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How to Reach the Land of Cockaigne? Edgeworth Cycle Theory and Why a Gasoline Station is the First to Raise Its Price

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Abstract

Competition in the German gasoline retail market is characterized by strong intraday price cycles. The cycles are described in the literature as corresponding to the well-known Edgeworth cycles. Cyclical pricing patterns are observable all over Germany and throughout the world. So far, research has focused on analyzing price patterns using average prices. We are the first to study the initiation of new price cycles by looking at the exact timing of competition in the daily cycle. We modified the data to be able to analyze local competition on a second-by-second level. What determines that a certain gasoline station increases its price to initiate a new price cycle? We are the first to empirically analyze whether the theoretically and economically significant price differences of the Edgeworth cycles explain the cyclical patterns throughout a day, or whether brand affiliation, local characteristics, or services offered predict the behavior of price increases. To provide first evidence and 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, as well as services offered, play a minor role in explaining why a gasoline station is the first to increase its price. Brand affiliation, as well as location parameters, are much more important in a gasoline stations' decision on whether they will be the first to increase prices. Furthermore, we show that 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 size of the 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.

JEL codes: L13, L41, K21

Keywords: Edgeworth cycles, gasoline prices, dynamic pricing, gasoline market

Declarations of interest: none

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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 of 2013, 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 observation to find out if there was an abuse of power within the market.

The Edgeworth cycle theory by Maskin and Tirole (1988) is the prevailing theory in explaining price patterns in the German gasoline market. In an oligopoly market, Edgeworth cycles describe pricing behaviors in three phases. In the first phase, oligopolists undercut each other successively to increase their market share until they reach marginal costs. At that time, they enter the second phase – the so-called war of attrition. When it becomes too costly to stay at the marginal cost, the third phase starts. The third phase is referred to as the relenting phase where one or more players raise prices, and the others follow. As price undercutting begins again, the cycle starts anew.

Why are we studying price competition within the German gasoline retail market? So far, research has focused on analyzing price cycles based on daily or weekly average price data. Until our research, no one has looked at the second-by-second order of events. Castanias and Johnson (1993) tested Maskin and Tirole's (1988) theory based on weekly price data in Los Angeles and 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 all over the world. Doyle et al. (2010), Lewis and Noel (2011), Lewis (2012), and Zimmerman et al. (2013) look at price patterns in the United States. Atkinson (2009), Atkinson et al. (2014), and Noel (2007, 2015) looked at price patterns in Canada. Noel (2019), Roos and Katayama (2013), and Wang (2009) looked at patterns in Australia. Most recently, Siekmann (2017), and Wein (2021), among others, studied Germany's price patterns.

What we observed were cycles similar to the one described by Maskin and Tirole (1988); however, the theory might describe the symptoms rather than the cause of the cycles. What factors are causing the price cycles we observe all over the world? Is price competition resulting from the struggle for a larger market share? What role do other factors such as brand affiliation, local characteristics, and services offered play?

We are the first to study the price increaser that initiates a new price cycle, while looking at the exact timing of competition changes within in each day. Our analysis is very similar and based on the same data set as in 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 probit, logit, and Poisson estimation techniques. We identify the factors that determine whether a certain gasoline station will increase its price to initiate a new price cycle.

We find that price considerations, as well as services offered, play a minor role in explaining why a gasoline station is the first to increase prices. Brand affiliation, as well as location parameters, are much more important in a gasoline station's decisions on whether to be the first to increase prices. We are the first to present these novel results based on our modified data set. Furthermore, we show that the dominant suppliers, Aral and Shell, are the major drivers of the size of the price cycles. Jointly, they account for more than 80 percent of price increases in the market.

This paper is structured as follows. In section 2, we present the data. In section 3, we explain the data modification in detail. We explain our estimation approach in section 4 and present the descriptive results in section 5. In section 6, we present and discuss the regression results. We dedicate section 7 to robustness checks and section 8 to the discussion of validity. We summarize and conclude in section 9.

2 Data

Since August of 2013 (Bundeskartellamt 2021), all German gasoline stations have had to report gasoline price changes to the MTU. The German federal cartel office created the MTU to supervise competition in the gasoline retail market, and to enable them to "intervene in the case of illegal predatory strategies and other forms of market power abuse" (Bundeskartellamt 2021). The data are available to certain registered information service providers, and is made available to researchers by tankerkoenig.de. We prepared panel data for the most common gasoline types, diesel and petrol (with 5 and 10 percent ethanol), for the years 2018 and 2019.[3] We limit our sample to one local market – the town and area

[3] Our data set includes all price changes from 3 January 2018 to 31 December 2019. Thus, we have 728 days of data.

around Lueneburg – where there are 26 gasoline stations. Following existing literature, we differentiate between three brand categories: 1) oligopoly players (ARAL, Shell, TOTAL, ESSO, and JET); 2) superregional brands without upstream structure which we call non-oligopoly players category 1, NO1 (Star, AVIA, HEM, OIL!, Agip, OMV, and Westfalen); and 3) the independent local gasoline stations called non-oligopoly players category 2, NO2. We use single brand dummies whenever possible, but 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.

Table 1: Brand and Categorization

Brand or category	**Number of gasoline stations**	**Category**
ARAL	5	Oligopoly player
Shell	7	Oligopoly player
Esso Jet	2	Oligopoly players
NO1	8	Non-oligopoly superregional players
NO2	4	Non-oligopoly regional 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. Driving distances between all gasoline stations are estimated using GoogleMaps and are based on the mean value of driving the distances in both directions. During 2019, two gasoline stations ceased operation – an ARAL station in Brietlingen and a Raiffeisen station in Barendorf.

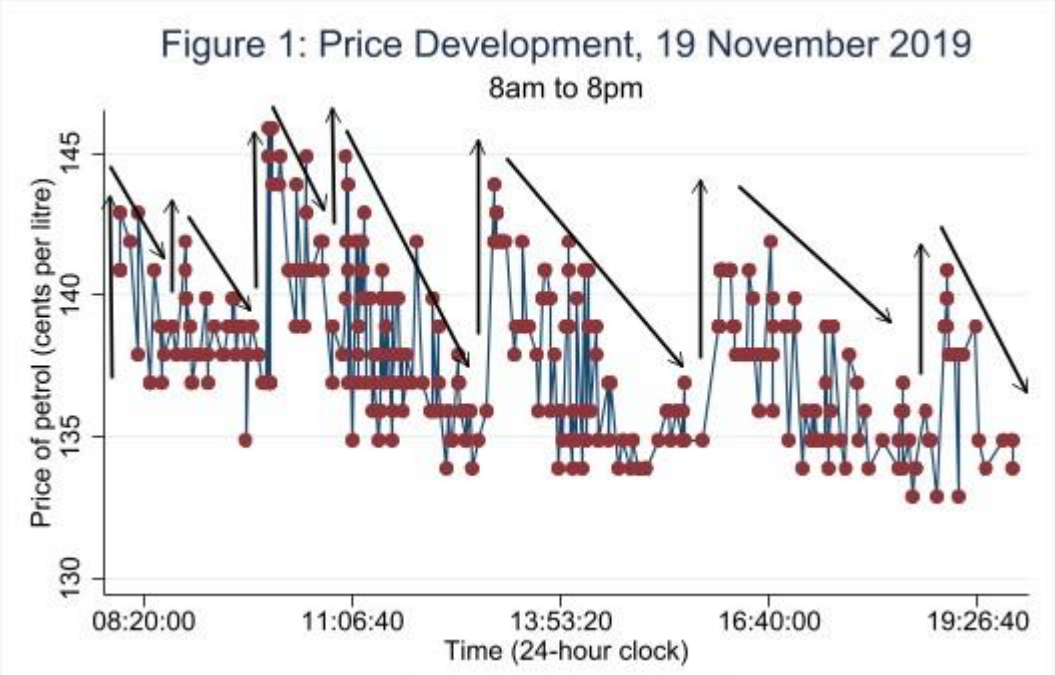
The data set is supplemented with information on services and gasoline station characteristics from the official service providers tankerkoenig.de and clevertanken.de. Moreover, we added information on services offered and characteristics from gasoline stations' websites, as well as from the authors'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

3 Data Modification

If a gasoline station increases its price, we call it a price increase event. Specifically, we define a price increase event as an increase in prices which occurs after at least five gasoline stations successively lowered prices in our market. If two or more gas stations increase their prices simultaneously, then we identify all of them as initiating the price increase. Thus, we artificially increase the number of "cycles" in order 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. As we focus on the price increase event, all subsequent price observations are dropped.

Additionally, the earliest possible event has to occur at least one hour after the last gasoline station opened for the day. This ensures that the usual price corrections made daily at opening to adapt to the current price level are not wrongly identified as events that influence the cycle structure. 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 (defined as a price increase after a series of at least five price decreases).



In Figure 1, we present an example of petrol prices on a randomly chosen day, November 19, 2019. The example shows the "Super E5" prices at all 26 gasoline stations in the Lueneburg, Germany area. We added a line and drew arrows to illustrate intraday cycles. There were eight cycles that day; seven are illustrated using arrows, while the last cycle in the late evening is omitted to keep the graph simple. Looking at the data, we can see that the cycles at 1 p.m., 4 p.m., and 10 p.m. were initiated simultaneously by three gasoline stations. The cycle at 7 p.m. was initiated simultaneously by two gas stations. All of the simultaneous initiators on this particular day were Shell stations.

Generally, in the Lueneburg market, there are at most 10 gasoline stations simultaneously initiating a new price cycle by raising prices. For each "event station," 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 initiate a new price cycle by increasing their prices at the same time.

Our research looks at 728 days of data with an average of 5.06 cycles per day between 8 a.m. and 22 p.m., with a standard deviation of 1.53, and a minimum of 3 and maximum of 11 cycles per day. As mentioned earlier, many cycles are initiated by several gasoline stations raising prices at the same time, so we act as if each of these increases is a time 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 11,586 cycles in the data set, with an average of 15.92 cycles per day (sd=6.34, min=4, max=38). We chose this definition because we do not want to exclude any of the stations that raised prices simultaneously with other stations.

In addition, a variable indicates the duration for which a price was valid. It is calculated as the difference between the time of the event and the time of the latest price change of a gasoline station before that event. Hence, it is the time period a price was valid before a gasoline station decided to jump its price. If a gasoline station reports the latest price change before it opened in the morning, then the duration is calculated as the difference between the opening time and the event. Based on this duration variable, we create a variable indicating the duration weighted price difference.

We differentiate between 12 services: self-service, shops, 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. We present a categorization and overview of all variables in Table 2. We use all explanatory variables as in previous research, and more. Data on traffic intensity is unfortunately not available.

