner Index and the German Fuel Market. Review of Economics 70, 157–192. https://doi.org/10.1515/roe-2019-0016.

Noel, M.D., 2007a. Edgeworth Price Cycles, Cost-Based Pricing, and Sticky Pricing in Retail Gasoline Markets. Review of Economics and Statistics 89, 324–334. https://doi.org/10.1162/rest.89.2.324.

Noel, M.D., 2007b. Edgeworth Price Cycles: Evidence from the Toronto Retail Gasoline Market. J Ind Econ 55, 69–92. https://doi.org/10.1111/j.1467-6451.2007.00303.x.

Noel, M.D., 2008. Edgeworth Price Cycles and Focal Prices: Computational Dynamic Markov Equilibria. J Econ Manage Strat 17, 345–377. https://doi.org/10.1111/j.1530-9134.2008.00181.x.

Noel, M.D., 2009. Do retail gasoline prices respond asymmetrically to cost shocks? The influence of Edgeworth Cycles. The RAND Journal of Economics 40, 582–595. https://doi.org/10.1111/j.1756-2171.2009.00078.x.

Noel, M.D., 2015. Do Edgeworth Price Cycles Lead to Higher or Lower Prices? International Journal of Industrial Organization 42, 81–93. https://doi.org/10.1016/j.ijindorg.2015.07.003.

Noel, M.D., 2018a. Edgeworth Price Cycles, in: The New Palgrave Dictionary of Economics. Palgrave Macmillan UK, London, pp. 3463–3468.

Noel, M.D., 2018b. Gasoline Price Dispersion and Consumer Search: Evidence from a Natural Experiment. The J Industrial Economics 66, 701–738. https://doi.org/10.1111/joie.12179.

Noel, M.D., 2019. Calendar Synchronization of Gasoline Price Increases. J Econ Manage Strat 28, 355–370. https://doi.org/10.1111/jems.12267.

Noel, M.D., Chu, L., 2015. Forecasting gasoline prices in the presence of Edgeworth Price Cycles. Energy Economics 51, 204–214. https://doi.org/10.1016/j.eneco.2015.06.017.

Organisation for Economic Co-operation and Development, 2018a. Taxing Energy Use 2018. OECD, 58 pp.

Organisation for Economic Co-operation and Development, 2018b. Taxing Energy Use 2018: Germany, 8 pp. https://www.oecd.org/tax/tax-policy/taxing-energy-use-2018-germany.pdf (accessed 29 May 2018).

Organisation for Economic Co-operation and Development, 2018c. Taxing Energy Use 2018: Poland, 7 pp. https://www.oecd.org/tax/tax-policy/taxing-energy-use-2018-poland.pdf (accessed 29 May 2018).

Organisation for Economic Co-operation and Development, 2020. Country Notes. ENERGY PRICES AND TAXES FOR OECD COUNTRIES: Country notes (2nd Quarter 2020). https://iea.blob.core.windows.net/assets/17127234-f7c5-4168-98f8-b69340ec6305/EPT_CountryNotes.pdf (accessed September 2020).

Organisation for Economic Co-operation and Development, 2023a. Quarterly National Accounts: GDP - output approach. https://stats.oecd.org/index.aspx?queryid=350# (accessed 27 January 2023).

Organisation for Economic Co-operation and Development, 2023b. Quarterly National Accounts: Quarterly Growth Rates of real GDP. https://stats.oecd.org/index.aspx?queryid=350# (accessed 27 January 2023).

Pennerstorfer, D., Schmidt-Dengler, P., Schutz, N., Weiss, C., Yontcheva, B., 2020. Information and Price Dispersion: Theory and Evidence. International Economic Review 61, 871–899. https://doi.org/10.1111/iere.12443.

Pesaran, M.H., Zhou, Q., 2018. Estimation of time-invariant effects in static panel data models. Econometric Reviews 37, 1137–1171. https://doi.org/10.1080/07474938.2016.1222225.

Pollak, A., 2017. Do Price-Matching Guarantees with Markups Facilitate Tacit Collusion? Theory and Experiment. University of Cologne Working Paper Series in Economics 93. Department of Economics, 56 pp.

Poterba, J.M., 1996. Retail price reactions to changes in state and local sales taxes. National Tax Journal 49, 165–176. https://doi.org/10.1086/NTJ41789195.

Quack, L., Mechtel, M., forthcoming. Fuel price elasticities by socioeconomic groups. Lueneburg.

Quandl, 2019. Crude Oil Prices: Brent - Europe. https://www.quandl.com/data/FRED/DCOILBRENTEU-Crude-Oil-Prices-Brent-Europe (accessed 2 December 2019).

Rambachan, A., Roth, J., 2023. A More Credible Approach to Parallel Trends. The Review of Economic Studies, rdad018. https://doi.org/10.1093/restud/rdad018.

Rietveld, P., Bruinsma, F., van Vuuren, D., 2001. Spatial graduation of fuel taxes; consequences for cross-border and domestic fuelling. Transportation Research Part A: Policy and Practice 35, 433–457. https://doi.org/10.1016/S0965-8564(00)00002-1.

Rietveld, P., van Woudenberg, S., 2005. Why fuel prices differ. Energy Economics 27, 79–92. https://doi.org/10.1016/j.eneco.2004.10.002.

Romero-Jordán, D., García-Inés, M.J., García, S.Á., 2013. The impact of fuel tourism on retailers' diesel price in Spanish neighbouring regions. Applied Economics 45, 407–413. https://doi.org/10.1080/00036846.2011.605757.

Roos, N. de, Katayama, H., 2013. Gasoline Price Cycles Under Discrete Time Pricing. Econ Rec 89, 175–193. https://doi.org/10.1111/1475-4932.12036.