Table 2: Variables Overview

Category	Variable
Dependent variables	***Increasing price observation**:* Dummy = 1 for increasing price observation and 0 for non-increasing price observation. ***Magnitude of the price increase***: Measures by how much the increasing gasoline station raises its price, i.e. difference between new and old price. In euro cents per liter (cpl).
Price competition	***Price difference to price increaser, before jump***: Thus, the difference observed for each gasoline station minus the price of the increaser before the price was raised. ***Duration***: The time period for which a price was effective before the price increase event occurred. (Measured in machine hours, hence, 0.5 corresponding to 30 minutes.) ***Price difference*duration, measured in machine hours***: Price difference weighted by the *duration* (time it was active). ***Distance weighted price differences to nearest station, before jump***: The distance of the nearest gas station to the increaser weighted by the *price difference to price increaser, before jump*. ***Distance weighted price differences to second nearest station, before jump**:* The distance of the second nearest gas station to the increaser weighted by the *price difference to price increaser, before jump*. ***Distance weighted price differences to third nearest station, before jump**:* The distance of the third nearest gas station to the increaser weighted by the *price difference to price increaser, before jump*.
Local competition	***Distance***: Driving distances between gasoline stations are estimated using GoogleMaps and are based on the mean value of the distances of both driving directions. ***In sight?**:* Dummy = 1 if a competitor can be seen from the gasoline station and o 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 motorway (German "Autobahn") and 0 otherwise. ***Stations in 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 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 gas station is of brand "ARAL" and 0 otherwise. ***Shell***: Dummy = 1 if gas station is of brand "Shell" and 0 otherwise. ***Esso***: Dummy = 1 if gas station is of brand "Esso" and 0 otherwise. ***JET***: Dummy = 1 if gas station is of brand "JET" and 0 otherwise. ***ESSO_JET***: Dummy = 1 if brand is "ESSO" or "JET" and 0 otherwise. ***Hoyer***: Dummy = 1 if gas station is of brand "Hoyer" and 0 otherwise. ***LTG***: Dummy = 1 if gas station is of brand "LTG" and 0 otherwise. ***HEM***: Dummy = 1 if gas station is of brand "HEM" and 0 otherwise. ***Raiffeisen***: Dummy = 1 if gas station is of brand "Raiffeisen" and 0 otherwise. ***STAR***: Dummy = 1 if gas station is of brand "STAR" and 0 otherwise. ***BFT***: Dummy = 1 if 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 "BeckmannLindemann GmbH" and 0 otherwise. ***Freie Tankstelle Salewski***: Dummy = 1 if it is the regional gasoline station of the "Freie Tankstelle Salewski" and 0 otherwise. ***Freie Tankstelle***: 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 brand "TOTAL". Not used in regression analysis, because the use of single brands is preferred. ***Superregional non-oligopoly player? (NO1)***: Dummy = 1 if gasoline station of brand "Hoyer", "LTG", "HEM", "Raiffeisen" or "STAR" and 0 otherwise. ***Regional non-oligopoly player? (NO2)***: Dummy = 1 if gasoline station of brand "BeckmannLindemann GmbH", "BFT", "Freie Tankstelle Salewski", or "Freie Tankstelle" and 0 otherwise.
Station characteristics	***Self service station?***: Dummy = 1 if gasoline station is a self-service station and 0 otherwise. Gasoline station has an automated payment system without on-site staff. ***Station with Shop?***: Dummy = 1 if gasoline station has a shop and 0 otherwise. ***Station with Rewe-to-Go-Shop?***: Dummy = 1 if gas station has small supermarket of brand Rewe and 0 otherwise. ***Bistro?***: Dummy = 1 if gasoline station has a bistro and 0 otherwise. ***In-Store-Bakery?***: Dummy = 1 if gasoline station has a bakery and 0 otherwise. ***Kiosk?***: Dummy = 1 if gasoline station has a kiosk and 0 otherwise. Mostly omitted due to collinearity. ***Number of accepted credit cards?***: Number of credit card types that are accepted for payment. ***ATM?***: Dummy = 1 if gasoline station has a cash dispenser and 0 otherwise. ***Restrooms available?***: Dummy = 1 if gasoline station has restrooms and 0 otherwise. ***Car repair?***: Dummy = 1 if gasoline station has a car repair on premises and 0 otherwise. ***Car wash?***: Dummy = 1 if gasoline station has a car wash and 0 otherwise. ***Vacuum cleaner?***: Dummy = 1 if gasoline station has a vacuum cleaner and 0 otherwise. ***Number of Services?***: The number of services that a gasoline station offers. A simple count of all variables in the category "station characteristics" of this table with number of credit cards converted into a dummy variable = 1 if at least one type of credit card is accepted.

4 Estimation Approaches

We apply multivariate estimations to examine what factors explain the willingness of a gasoline station to be the first to increase its price after a series of price decreases and the magnitude by which it increases its price. Hence, we differentiate between the likelihood of being the first to raise the price and the strength of the price increase in cent per liter (cpl).

4.1 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. Consequently, we specify the dependent variable as a binary variable taking the value one if the gasoline station increases the price after a series of at least five price decreases and zero otherwise. Thus, the panel data structure allows us to run random effects probit and logit regression. We are interested in the regression coefficients of two kinds of variables.

First, the coefficient of the price difference variable, which captures the effect of competitors' prices on the likelihood of a station being the first to increase its price. The economic intuition behind this variable is that in the trough of a cycle there is price pressure on stations that cannot or do not want to lower their prices further. The pressure comes from competitors that undercut their station's price. Our price difference variable captures the price pressure on the increasing gasoline station just before the price increase. Next, we ask to what extent the price variable explains why a gasoline station is the first to increase prices. According to the Edgeworth cycle theory, this price variable is the decisive factor causing cyclical pricing patterns. The duration of a low price level also plays an important role in the theory. To capture this effect, we weigh the price difference variable with the duration.

The price difference variable changes over time and with different entities. We use fixed effects estimation techniques to capture the impact of price difference variables. The fixed effects logit model of the binary dependent variable y_{it} can be expressed as:

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

with $y_{it} = 1$ if a price-increasing event occurs, and $y_{it} = 0$ if the event does not occur. There are M regressors x_{it} with β representing the parameter vector ($M \times 1$) to be estimated. 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 time periods (T=11,586 is the total number of price cycles over the period of 728 days).[4] Each price-increasing event and the price valid just before each event is regarded as a separate time unit because the prevailing market constellation could be the reason why a gasoline station increases its price.

The second kind of variables we are interested in are station-specific, namely brand affiliation, location characteristics, and services offered. We use random effects logit as well as random effects probit estimation techniques to capture the effect of entity-specific variables.

4.2 Estimating effects of determinants of the strength of the price increase of the price increaser

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* 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 2018). 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 that accounts for 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 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 time fixed effects Poisson regression as well as pooled Poisson regression to capture the effect of entity-specific variables. Finally, we conduct several estimations based on various model specifications to check for robustness.

[4] No incidental parameters problem since T is large.

5 Descriptive Results

In our data set, we identified 11,586 price-increasing events, as seen in Table 3. The table shows the magnitude of the price increase that initiates a new price cycle and the frequency of these price increases. With a share of 50 percent, a price increase of 6 cpl is the modal value. Price increases of 4 cpl and 5 cpl occur in about 16 percent and 13 percent of cases, respectively.

Table 3: Frequency and magnitude of price increasing events

Price increasing value	Freq.	Percent	Cum.
.9	3	0.03	0.03
1	240	2.07	2.10
2	967	8.35	10.44
3	249	2.15	12.59
4	1857	16.03	28.62
5	1503	12.97	41.59
6	5846	50.46	92.05
7	521	4.50	96.55
8	300	2.59	99.14
9	39	0.34	99.47
10	14	0.12	99.59
11	6	0.05	99.65
12	8	0.07	99.72
13	12	0.10	99.82
14	6	0.05	99.87
15	4	0.03	99.91
16	2	0.02	99.92
18	1	0.01	99.93
20	2	0.02	99.95
22	4	0.03	99.98
26	1	0.01	99.99
30	1	0.01	100.00
Total	11586	100.00	

Table 4 displays price increases by each gasoline station. Three gasoline stations dominate the pricing structure, gasoline station numbers 1, 7, and 16. All three are Shell stations, which is the dominant brand on the market. Shell's market share is about 27 percent (7 gasoline stations out of 26); however, Shell accounts for about 52 percent of price increasing events, as seen on Table 5. Similarly, ARAL holds a market share of almost 20 percent, and accounts for about 29 percent of price-increasing events.

Table 4 reveals that the two dominating brands work differently. Shell works through three out of seven of its gasoline stations when initiating price cycles, while ARAL has rather a uniform distribution when it comes to 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.

Table 4: Price increases by gasoline station

Station numbers	Brand or category	Within one round: 1 = increasing price observ., 0= non-increasing price observ.		
		0	1	Total
1	Shell	9486	1957	11443
2	ARAL	10860	723	11583
3	ARAL	10797	782	11579
4	ARAL	10787	796	11583
5	NO1	11568	1	11569
6	ESSO	11532	52	11584
7	Shell	9776	1794	11570
8	NO1	11566	18	11584
9	ARAL	10850	719	11569
10	NO1	10592	30	10622
11	NO1	11562	11	11573
12	NO2	10833	717	11550
13	NO2	10789	201	10990
14	Shell	11411	15	11426
15	NO2	7222	312	7534
16	Shell	9471	2099	11570
17	NO2	11334	112	11446
18	JET	11260	14	11274
19	Shell	11571	13	11584
20	NO1	10937	143	11080
21	ARAL	4808	335	5143
22	Shell	11472	81	11553
23	NO1	10448	618	11066
24	Shell	11449	29	11478
25	NO1	11575	9	11584
26	NO1	9995	5	10000
Total		273951	11586	285537

Table 5 shows the brand affiliation of gasoline stations and the number of price increasing events initiated by each brand.

Table 5: Frequency of price increasing events by brand

Brand	Within one round: 1 = increasing price observ., 0= non-increasing price observ.		
	0	1	Total
ARAL	48102	3355	51457
BeckmannLindemann GmbH	10789	201	10990
ESSO	11532	52	11584
Freie Tankstelle	7222	312	7534
Freie Tankstelle Salewski	11334	112	11446
HEM	11562	11	11573
Hoyer	10592	30	10622
JET	11260	14	11274
LTG	33138	15	33153
Raiffeisen	21385	761	22146
STAR	11566	18	11584
Shell	74636	5988	80624
BFT	10833	717	11550
Total	273951	11586	285537

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 price is about 140 cpl of petrol over the entire observation period. On average, there are significantly more cycles per day on weekends and on public and school holidays.[5]

6 Regression Results and Discussion

First, we present estimation results on the factors that determine the likelihood of being the station to initiate a price increase. We applied fixed effects logit regression as well as random effects logit and probit regression for analyzing why a particular gasoline station decides to jump up its price. Second, we present results on factors that determine the strength of the price increase of each initiating station. We applied a fixed effects Poisson regression for analyzing how much a gasoline station increases its price.

6.1 Factors that determine the likelihood of being the price increaser

Table 6 shows results for the conditional fixed effects logit regression. Due to limited calculation capacity,[6] we had to limit the time to four months and present results for the first four months of both years.

We limit ourselves to one local market, so station characteristics, location parameters, and brands' market power do not change in the data set. Thus, 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.

There is a negative effect of the price difference on a price increasing station before the price jump. Thus, higher the prices of the competition the lower the probability is that the gasoline station raises its price. The effect is statistically significant at the 1 percent confidence level in 2018, and at the 0.1 percent confidence level in 2019. A 1 cpl higher price by the competition lowers the probability of a gasoline station to increase their price by 1 to 3 percentage points. This matches economic intuition, as we expect gasoline stations to be more likely to raise their prices to initiate a new cycle when most competitors already undercut their prices, when the price level is in the trough.

Similarly, the coefficient of the price difference variable, weighted by the time duration for which prices of competitors were valid before the price jump, is negative and statistically

[5] According to the one-sided Z-test and T-test, the average number of cycles per day is 5.49 on weekends (Saturday and Sunday), which is higher than the mean of 4.99 on weekdays. Similarly, the average number of cycles on holidays is 5.22, which is also higher. These tests are significant at the 1 percent confidence level.

[6] Using all time periods (January 2018 to December 2019) leads Stata to report the error (1400) that the "combinations results 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 time period to the first three months of each year and obtain very similar results respectively.

significant at the 5 percent and 0.1 percent confidence level for 2018 and 2019, respectively. The remaining variables are not significantly different from zero. As expected, there is no significant effect on any particular day of the week. Therefore, the likelihood of price jumps is the same no matter what day it is. The same applies to public holidays and school holidays in Lower Saxony. Overall, these estimation results leave no doubt that price plays a minor role in gasoline stations' decision whether to be the first to initiate a new price cycle through raising their prices.

Table 6: Fixed Effects Logit Estimation

	Logit, Jan-April, 2018	ME	Logit, Jan-April, 2019	ME
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.				
Price difference to price increaser, before jump	-0.051*	-0.013	-0.122***	-0.03
	(0.020)		(0.02)	
Price difference * duration; measured in machine hours	-0.016	-0.004	-0.033***	-0.008
	(0.009)		(0.009)	
Price observation occurred Tuesday?	0.016	0.004	-0.034	-0.008
	(0.104)		(0.101)	
Price observation occurred Wednesday?	-0.011	-0.003	-0.062	-0.016
	(0.100)		(0.108)	
Price observation occurred Thursday?	-0.035	-0.009	-0.032	0.008
	(0.1)		(0.104)	
Price observation occurred Friday?	0.003	0.001	-0.031	-0.008
	(0.101)		(0.103)	
Price observation occurred Saturday?	0.014	0.004	-0.071	-0.018
	(0.099)		(0.107)	
Price observation occurred Sunday?	0.034	0.009	0.004	0.001
	(0.101)		(0.108)	
Lower Saxony school holidays extended	0.045	0.011	0.028	0.007
	(0.061)		(0.063)	
Observations	38052		32162	
AIC	9823.5		9167.4	
BIC	9900.5		9242.8	
chi2type	LR		LR	
chi2	34.045		162.135	
p	0.000		0.000	

Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means (ME) in column to the right of the coefficients respectively.

Next, we present the results of random effects conditional probit models, in Table 7. Analogous random effects conditional logit models are moved to Appendix Table 2. We compared different model specifications and decided on a table entry based on Akaike's (AIC) and Schwarz's Bayesian (BIC) information criteria. Furthermore, we report the number of observations. We use the service index instead of single services because there are only 26 gasoline stations in the data set and including all dummies for services offered might lead to collinearity problems.

Overall, the coefficients of time-varying variables and their signs are similar to the results in Table 6. Most coefficients are statistically significant at the 0.1 percent confidence level. We present coefficients of the model accounting for single brands in the far left column (column 1), flanked on the right by a column with standard errors, and another column to the right with marginal effects at means. Column 4 contains model specification accounting for single days of the week for non-oligopoly brands, with further columns showing the associated standard errors and marginal effects at means.

There is no statistically significant effect on the price difference of the price-increasing station before the price jump. However, the coefficient of this variable, weighted by the time duration for which the price is valid, is statistically significant at the 0.1 percent confidence level and negative. Overall, the effect of the price difference is again small.

Looking at geographic effects, we see that gasoline stations located on federal roads are between 0.8 and 5.1 percentage points more likely to initiate a new price cycle, and a stations located in rural areas are between 0.4 and 3.5 percentage points less likely. Similar to the fixed effects logit results, there are no significant day of the week effects.

For the Probit 2 case, the consumer satisfaction effect is negative and statistically significant at the 1 percent confidence level. A one-star higher consumer satisfaction rating (values from 1 = not satisfied to 5 = satisfied) is associated with 4 percentage points lower probability of being the station to increase prices first. In the Probit 1 case, however, the sign is different and the marginal effect goes toward zero. Note that causality may run in the opposite direction here.[7]

Brand affiliation explains the likelihood of price jumps relatively well. If we account for days of the week as well as brand categories (Probit 2), we see that gasoline stations belonging to the premium brand Aral are about 4.9 percentage points more likely to raise their prices to initiate a new price cycle than are stations belonging to the superregional player, JET – the baseline brand. Shell gasoline stations are 8.4 percentage points more likely to initiate a new price cycle, and the Esso gasoline station is about 7 percentage points more likely to initiate. Superregional players are only about 2.9 percentage points more likely to initiate a new price cycle. Turning to the preferred[8] model (Probit 1) in which we account for brands separately and leave weekdays aside, the three premium brands Aral, Shell, and

[7] Note, a reputation is built over the long run and, hence, causality likely runs the other direction than could be wrongly assumed from looking only at these results.
[8] Based on AIC and BIC, Probit 1 is the preferred model.

Esso are between 10.4 and 12.7 percentage points more likely to initiate a new price cycle compared to regional players.

Table 7: Random Effects Probit Estimation

	Probit 1	SE 1	ME 1	Probit 2	SE 2	ME 2
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Price difference to price increaser, before jump	-0.036	(0.036)	|-0.001|	-0.036	(0.035)	|-0.001|
Price difference * duration; measured in machine hours	-0.018***	(0.005)	|-0.000|	-0.018***	(0.004)	|-0.000|
In sight?	-0.078	(.)	|-0.002|	-1.286	(.)	|-0.034|
Located near Motorway?	0.998	(.)	|0.028|	0.173	(0.195)	|0.005|
Located at Federal Road?	0.268***	(0.033)	|0.008|	1.958***	(0.032)	|0.051|
Stations in rural area?	-0.149**	(0.050)	|-0.004|	-1.322***	(0.038)	|-0.035|
Price observation occurred Tuesday?				-0.004	(0.017)	|-0.000|
Price observation occurred Wednesday?				-0.002	(0.012)	|-0.000|
Price observation occurred Thursday?				-0.003	(0.023)	|-0.000|
Price observation occurred Friday?				-0.004	(0.019)	|-0.000|
Price observation occurred Saturday?	-0.000	(0.021)	|-0.000|	-0.003	(0.023)	|-0.000|
Price observation occurred Sunday?	0.025	(0.023)	|0.001|	0.022	(0.03)	|0.001|
Lower Saxony school holidays extended	0.011	(0.021)	|0.000|	0.011	(0.021)	|0.000|
Opening hours Saturday?	0.160***	(0.045)	|0.004|	0.296***	(0.008)	|0.008|
Opening hours Sunday/Public Holiday?	-0.125**	(0.043)	|-0.003|	-0.123***	(0.004)	|-0.003|
Aral	4.540***	(0.102)	|0.127|	1.877***	(0.067)	|0.049|
Shell	3.736***	(0.158)	|0.105|	3.216***	(0.053)	|0.084|
ESSO	3.725	(.)	|0.104|	2.677	(.)	|0.070|
Superregional non-oligopoly player?				1.121***	(0.057)	|0.029|
LTG	1.363***	(0.165)	|0.038|			
HEM	0.730	(0.401)	|0.020|			
STAR	3.613	(.)	|0.101|			
BFT	0.670***	(0.068)	|0.019|			
BLG	-1.218***	(0.212)	|-0.034|			
Freie Tankstelle	-0.716**	(0.259)	|-0.020|			
Consumer satisfaction?	0.125***	(0.030)	|0.004|	-1.449***	(0.020)	|-0.038|
Self service station?	1.344***	(0.235)	|0.038|	-0.873	(.)	|-0.023|
Station with Shop?	0.132*	(0.055)	|0.004|	-0.088*	(0.037)	|-0.002|
Station with Rewe-to-Go-Shop?	0.130***	(0.033)	|0.004|	-1.126***	(0.034)	|-0.029|
Bistro?	0.010	(0.026)	|0.000|	-0.508***	(0.023)	|-0.013|
In-Store-Backery?	-0.611***	(0.136)	|-0.017|	-1.504	(.)	|-0.039|
Number of accepted credit cards?	-0.781***	(0.03)	|-0.022|	-0.197***	(0.009)	|-0.005|
ATM?	1.288***	(0.117)	|0.036|	-1.685***	(0.078)	|-0.044|
Restrooms available?				0.207***	(0.037)	|0.005
Car Wash?				-2.176***	(0.028)	|-0.057|
Car repair?				-1.429***	(0.03)	|-0.037|
Vacuum cleaner?				-1.295***	(0.037)	|-0.034|
Constant	-3.645	(.)		2.109	(.)	
Observations	269328			269328		
AIC	69679.4			69689.3		
BIC	69910.5			69941.4		

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Probit 1: gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski", as well as services restrooms, car wash, repair, and vacuum cleaner omitted because of collinearity and "JET" as baseline; Probit 2: gasoline stations "Hoyer", "Raifeisen", "Freie Tankstelle Salewski", and "JET" omitted because of collinearity and NO2 as baseline.

Results analogously to Table 7 but based on logit estimation are very similar (see Appendix Table 2), except that marginal brand effects at means are a little smaller in magnitude. In summary, brand affiliation is the major explanatory factor for the occurrence of the cyclical price pattern in the German gasoline retail market.