Schmerer, H.-J., Hansen, J., 2023. Pass-through effects of a temporary tax rebate on German fuel prices. Economics Letters 227, 111104. https://doi.org/10.1016/j.econlet.2023.111104.

Seiler, V., Stöckmann, N., 2023. The Impact of the German Fuel Discount on Prices at the Petrol Pump. German Economic Review 24, 191–206. https://doi.org/10.1515/ger-2022-0108.

Sgaravatti, G., Tagliapietra, S., Zachmann, G., 2021. National policies to shield consumers from rising energy prices: Bruegel Datasets. first published 4 November 2021. https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices.

Shepard, A., 1993. Contractual Form, Retail Price, and Asset Characteristics in Gasoline Retailing. The RAND Journal of Economics 24, 58–77.

Siekmann, M., 2017. Characteristics, Causes, and Price Effects: Empirical Evidence of Intraday Edgeworth Cycles. düsseldorf university press, Düsseldorf, Germany, 27 pp.

Statistisches Bundesamt, 2019. Alle politisch selbständigen Gemeinden mit ausgewählten Merkmalen am 31.12.2018. https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/Administrativ/Archiv/GVAuszugJ/31122018_Auszug_GV.html (accessed 4 December 2019).

Statistisches Bundesamt, 2020. GV-ISys: Verzeichnis der Regional- und Gebietseinheiten Definitionen und Beschreibungen. Statistisches Bundesamt. https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/_inhalt.html (accessed April 2024).

Statistisches Bundesamt, 2022. 9-Euro-Ticket: Mobilität steigt deutlich auf kurzen Distanzen im Schienenverkehr. Wiesbaden.

Statistisches Bundesamt, 2023a. Gemeinden nach Bundesländern und Einwohnergrößenklassen am 31.12.2022. Gemeinden nach Bundesländern und Einwohnergrößenklassen am 31.12.2022 (only in German language). Statistisches Bundesamt. https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/Administrativ/08-gemeinden-einwohner-groessen.html (accessed April 2024).

Statistisches Bundesamt, 2023b. Kreisfreie Städte und Landkreise nach Fläche, Bevölkerung und Bevölkerungsdichte am 31.12.2022. Kreisfreie Städte und Landkreise am 31.12.2022 (only in German language). https://www.destatis.de/DE/Themen/Laender-Regionen/Regionales/Gemeindeverzeichnis/Administrativ/04-kreise.html (accessed April 2024).

Statistisches Bundesamt, 2024. Abkürzungen für Deutschland und seine Bundesländer: Abbreviations used for Germany and the Länder. https://www.destatis.de/DE/Methoden/abkuerzung-bundeslaender-DE-EN.html (accessed April 2024).

tankerkoenig.de, 2019. Historische Preisdaten. https://creativecommons.tankerkoenig.de/#history (accessed September 2018).

U.S. Energy Information Administration, 2024. Petroleum & Other Liquids: Europe Brent Spot Price FOB. U.S. Energy Information Administration. https://www.eia.gov/dnav/pet/hist/rbrteD.htm (accessed 2 March 2024).

Uexkull, N. von, Rød, E.G., Svensson, I., 2024. Fueling protest? Climate change mitigation, fuel prices and protest onset. World Development 177, 106536. https://doi.org/10.1016/j.worlddev.2024.106536.

University of California Berkeley, 2018. Useful Conversion Factors. http://w.astro.berkeley.edu/~wright/fuel_energy.html (accessed 29 November 2018).

vacances-scolaires-education.fr, 2022. À quelle zone scolaire est rattachée mon département ? https://www.vacances-scolaires-education.fr/departements.html.

Viren, M., 2009. Does the Value-Added Tax Shift to Consumption Prices? Czech Economic Review 3, 123–142.

Wang, Z., 2008. Collusive Communication and Pricing Coordination in a Retail Gasoline Market. Rev Ind Organ 32, 35–52. https://doi.org/10.1007/s11151-008-9163-2.

Wang, Z., 2009a. (Mixed) Strategy in Oligopoly Pricing: Evidence from Gasoline Price Cycles Before and Under a Timing Regulation. Journal of Political Economy 117, 987–1030. https://doi.org/10.1086/649801.

Wang, Z., 2009b. Station Level Gasoline Demand in an Australian Market with Regular Price Cycles. Australian Journal of Agricultural and Resource Economics 53, 467–483. https://doi.org/10.1111/j.1467-8489.2009.00468.x.

Wein, T., 2021. Why Abandon the Paradise? Stations' Incentives to Reduce Gasoline Prices at First. J Ind Compet Trade 21, 465–504. https://doi.org/10.1007/s10842-021-00362-8.

Wills-Johnson, N., Bloch, H., 2010. A simple spatial model for Edgeworth Cycles. Economics Letters 108, 334–336. https://doi.org/10.1016/j.econlet.2010.06.007.

Wlazlowski, S., Giulietti, M., Binner, J., Milas, C., 2009. Price dynamics in European petroleum markets. Energy Economics 31, 99–108. https://doi.org/10.1016/j.eneco.2008.08.009.

Wooldridge, J.M., 1999. Distribution-free estimation of some nonlinear panel data models. Journal of Econometrics 90, 77–97. https://doi.org/10.1016/S0304-4076(98)00033-5.

Wooldridge, J.M., 2002. Econometric analysis of cross section and panel data. MIT Press, Cambridge, Mass, 752 pp.

Zimmerman, P.R., Yun, J.M., Taylor, C.T., 2013. Edgeworth Price Cycles in Gasoline: Evidence from the United States. Rev Ind Organ 42, 297–320. https://doi.org/10.1007/s11151-012-9372-6.