The results of the fixed effects logit regression, as well as the results of random effects probit and 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. Results for linear probability and fixed effects regression are in Appendix Table 3.

6.2 Factors that determine the strength of the price increase of the price increaser

Finally, we present results of pooled Poisson, fixed effects Poisson, and time fixed effects Poisson estimates in Table 8. There are 11,586 price cycles over the time period of two years from 2018 to 2019. On average, gasoline stations initiating a new cycle increase the price by 5.19 cpl (Std. Dev. 1.66). Why is it important to analyze the magnitude of price jumps in the first place? Analyzing the magnitude of price jumps helps to identify which factors determine the size of the cycle. The size of the cycle 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 duration weighted price difference coefficient. The price coefficients still show no economically relevant effect.

All coefficients of the time fixed effects Poisson (Time FE Poisson) regression are statistically significant at the 0.1 percent confidence level, except the ones for BLG, LTG, consumer satisfaction, and motorway. Again, the price difference coefficients are economically irrelevant.

A station being located within sight of a competitor or in a rural area is associated on average with an almost 2 cpl weaker price increase. The negative effect that being located within sight of a competitor has on price increases is not surprising from a microeconomic point of view. If a gasoline station wants to initiate a new price cycle but the nearest competitor is in

sight, it would lose almost all demand to the cheaper competitor. Thus, it does not dare raise the price by too much, if it does at all.

Table 8: Pooled Poisson and Fixed Effects Poisson

	Pooled Poisson		FE Poisson		Time FE Poisson	
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e. difference between new and old price. In euro cents per liter (cpl).						
Price increasing value						
Price difference to price increaser, before jump	-0.071***	(0.003)	-0.074	(0.051)	-0.191***	(0.013)
Price difference * duration; measured in machine hours	-0.032***	(0.002)	-0.031***	(0.007)	-0.028***	(0.003)
In sight?	-1.706***	(0.099)			-1.649***	(0.101)
Located near Motorway?	-0.617**	(0.225)			-0.639**	(0.225)
Located at Federal Road?	2.439***	(0.086)			2.477***	(0.087)
Stations in rural area?	-1.853***	(0.079)			-1.857***	(0.079)
Price observation occurred Tuesday?	-0.001	(0.036)	-0.001	(0.031)		
Price observation occurred Wednesday?	-0.012	(0.036)	-0.012	(0.020)		
Price observation occurred Thursday?	-0.012	(0.036)	-0.013	(0.036)		
Price observation occurred Friday?	-0.011	(0.035)	-0.011	(0.028)		
Price observation occurred Saturday?	0.017	(0.036)	0.015	(0.03)		
Price observation occurred Sunday?	0.035	(0.036)	0.033	(0.051)		
Lower Saxony school holidays extended	0.030	(0.020)	0.032	(0.040)		
Opening hours Saturday?	0.497***	(0.027)			0.494***	(0.027)
Opening hours Sunday/Public Holiday?	-0.256***	(0.024)			-0.246***	(0.024)
Aral	3.326***	(0.095)			3.605***	(0.097)
Shell	3.848***	(0.102)			3.983***	(0.104)
ESSO	1.372***	(0.198)			1.575***	(0.199)
LTG	-0.237	(0.332)			-0.210	(0.333)
HEM	-1.557***	(0.343)			-1.595***	(0.343)
STAR	-0.373	(0.276)			-0.295	(0.277)
BFT	3.380***	(0.101)			3.439***	(0.103)
BLG	0.007	(0.112)			0.108	(0.113)
Freie Tankstelle	1.102***	(0.106)			1.322***	(0.108)
Consumer satisfaction?	0.015	(0.059)			0.025	(0.062)
Number of services offered	-0.366***	(0.016)			-0.358***	(0.016)
Constant	-8.578***	(0.364)				
Observations	269501		269501		247367	
AIC	299274.5		290308.0		246268.8	
BIC	299558.2		290402.5		246466.7	
chi2type	Wald		Wald		Wald	
chi2	9703.736		143.045		10341.963	

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski" omitted because of collinearity and "JET" as base.

When located near a motorway, a gasoline station's price increase is almost 1 cpl weaker on average. This effect is statistically significant at the 1 percent confidence level. In contrast,

gas stations located on federal roads increase their prices by an average of 2.5 cpl more. Economically, the time a station opens has little effect on price setting.

Again, brand affiliation plays a major role in explaining the magnitude of price jumps. The oligopoly players Aral, Shell, and ESSO increase their prices by about 3.6, 4, and 1.6 cpl more respectively, compared to JET. The other superregional players (LTG, HEM, and STAR) increase prices by a smaller amount than JET, while gasoline stations belonging to BFT increase their prices by about 3.4 cpl more. BLG's price increases do not differ significantly from those of JET. The price increases by Freie Tankstelle are about 1.3 cpl larger in magnitude. Overall, the 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 each cycle. BFT is the only non-oligopoly superregional player that seems to mimic this behavior.

The consumer satisfaction coefficient is statistically insignificant. If a gasoline station offers one more service, it increases the price on average by about 0.4 cpl less. This result matches economic intuition, according to which gasoline stations relying more heavily on services and the sale of by-products to generate profits are less motivated to increase their prices.

Results for the pooled Poisson regression are similar to the fixed effects Poisson regressions. Overall, location characteristics and brand affiliation are the most important factors determining the strength of a price increase. Actual price plays a minor role in explaining the strength of price increases.

7 Robustness Checks

As mentioned before, two gasoline stations ceased operations in 2019 (an ARAL station in Brietlingen and a Raiffeisen station in Barendorf). This could possibly distort results, as discussed in Wein (2021). We present robustness checks that exclude these gasoline stations from the data set in Table 9. There are no notable changes compared to the reference model from Table 7, Probit 1.

Generally, the first round of price increases of 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. Moreover, we believe, that the restrictive identification mechanism for relevant price-increasing events prevents us from

running into false cycles. Recall, we define a price-increasing event as the first price jump after a series of at least five price decreases. If we define a false price increase as one in which none of the five subsequent price changes (at any gasoline station) is positive, 644 of 11,586 (about 0.06 percent) price-increasing events are false price increases.

Furthermore, observations of prices changes in the late evening hours may distort results because competition patterns change as gasoline stations close. We include a robustness check excluding observations that occur after 9 p.m.[9] and one limited to the first 25 cycles of each day.[10] The robustness checks in Table 9 show that there are no notable differences if only observations until 9 p.m. are taken into account, or if the number of cycles is limited to the first 25 cycles of each day.

To recap, we focus on the Lueneburg and surrounding area gasoline market. We 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 Table 9, 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 neglecting the topography of the area. This drastically limits the number of gasoline stations to 15. Therefore, it is no surprise that estimation results are somewhat different. Many station characteristics had to be excluded due to collinearity.

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

[10] We look at 728 days of data with an average of 5.06 cycles per day between 8 a.m. and 22 p.m. with a standard deviation of 1.53, a minimum of 3, and a maximum of 11 cycles per day. However, many cycles are initiated by several gasoline stations raising their prices at the same time and, as mentioned earlier, we act as if each of these increases is a time period (or 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 11,586 cycles in the data set with an average of 15.92 cycles per day (sd=6.34, min=4, max=38). We chose this definition as it is more appropriate for the research question because we do not randomly exclude any of the gasoline stations that raised prices simultaneously with other stations. We present estimations with a limited number of cycles (25) to show that results do not change when taking away some of the cycles. When only keeping the first 25 price increases, and looking at the 728 days of data, we find there are on average 4.98 cycles per day (sd=1.47, min=3 and max=11).

Table 9: Robustness Checks – Random Effects Probit Estimation

	Reference estimates from Table 7 (Probit 1)	Without Aral-Brietlingen, Raiffeisen-Barendorf	Only observations before 9pm	Only the first 25 cycles	Only town area of Lueneburg	Latest price decrease 6 minutes before price jump	Distance weighted price differences	Price increases of at least 2 cpl
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.								
Price difference to price increaser, before jump	-0.036	-0.033	-0.035	-0.037	-0.037***	-0.035	-0.14*	-0.027
	(0.036)	(0.037)	(0.035)	(0.036)	(0.005)	(0.036)	(0.057)	(.)
	|-0.001|	|-0.001|	|-0.001|	|-0.001|	|-0.002|	|-0.001|	|-0.005|	|-0.001|
Price difference * duration; measured in machine hours	-0.018***	-0.016***	-0.017***	-0.017***	-0.017***	-0.018***		-0.018***
	(0.005)	(0.005)	(0.005)	(0.0048)	(0.002)	(0.005)		(0.000)
	|-0.000|	|-0.001|	|-0.000|	|-0.000|	|-0.001|	|-0.001|		|-0.000|
In sight?	-0.078	-0.088	-0.116	-0.087	0.247**	-0.077	-0.345	-0.542***
	(.)	(.)	(.)	(.)	(0.075)	(.)	(1.519)	(0.002)
	|-0.002|	|-0.003|	|-0.003|	|-0.002|	|0.014|	|-0.002|	|-0.012|	|-0.014|
Located near Motorway?	0.998	0.981	0.972***	0.952	-1.252***	0.961**	0.088	0.637***
	(.)	(.)	(0.226)	(.)	(0.093)	(0.311)	(.)	(0.003)
	|0.028|	|0.030|	|0.026|	|0.027|	|-0.070|	|0.028|	|0.003|	|0.016|
Located at Federal Road?	0.268***	0.27	0.303***	0.262***	0.000	0.254***	0.631	0.382***
	(0.033)	(0.299)	(0.027)	(0.034)	(.)	(0.026)	(1.553)	(0.001)
	|0.008|	|0.008|	|0.008|	|0.007|	||	|0.007|	|0.022|	|0.010|
Stations in rural area?	-0.149**	-0.146	-0.141	-0.142**	0.000	-0.142***	-0.484	-0.138***
	(0.050)	(0.368)	(0.076)	(0.052)	(.)	(0.034)	(1.497)	(0.001)
	|-0.004|	|-0.004|	|-0.004|	|-0.004|	||	|-0.004|	|-0.017|	|-0.003|
Price observation occurred Saturday?	-0.000	-0.004	-0.006	-0.001	0.002	-0.004	0.005	-0.001
	(0.021)	(0.021)	(0.022)	(0.021)	(0.018)	(0.021)	(0.022)	(0.021)
	|-0.000|	|-0.001|	|-0.000|	|-0.000|	|0.000|	|-0.000|	|0.000|	|-0.000|
Price observation occurred Sunday?	0.025	0.016	0.027	0.025	0.008	0.022	0.028	0.018
	(0.023)	(0.023)	(0.020)	(0.021)	(0.017)	(0.024)	(0.025)	(0.025)
	|-0.001|	|0.000|	|0.001|	|0.001|	|0.000|	|0.001|	|0.001|	|0.000|
Lower Saxony school holidays extended	0.011	0.001	-0.004	0.011	0.003	0.012	0.011	0.011
	(0.021)	(0.021)	(0.020)	(0.023)	(0.013)	(0.021)	(0.023)	(0.021)

Table 9: Robustness Checks – Random Effects Probit Estimation

	Reference estimates from Table 7 (Probit 1)	Without Aral-Brietlingen, Raiffeisen-Barendorf	Only observations before 9pm	Only the first 25 cycles	Only town area of Lueneburg	Latest price decrease 6 minutes before price jump	Distance weighted price differences	Price increases of at least 2 cpl
	|0.000|	|0.000|	|-0.000|	|0.000|	|0.000|	|0.000|	|0.000|	|0.000|
Opening hours Saturday?	0.160***	0.157**	0.156***	0.152**	-14.168***	0.15***	0.181	0.046***
	(0.045)	(0.054)	(0.020)	(0.05)	(0.683)	(0.034)	(0.177)	(0.001)
	|0.004|	|0.005|	|0.004|	|0.004|	|-0.797|	|0.004|	|0.006|	|0.001|
Opening hours Sunday/Public Holiday?	-0.125**	-0.122*	-0.122***	-0.119*	12.633***	-0.117***	-0.083	-0.032***
	(0.043)	(0.051)	(0.016)	(0.046)	(0.602)	(0.024)	(0.16)	(0.001)
	|-0.003|	|-0.004|	|-0.003|	|-0.003|	|0.711|	|-0.003|	|-0.003|	|-0.001|
Aral	4.540***	4.473***	4.379***	4.394***	0.420***	4.403***	1.289	2.429***
	(0.102)	(0.585)	(0.158)	(0.156)	(0.08)	(0.237)	(1.891)	(0.012)
	|0.127|	|0.137|	|0.116|	|0.125|	|0.024|	|0.127|	|0.044|	|0.061|
Shell	3.736***	3.655***	3.570***	3.570***	0.933***	3.592***	1.578	1.096***
	(0.158)	(0.466)	(0.164)	(0.263)	(0.102)	(0.393)	(1.860)	(0.011)
	|0.105|	|0.112|	|0.094|	|0.101|	|0.052|	|0.104|	|0.054|	|0.028|
ESSO	3.725	3.637	3.424	3.503	-13.107***	3.567	0.667	0.825***
	(.)	(.)	(.)	(.)	(0.718)	(.)	(.)	(0.012)
	|0.104|	|0.111|	|0.091|	|0.100|	|-0.737|	|0.103|	|0.023|	|0.021|
LTG	1.363***	1.314**	1.278***	1.268***	-3.134***	1.282***	0.358	-0.111***
	(0.166)	(0.450)	(0.173)	(0.196)	(0.211)	(0.254)	(2.818)	(0.007)
	|0.038|	|0.040|	|0.034|	|0.036|	|-0.176|	|0.037|	|0.012|	|-0.003|
HEM	0.73	0.644	0.723	0.630	-1.665***	0.61	-0.074	-1.177***
	(0.401)	(0.867)	(0.402)	(0.579)	(0.127)	(0.932)	(.)	(0.008)
	|0.020|	|0.020|	|0.019|	|0.018|	|-0.094|	|0.018|	|-0.003|	|-0.030|
STAR	3.613	3.541***	3.456	3.458	11.581***	3.487	0.233	0.952***
	(.)	(0.724)	(.)	(.)	(0.539)	(.)	(.)	(0.011)
	|0.101|	|0.108|	|0.091|	|0.098|	|0.651|	|0.101|	|0.008|	|0.024|
BFT	0.670***	0.680*	0.681***	0.672***	-1.291***	0.675***	1.275	0.715***
	(0.068)	(0.326)	(0.118)	(0.071)	(0.173)	(0.149)	(1.963)	(0.001)
	|0.019|	|0.021|	|0.018|	|0.019|	|-0.073|	|0.019|	|0.044|	|0.018|
BLG	-1.218***	-1.169**	-1.081***	-1.123***	-0.509***	-1.139***	-0.084	0.142***
	(0.212)	(0.387)	(0.065)	(0.242)	(0.074)	(0.067)	(2.082)	(0.006)

Table 9: Robustness Checks – Random Effects Probit Estimation

	Reference estimates from Table 7 (Probit 1)	Without Aral-Brietlingen, Raiffeisen-Barendorf	Only observations before 9pm	Only the first 25 cycles	Only town area of Lueneburg	Latest price decrease 6 minutes before price jump	Distance weighted price differences	Price increases of at least 2 cpl
	|-0.034|	|-0.036|	|-0.029|	|-0.032|	|-0.029|	|-0.033|	|-0.003|	|0.004|
FreieT	-0.716**	-0.669	-0.569***	-0.618*	0.000	-0.637***	0.463	0.964***
	(0.259)	(0.387)	(0.106)	(0.278)	(.)	(0.095)	(2.207)	(0.005)
	|-0.020|	|-0.020|	|-0.015|	|-0.018|	||	|-0.018|	|0.016|	|0.024|
Consumer satisfaction?	0.125***	0.117	0.098*	0.103**	0.158	0.117*	-0.619	-0.386***
	(0.030)	(0.55)	(0.040)	(0.034)	(0.121)	(0.054)	(0.603)	(0.003)
	|0.004|	|0.004|	|0.003|	|0.003|	|0.009|	|0.003|	|-0.021|	|-0.010|
Self service station?	1.344***	1.308*	1.268	1.282***	0.000	1.273		0.082***
	(0.235)	(0.517)	(.)	(0.254)	(.)	(.)		(0.006)
	|0.038|	|0.040|	|0.034|	|0.036|	||	|0.037|		|0.002|
Station with Shop?	0.132*	0.145	0.171**	0.153**	0.000	0.131		0.405***
	(0.055)	(0.151)	(0.058)	(0.056)	(.)	(0.109)		(0.002)
	|0.004|	|0.004|	|0.005|	|0.004|	||	|0.004|		|0.010|
Station with Rewe-to-Go-Shop?	0.13***	0.125	0.107*	0.114***	0.136	0.125*		-0.324***
	(0.033)	(0.432)	(0.046)	(0.034)	(0.087)	(0.056)		(0.002)
	|0.004|	|0.004|	|0.003|	|0.003|	|0.008|	|0.004|		|-0.008|
Bistro?	0.010	0.008	0.005	0.006	0.000	0.010		-0.145***
	(0.026)	(0.085)	(0.047)	(0.027)	(.)	(0.040)		(0.001)
	|0.000|	|0.000|	|0.000|	|0.000|	||	|0.000|		|-0.004|
In-Store-Backery?	-0.611***	-0.613	-0.600***	-0.605***	0.000	-0.617		-0.176***
	(0.136)	(.)	(0.148)	(0.129)	(.)	(.)		(0.000)
	|-0.017|	|-0.019|	|-0.016|	|-0.017|	||	|-0.018|		|-0.004|
Number of accepted credit cards?	-0.781***	-0.767***	-0.749***	-0.750***	0.000	-0.753***		-0.319***
	(0.03)	(0.068)	(0.02)	(0.041)	(.)	(0.032)		(0.002)
	|-0.022|	|-0.023|	|-0.020|	|-0.021|	||	|-0.022|		|-0.008|
ATM?	1.288***	1.318***	1.194***	1.277***	0.000	1.307***		1.538***
	(0.117)	(0.370)	(0.104)	(0.151)	(.)	(0.237)		(0.001)
	|0.036|	|0.040|	|0.032|	|0.036|	||	|0.038|		|0.039|
Distance weighted price differences to nearest station, before jump							0.008	
							(0.045)	

Table 9: Robustness Checks – Random Effects Probit Estimation

	Reference estimates from Table 7 (Probit 1)	Without Aral-Brietlingen, Raiffeisen-Barendorf	Only observations before 9pm	Only the first 25 cycles	Only town area of Lueneburg	Latest price decrease 6 minutes before price jump	Distance weighted price differences	Price increases of at least 2 cpl
Distance weighted price differences to second nearest station, before jump							|0.000| 0.074 (0.038)	
Distance weighted price differences to third nearest station, before jump							|0.003| -0.042 (0.042)	
Number of services offered							|-0.001| -0.345 (0.223)	
Constant	-3.645 (.)	-3.557 (2.3343)	-3.537 (.)	-3.512 (.)	34.535*** (2.3311)	-3.551 (.)	|-0.012| -1.408 (3.91)	-1.258*** (0.009)
Observations	269328	247226	268303	259929	142830	262823	269328	243306
AIC	69679.4	67852.9	65600.7	67553.1	56636.9	69198.4	69454.2	62254.2
BIC	69910.5	68082.1	65852.7	67783.4	56844.2	69428.9	69674.8	62389.4

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski", as well as services restrooms, car wash, repair, and vacuum cleaner omitted because of collinearity and "JET" as baseline.

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 6 minutes before the price jump, as done in Wein (2021). This new identification mechanism for price jumps accounts for the fact that gasoline stations only have to transmit price changes within five minutes to the MTU. The new estimates are very similar to the reference model, as shown in Table 9.

Prices of competitors located near the initiating station may play a decisive role in explaining why the particular gasoline station is the one to increase prices first. We present results of estimates that include distance weighted price differences between the initiating station and the three nearest competitors in Table 9. Surprisingly, there are no significant effects.

Finally, we show estimation results that include only price increases of 2 cpl or more. In terms of the effect direction as well as the statistical significance, the results do not change. Only the strength of the estimated effects seems to be lower when excluding price increases of 1 cpl.

Overall, the results of our robustness checks are consistent with the estimates discussed above, except that the estimates included only gasoline stations in the town of Lueneburg and those with distance weights.

Although the market for petrol and the market for diesel are considered strictly separate, previous research shows that estimation results and market mechanics are the same for the different types of fuels (Linder 2018; Haas 2019; Neukirch and Wein 2019; Kahl 2020). We present the result of estimates similar to the ones in Tables 5 and 6, but for the different fuel types in Table 10 and 11 respectively.[11]

Fixed effects logit estimates for diesel are very similar to the ones for petrol E5; however, estimates for the fuel type petrol E10 are statistically insignificant and the regression model provides no better fit to the data than an empty model. Results for 2019 are similar and much more homogenous. All regression models provide a better fit to the data than a model that contains no independent variables (Appendix Table 4).

[11] Results of the fixed effects logit regression for 2019 in Appendix Table 4.

Table 10: Different Fuel Types - Fixed Effects Logit Estimation (Jan-Apr, 2018)

	FE Logit E5	ME E5	FE Logit E10	ME E10	FE Logit Diesel	ME Diesel
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Price difference to price increaser, before jump	-0.0506*	-0.013	-0.0287	-0.007	-0.0710***	-0.018
	(0.0202)		(0.0180)		(0.0175)	
Price difference * duration; measured in machine hours	-0.0159	-0.004	-0.00601	-0.002	-0.0171*	-0.004
	(0.00851)		(0.00725)		(0.00730)	
Price observation occurred Tuesday?	0.0162	0.004	0.000133	0.000	0.00395	0.001
	(0.104)		(0.105)		(0.101)	
Price observation occurred Wednesday?	-0.0108	-0.003	-0.0181	-0.005	0.0319	0.008
	(0.100)		(0.101)		(0.0984)	
Price observation occurred Thursday?	-0.0345	-0.009	0.00699	0.002	0.00719	0.002
	(0.0996)		(0.0987)		(0.0979)	
Price observation occurred Friday?	0.00301	0.001	0.00259	0.001	-0.0136	-0.003
	(0.101)		(0.101)		(0.100)	
Price observation occurred Saturday?	0.0141	0.004	0.0371	0.009	0.0301	0.008
	(0.0986)		(0.0977)		(0.0993)	
Price observation occurred Sunday?	0.0342	0.009	0.0131	0.003	0.0108	0.003
	(0.101)		(0.102)		(0.103)	
Lower Saxony school holidays extended	0.0452	0.011	0.0473	0.012	0.0640	0.016
	(0.0611)		(0.0612)		(0.0600)	
Observations	38052		34610		41182	
AIC	9823.5		9833.3		10388.9	
BIC	9900.5		9909.4		10466.5	
chi2type	LR		LR		LR	
chi2	34.045		10.930		66.765	
p	0.000		0.281		0.000	

Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means (ME) in column to the right of the coefficients respectively.

Estimation results from random effects probit regression are very similar for markets for all fuel types (Table 11). Estimated effects for services and brand affiliation are especially more pronounced in the markets for diesel and petrol E10 when using the random effects probit approach. Throughout this paper, we present the most conservative results by focusing on the market for petrol E5.

These robustness checks support our result from above. Namely, price plays a minor role in gasoline stations' decision whether to be the first to raise prices and initiate a new price cycle. Overall, our results are valid for the Lueneburg market for the three most common fuel types.

Table 11: Different Fuel Types – Random Effects Probit Estimation

	Probit E5	ME E5	Probit Diesel	ME Diesel	Probit E10	ME E10
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Price difference to price increaser, before jump	-0.036	-0.001	-0.048***	-0.001	-0.027***	-0.001
	(0.036)		(0.004)		(0.003)	
Price difference * duration; measured in machine hours	-0.018***	-0.000	-0.015***	-0.000	-0.007***	-0.000
	(0.005)		(0.002)		(0.001)	
In sight?	-0.078	-0.002	0.268	0.008	0.377	0.012
	(.)		(0.329)		(0.347)	
Located near Motorway?	0.998	0.028	1.924***	0.057	1.585***	0.048
	(.)		(0.476)		(0.475)	
Located at Federal Road?	0.268***	0.008	0.324*	0.010	0.138	0.004
	(0.033)		(0.135)		(0.140)	
Stations in rural area?	-0.149**	-0.004	-0.296**	-0.009	-0.173	-0.005
	(0.050)		(0.097)		(0.099)	
Price observation occurred Saturday?	-0.000	-0.000	-0.004	-0.000	-0.003	-0.000
	(0.021)		(0.015)		(0.015)	
Price observation occurred Sunday?	0.025	0.001	0.009	0.000	0.017	0.001
	(0.023)		(0.015)		(0.015)	
Lower Saxony school holidays extended	0.011	0.000	0.01	0.000	0.009	0.000
	(0.021)		(0.011)		(0.011)	
Opening hours Saturday?	0.160***	0.004	0.403***	0.012	0.265*	0.008
	(0.045)		(0.115)		(0.112)	
Opening hours Sunday/Public Holiday?	-0.125**	-0.003	-0.316***	-0.009	-0.199*	-0.006
	(0.043)		(0.094)		(0.09)	
Aral	4.540***	0.127	8.258***	0.245	6.433***	0.196
	(0.102)		(1.926)		(1.905)	
Shell	3.736***	0.105	7.740***	0.230	5.886**	0.180
	(0.158)		(2.039)		(2.029)	
ESSO	3.725	0.104	8.173***	0.242	6.143**	0.188
	(.)		(2.270)		(2.260)	
LTG	1.363***	0.038	3.647**	0.108	2.711*	0.083
	(0.166)		(1.140)		(1.152)	
HEM	0.73	0.020	3.641*	0.108	2.255	0.069
	(0.401)		(1.476)		(1.459)	
STAR	3.613	0.101	7.169***	0.213	5.462**	0.167
	(.)		(1.885)		(1.878)	
BFT	0.670***	0.019	0.735***	0.022	0.736***	0.022
	(0.068)		(0.099)		(0.102)	
BLG	-1.218***	-0.034	-3.554**	-0.105	-2.597*	-0.079
	(0.212)		(1.227)		(1.217)	
Freie Tankstelle	-0.716**	-0.020	-3.418*	-0.101	-2.483	-0.076
	(0.259)		(1.405)		(1.406)	
Consumer satisfaction?	0.125***	0.004	0.784*	0.023	0.595	0.018
	(0.030)		(0.384)		(0.403)	
Self service station?	1.344***	0.038	3.286**	0.098	2.287*	0.070
	(0.235)		(1.036)		(1.017)	
Station with Shop?	0.132*	0.004	-0.096	-0.003	-0.199	-0.006
	(0.055)		(0.193)		(0.201)	
Station with Rewe-to-Go-Shop?	0.13***	0.004	0.653*	0.019	0.472	0.014
	(0.033)		(0.306)		(0.321)	
Bistro?	0.010	0.000	0.06	0.002	0.133	0.004
	(0.026)		(0.079)		(0.082)	
In-Store-Backery?	-0.611***	-0.017	-0.434***	-0.013	-0.615***	-0.019

Table 11: Different Fuel Types – Random Effects Probit Estimation

	Probit E5	ME E5	Probit Diesel	ME Diesel	Probit E10	ME E10
	(0.135)		(0.086)		(0.082)	
Number of accepted credit cards?	-0.781***	-0.022	-1.564***	-0.046	-1.194**	-0.036
	(0.03)		(0.400)		(0.396)	
ATM?	1.288***	0.036	1.201***	0.036	1.201***	0.037
	(0.117)		(0.113)		(0.111)	
Constant	-3.645		-7.265***		-5.954**	
	(.)		(1.949)		(2.026)	
Observations	269328		270397		269724	
AIC	69679.4		70340.3		70294.1	
BIC	69910.5		70655.5		70609.3	

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means (ME) in column to the right of Probit estimates; Probit: gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski", as well as services restrooms, car wash, repair, and vacuum cleaner omitted because of collinearity and "JET" as baseline; Time fixed effects at the day-round level.

Robustness checks analogous to Table 9 but for Poisson estimates are in Appendix Table 5. Poisson robustness checks for different fuel types are in Appendix Table 6. The Poisson results are similar to the fixed effects logit and random effects probit results robust with respect to different model specifications as well as different fuel types.

8 Threats to Validity

The overall research goal of this paper is to identify the relevant determinants that cause price cycles. Price cycles occur in some form all over the world 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, of course, change – especially in markets 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. Recording the single service variables on a daily basis would require a lot of effort, and locational changes, as well as brand changes, are rare in the German gasoline retail market (Wein 2021).

This results in a limited external validity of 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 the internal validity. Time, as well as an entity-fixed effects approach, ensure that we do not have to fear threats to internal validity from omitted variables. We present the results of a number of estimation techniques to fully capture the functional form. As complete data were available from the MTU and all prices of gasoline stations of the Lueneburg market enter the analysis, there is no problem with imprecise measurement or sample selection. Simultaneous causality is no issue here.[12]

9 Summary and Conclusion

Since August 2013, it has been mandatory for all gasoline retailers in Germany to report price changes of the most common fuel types within a few minutes to the MTU. There are more than 50 information service providers that are registered with the MTU who obtain price data and make it freely available. Most of these services can be accessed online or via phone applications. Utilizing these services, consumers can easily choose the cheapest gasoline station within a certain driving distance around their location. The information is not only useful to consumers, but also to the stations themselves, for whom it becomes much easier to monitor local competitor prices. From an economic perspective, one would expect gasoline stations to react very quickly to competitors' price changes.

As described by Wein (2021), gasoline prices in Germany fluctuate a lot over the course of 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 cycles are described in the literature 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 gasoline stations jump up with their prices initiating a new price cycle, and the other stations follow. Then undercutting begins again. We identify the gasoline station in the Lueneburg market which is the first to increase its price after a series of at least five price decreases. 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 initial increaser can respond by undercutting the competition again, and obtaining consumer surplus over the course of the price cycle. According to the Edgeworth cycle theory, such a

[12] We discussed reverse causality in context of interpreting the estimation results of the consumer satisfaction variable and explained why it is unlikely to cause problems in the estimation process.

price jump occurs because firms are following a mixed strategy between maintaining the lowest price and raising the price at the trough of the cycle, after the first gasoline station gives in and restores a higher price level.

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 occur if the gasoline station endured the trough of the cycle to continue the war of attrition. Those gasoline stations 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 shops or bistros to generate sales.

In order to show which stations are the first to raise prices during the trough, we use a publicly accessible data set that has been massively revised similarly to the one used by Wein (2021). We use the very same data set, which covers the years 2018 to 2019 almost completely, and is limited to the local market of the German town Lueneburg which consists of a maximum of 26 gasoline stations. Focusing on one region allows us to assume that the gasoline stations are in competition 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 event. Similar to Wein (2021), we build on the basic assumption that one second before the price increase event, all gasoline stations were facing the same price level, but only one gasoline station decided to raise its price. We format a panel unit that contains both the old and new prices of the price increaser, as well as all competitors' prices that were valid directly before the price increase event. 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 random effects probit, as well as fixed effects Poisson approaches, to test what distinguishes the price increaser 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 stations' pricing decisions. As we limit ourselves to one local market, gas station characteristics, location parameters, and brands' market power do not change in the data set.

The Edgeworth cycle theory is based on the assumption 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 gasoline stations' decision on whether to be the first to raise the price. In contrast, market structural factors play a relatively more important role. We used entity fixed effects regression to best identify the effects of price variables.[13] The statistically significant variables for price pressure show a vanishingly small economic effect on the likelihood of a gasoline station to raise the price to initiate a new price cycle. According to fixed effects logit estimates for petrol (E5) data, a 1 cent per liter higher price of the competition lowers the probability of a gasoline station to increase the price by at most 3 percentage points. This is similar to the effect of the number of services offered by a gasoline station. Throughout estimation approaches, the results indicate that offering one additional service is associated with a 1 to 2 percentage points lower probability of increasing the price.

In contrast, estimates from the random effects probit and logit approach[14] show that location parameters play a slightly larger role in explaining price jumps. Results from random effects probit regression show that a gasoline station located on a federal road is between 0.8 and 5.1 percentage points more likely to initiate a new price cycle, and a gasoline station located in a rural area is between 0.4 and 3.5 percentage points less likely. Similar to the fixed effects logit results, there are no significant day of the week effects.

According to random effects probit estimates, the three premium brands Aral, Shell, and Esso are between 10.4 and 12.7 percentage points more likely to initiate a new price cycle than the superregional player JET, which is the baseline brand, and 4.9 to 8.4 percentage points more likely to initiate raising prices than regional non-oligopoly players. Only estimation results for STAR are similar. Furthermore, fixed effects Poisson estimation results[15] 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. They increase the price by 3.6 to 4 cpl on average more than JET does. Only, the non-oligopoly superregional player BFT seems to mimic this behavior.

Overall, price considerations as well as services offered play a minor role in explaining why a gasoline station is the first to increase its price. Location parameters play a slightly larger

[13] Complete results of entity-fixed effects logit estimation approach in Table 6.
[14] Complete results of random effects probit and logit estimation are in Table 7 and Appendix Table 2.
[15] Complete results of Poisson estimation approaches are in Table 8.

role, but brand affiliation seems to play a major role. Brand affiliation and location parameters do not seem to be decisive either; however, these factors are much more important when it comes to a stations' decision to be the first to increase prices than are price considerations alone. 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 paper, we present the somewhat less pronounced results of the petrol E5 market. Estimation results for brand-specific effects are even larger when focusing on the market for diesel or petrol E10.

The results are robust to alternative model specifications. Excluding the two gasoline stations that ceased operations at the end of 2018 does not affect the results. The results are robust with respect to changes of the length of the day, e.g. dropping observations after 9 p.m. Requiring the latest price decrease to occur at least six minutes before the price increase also does not change the results. Excluding all price increases of 1 cpl affects only the strength of the estimates. Results change only if the data set is reduced to gasoline stations located inside the town of Lueneburg, and excluding the rural stations. This market definition is based on the historically evolved delineation of the town and neglects the topography of the area. Reducing the data set to stations inside the town limits the number of gasoline stations drastically to 15. Therefore, it is no surprise that estimation results are somewhat different. We present results of estimates that include distance weighted price differences to the three nearest competitors. Surprisingly, there are no significant effects.

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. Further research should also look at what happens shortly after a price increase. Other gasoline stations possibly react to the market situation in a similar way as the gas station that we identified to be the price increaser. These reactions are likely to occur shortly afterwards.

There is a risk to 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 lowering the price again. There is a similar risk to being the first gasoline station to follow the increaser. How many false starts on new price cycles were there 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, 644 of 11,586 (about 5.6 percent) price-increasing events are false price increases.

A brand with several gasoline stations in the market can coordinate its stations to jointly increase the prices, which reduces their risk of a false start because competitors face a lower risk of falling for a false start if half the market is already demanding higher prices. Thus, suppliers with market power should have a higher incentive to induce a new price cycle. Altogether, we believe that future empirical research should continue to focus on what drives cyclical pricing patterns in the retail gasoline market.

Appendix

Appendix Table 1: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Price	267654	140.074	6.085	122.9	167.9
Increasing price observation	267654	.041	.197	0	1
Magnitude of the price increase	267654	.211	1.079	0	30
Price difference to price increaser before jump	267654	-.286	2.255	-13	15
Duration	267654	.163	6.434	-91.138	228.023
Opening time	267654	3.171	3.092	0	9
Closing time	267654	22.793	1.478	14	24
Aral	267654	.18	.384	0	1
Shell	267654	.282	.45	0	1
ESSO JET	267654	.08	.271	0	1
Oligopoly	267654	.543	.498	0	1
NO1	267654	.312	.463	0	1
NO2	267654	.145	.353	0	1
In sight?	267654	.081	.272	0	1
Located at Federal Road?	267654	.241	.428	0	1
Located near Motorway?	267654	.037	.189	0	1
Car repair?	267654	.317	.465	0	1
Self service station?	267654	.221	.415	0	1
Station with Shop?	267654	.764	.425	0	1
Station with Rewe-to-Go Shop?	267654	.081	.273	0	1
ATM?	267654	.162	.368	0	1
Restrooms available?	267654	.556	.497	0	1
Number of accepted credit cards?	252507	3.611	1.923	0	5
Car wash?	267654	.439	.496	0	1
Bistro?	267654	.419	.493	0	1
Vacuum cleaner?	267654	.322	.467	0	1
In-Store-Bakery?	267654	.202	.401	0	1
Kiosk?	267654	.057	.231	0	1
Stations in rural area?	267654	.412	.492	0	1
Consumer satisfaction	252507	4.074	.346	3.4	4.8
Monday	267654	.15	.357	0	1
Tuesday	267654	.143	.35	0	1
Wednesday	267654	.148	.355	0	1
Thursday	267654	.149	.356	0	1
Friday	267654	.148	.355	0	1
Saturday	267654	.135	.341	0	1
Sunday	267654	.127	.333	0	1
Lower Saxony school holidays extended	267654	.326	.469	0	1
Opening hours Monday to Friday	267654	20.698	4.067	12	24
Opening hours Saturday	267654	20.34	4.842	6	24
Opening hours Sunday	267654	19.91	5.893	0	24
Price increase simultaneously?	267654	.225	1.166	0	10
Price increase simultaneously same brand?	267654	.13	.676	0	5

Appendix Table 2: Random Effects Logit Estimation

	Logit 1	Logit 1, SE	Logit 1, ME	Logit 2	Logit 2, SE	Logit 2, ME
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Price difference to price increaser, before jump	-0.0674	(0.0617)	|-0.001|	-0.0673	(0.0616)	|-0.001|
Price difference * duration; measured in machine hours	-0.0352***	(0.00977)	|-0.000|	-0.0352***	(0.00771)	|-0.000|
In sight?	-0.852*	(0.336)	|-0.007|	-3.052***	(0.479)	|-0.023|
Located near Motorway?	1.638	(5.382)	|0.013|	0.842	(.)	|0.006|
Located at Federal Road?	0.712*	(0.298)	|0.006|	4.947***	(0.509)	|0.037|
Stations in rural area?	-0.318	(0.213)	|-0.003|	-3.796***	(0.281)	|-0.029|
Price observation occurred Tuesday?				-0.00302	(0.0320)	|-0.000|
Price observation occurred Wednesday?				-0.00876	(0.0241)	|-0.000|
Price observation occurred Thursday?				-0.00800	(0.0447)	|-0.000|
Price observation occurred Friday?				-0.00309	(0.0348)	|-0.000|
Price observation occurred Saturday?	0.0153	(0.0363)	|0.000|	0.0108	(0.0390)	|0.000|
Price observation occurred Sunday?	0.0424	(0.0454)	|0.000|	0.0379	(0.0593)	|0.000|
Lower Saxony school holidays extended	0.0285	(0.0412)	|0.000|	0.0284	(0.0410)	|0.000|
Opening hours Saturday?	0.0974***	(0.0227)	|0.001|	0.583***	(0.00712)	|0.004|
Opening hours Sunday/Public Holiday?	-0.0699	(.)	|-0.001|	-0.117	(.)	|-0.001|
Aral	7.041***	(2.041)	|0.057|	3.906***	(0.201)	|0.029|
Shell	4.788***	(1.347)	|0.039|	9.164	(.)	|0.069|
ESSO	4.084	(.)	|0.033|	6.054	(.)	|0.046|
Superrigional non-oligopoly player?				3.181***	(0.414)	|0.024|
LTG	0.316	(0.601)	|0.003|			
HEM	-1.373	(.)	|-0.011|			
STAR	4.996	(.)	|0.041|			
BFT	1.499	(.)	|0.012|			
BLG	-0.0716	(0.727)	|-0.001|			
Freie Tankstelle	1.517	(.)	|0.012|			
Consumer satisfaction?	-0.614*	(0.307)	|-0.005|	-4.191***	(0.0364)	|-0.032|
Self service station?	0.874	(2.303)	|0.007|	-3.577***	(0.113)	|-0.027|
Station with Shop?	0.673	(1.586)	|0.005|	-1.331***	(0.150)	|-0.010|
Station with Rewe-to-Go-Shop?	-0.432*	(0.175)	|-0.004|	-3.290***	(0.0414)	|-0.025|
Bistro?	-0.153	(0.134)	|-0.001|	-0.910***	(0.260)	|-0.007|
In-Store-Backery?	-1.859	(2.420)	|-0.015|	-5.214***	(0.255)	|-0.039|
Number of accepted credit cards?	-1.072**	(0.399)	|-0.009|	-0.362***	(0.0403)	|-0.003|
ATM?	2.832***	(0.802)	|0.023|	-6.151	(.)	|-0.046|
Restrooms available?				0.0448	(0.262)	|0.000|
Car Wash?				-5.815***	(0.233)	|-0.044|
Car repair?				-4.182***	(0.110)	|-0.032|
Vacuum cleaner?				-3.383***	(0.165)	|-0.025|
Constant	-2.888	(.)		9.733	(.)	
Observations	269328			269328		
AIC	69687.2			69699.8		
BIC	69886.8			69951.9		

Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means in ||; Logit 1: gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski" , as well as services restrooms, car wash, repair, and vacuum cleaner omitted because of collinearity and "JET" as baseline; Logit 2: gasoline stations "Hoyer", "Raifeisen", "Freie Tankstelle Salewski", and "JET" omitted because of collinearity and NO2 as baseline; Wald test reported; likelihood-ration test not combinable with robust se.

Appendix Table 3: Linear Probability and Time Fixed Effects Estimation

	LPM		Time FE	
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.				
Price difference to price increaser, before jump	-0.0021***	(0.0001)	-0.0061***	(0.0004)
Price difference * duration; measured in machine hours	-0.0005***	(0.0000)	-0.0001**	(0.0000)
In sight?	-0.0599***	(0.0030)	-0.0594***	(0.0032)
Located near Motorway?	0.0115***	(0.0020)	0.0090***	(0.0021)
Located at Federal Road?	0.0913***	(0.0022)	0.0925***	(0.0022)
Stations in rural area?	-0.0684***	(0.0017)	-0.0687***	(0.0017)
Price observation occurred Tuesday?	-0.0001	(0.0013)		
Price observation occurred Wednesday?	-0.0002	(0.0013)		
Price observation occurred Thursday?	-0.0003	(0.0013)		
Price observation occurred Friday?	0.0000	(0.0013)		
Price observation occurred Saturday?	0.0008	(0.0014)		
Price observation occurred Sunday?	0.0015	(0.0014)		
Lower Saxony school holidays extended	0.0006	(0.0008)	0.0109	(0.0215)
Opening hours Saturday?	0.0179***	(0.0003)	0.0178***	(0.0003)
Opening hours Sunday/Public Holiday?	-0.0097***	(0.0003)	-0.0096***	(0.0003)
Aral	0.0565***	(0.0029)	0.0617***	(0.0030)
Shell	0.1305***	(0.0035)	0.1314***	(0.0035)
ESSO	0.0466***	(0.0026)	0.0479***	(0.0028)
LTG	0.0947***	(0.0023)	0.0925***	(0.0023)
HEM	0.0096***	(0.0019)	0.0066**	(0.0020)
STAR	0.0380***	(0.0018)	0.0357***	(0.0019)
BFT	0.0819***	(0.0035)	0.0793***	(0.0036)
BLG	-0.0258***	(0.0032)	-0.0243***	(0.0034)
Freie Tankstelle	0.0116**	(0.0045)	0.0214***	(0.0050)
Consumer satisfaction?	-0.0430***	(0.0018)	-0.0449***	(0.0019)
Number of services offered	-0.0191***	(0.0009)	-0.0189***	(0.0009)
Constant	0.0510***	(0.0089)	0.0534***	(0.0117)
Observations	269328		269328	
p	0.0000		0.0000	

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski" omitted because of collinearity and "JET" as baseline; time fixed effects at the day-round level.

Appendix Table 4: Different Fuel Types - Fixed Effects Logit Estimation (Jan-Apr, 2019)

	FE Logit E5	ME E5	FE Logit E10	ME E10	FE Logit Diesel	ME Diesel
Dependent variable: Increasing price observation: Dummy = 1 for increasing price observation and 0 for non-increasing price observation.						
Price difference to price increaser, before jump	-0.122***		-0.113***		-0.140***	
	(0.0197)		(0.0165)		(0.0209)	
Price difference * duration; measured in machine hours	-0.0329***		-0.0101		-0.0249**	
	(0.00928)		(0.00707)		(0.00903)	
Price observation occurred Tuesday?	-0.0336		0.000134		0.00335	
	(0.101)		(0.0996)		(0.102)	
Price observation occurred Wednesday?	-0.0623		-0.0736		-0.00918	
	(0.108)		(0.107)		(0.109)	
Price observation occurred Thursday?	-0.0316		-0.0333		0.00867	
	(0.104)		(0.103)		(0.106)	
Price observation occurred Friday?	-0.0310		-0.0163		-0.0448	
	(0.103)		(0.104)		(0.106)	
Price observation occurred Saturday?	-0.0713		-0.0173		0.0000549	
	(0.107)		(0.106)		(0.108)	
Price observation occurred Sunday?	0.00393		-0.0145		0.00940	
	(0.108)		(0.109)		(0.113)	
Lower Saxony school holidays extended	0.0281		0.00939		0.0362	
	(0.0633)		(0.0639)		(0.0643)	
Observations	32162		35099		33052	
AIC	9167.4		9312.7		9071.9	
BIC	9242.8		9388.9		9147.5	
chi2type	LR		LR		LR	
chi2	162.135		109.603		148.301	
p	0.000		0.000		0.000	

Standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; marginal effects at means (ME) in column to the right of the coefficients respectively.

Appendix Table 5: Robustness Checks - Time Fixed Effects Poisson

	Reference estimate from Table 8 (Time FE Poisson)	Without Aral-Brietlingen, Raiffeisen-Barendorf	Only observations before 9pm	Only the first 25 cycles	Only town area of Lueneburg	Latest price decrease 6 minutes before price jump	Distance weighted price differences	Price increases of at least 2 cpl
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e. difference between new and old price. In euro cents per liter (cpl).								
Price increasing value Price difference to price increaser, before jump	-0.191***	-0.191***	-0.193***	-0.191***	-0.191***	-0.191***	-0.393***	-0.168***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.016)	(0.013)	(0.011)	(0.014)
Price difference * duration; measured in machine hours	-0.028***	-0.028***	-0.022***	-0.027***	-0.034***	-0.028***		-0.03***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)		(0.003)
In sight?	-1.654***	-1.654***	-1.605***	-1.620***	0.328***	-1.654***	-1.624***	-1.550***
	(0.101)	(0.101)	(0.105)	(0.102)	(0.05)	(0.101)	(0.104)	(0.105)
Located near Motorway?	-0.624**	-0.624**	-0.578*	-0.625**	-3.407***	-0.624**	-1.011***	-0.468*
	(0.226)	(0.226)	(0.226)	(0.226)	(0.249)	(0.226)	(0.228)	(0.224)
Located at Federal Road?	2.484***	2.484***	2.422***	2.446***		2.484***	2.502***	2.384***
	(0.087)	(0.087)	(0.089)	(0.087)		(0.087)	(0.09)	(0.09)
Stations in rural area?	-1.862***	-1.862***	-1.739***	-1.824***		-1.862***	-1.911***	-1.777***
	(0.08)	(0.08)	(0.081)	(0.08)		(0.08)	(0.083)	(0.083)
Opening hours Saturday?	0.497***	0.497***	0.481***	0.491***	-30.36***	0.497***	0.527***	0.480***
	(0.027)	(0.027)	(0.028)	(0.028)	(1.760)	(0.027)	(0.028)	(0.026)
Opening hours Sunday/Public Holiday?	-0.249***	-0.249***	-0.247***	-0.246***	27.06***	-0.249***	-0.267***	-0.227***
	(0.025)	(0.025)	(0.025)	(0.025)	(1.558)	(0.025)	(0.025)	(0.024)
Aral	3.616***	3.616***	3.562***	3.592***	1.328***	3.616***	3.592***	3.628***
	(0.097)	(0.097)	(0.099)	(0.098)	(0.116)	(0.097)	(0.096)	(0.101)
Shell	3.997***	3.997***	3.774***	3.931***	1.816***	3.997***	3.932***	3.999***
	(0.104)	(0.104)	(0.107)	(0.105)	(0.116)	(0.104)	(0.103)	(0.108)
ESSO	1.591***	1.591***	1.249***	1.462***	-29.04***	1.591***	1.599***	1.177***
	(0.199)	(0.199)	(0.231)	(0.210)	(1.666)	(0.199)	(0.199)	(0.271)
LTG	-0.193	-0.193	-0.302	-0.234	-8.322***	-0.193	-0.192	-0.308
	(0.333)	(0.333)	(0.334)	(0.333)	(0.732)	(0.333)	(0.334)	(0.372)
HEM	-1.581***	-1.581***	-1.543***	-1.584***	-4.732***	-1.581***	-1.558***	-1.614***
	(0.343)	(0.343)	(0.343)	(0.343)	(0.430)	(0.343)	(0.343)	(0.362)

Appendix Table 5: Robustness Checks - Time Fixed Effects Poisson

	Reference estimate from Table 8 (Time FE Poisson)	Without Aral-Brietlingen, Raiffeisen-Barendorf	Only observations before 9pm	Only the first 25 cycles	Only town area of Lueneburg	Latest price decrease 6 minutes before price jump	Distance weighted price differences	Price increases of at least 2 cpl
STAR	-0.284	-0.284	-0.338	-0.303	23.55***	-0.284	-0.437	-0.580
	(0.277)	(0.277)	(0.278)	(0.277)	(1.499)	(0.277)	(0.278)	(0.341)
BFT	3.451***	3.451***	3.425***	3.435***	-3.115***	3.451***	3.350***	3.463***
	(0.103)	(0.103)	(0.104)	(0.103)	(0.297)	(0.103)	(0.104)	(0.107)
BLG	0.118	0.118	0.194	0.126	-1.652***	0.118	-0.095	-0.253
	(0.113)	(0.113)	(0.114)	(0.114)	(0.116)	(0.113)	(0.113)	(0.134)
Freie Tankstelle	1.330***	1.330***	1.376***	1.325***		1.330***	1.106***	1.081***
	(0.108)	(0.108)	(0.111)	(0.109)		(0.108)	(0.109)	(0.118)
Consumer satisfaction?	0.025	0.0253	-0.005	0.017	-0.011	0.025	0.148*	0.099
	(0.062)	(0.062)	(0.064)	(0.063)	(0.057)	(0.062)	(0.064)	(0.061)
Number of services offered	-0.359***	-0.359***	-0.337***	-0.354***	-0.026	-0.359***	-0.365***	-0.373***
	(0.016)	(0.016)	(0.017)	(0.017)	(0.023)	(0.016)	(0.017)	(0.017)
Distance weighted price differences to nearest station, before jump							0.058***	
							(0.004)	
Distance weighted price differences to second nearest station, before jump							0.132***	
							(0.005)	
Distance weighted price differences to third nearest station, before jump							-0.078***	
							(0.004)	
Observations	247216	247204	223402	238380	142774	247216	247216	222769
AIC	245975.1	245974.2	223330.3	239474.9	194977.2	245975.1	243816.3	236997.3
BIC	246173.1	246172.1	223526.3	239672.1	195135.1	246173.1	244035.1	237193.3
chi2type	Wald	Wald	Wald	Wald	Wald	Wald	Wald	Wald
chi2	10346.956	10345.193	8796.710	9850.051	8263.727	10346.956	10836.749	9166.166
p	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski" omitted because of collinearity and "JET" as base.

Appendix Table 6: Different Fuel Types - Pooled Poisson and Fixed Effects Poisson

	Pooled E10	FE E10	Time FE E10	Pooled Diesel	FE Diesel	Time FE Diesel
Dependent variable: Magnitude of the price increase: Measures by how much the increasing gasoline station raises its price, i.e. difference between new and old price. In euro cents per liter (cpl).						
Price increasing value						
Price difference to price increaser, before jump	-0.055***	-0.059	-0.146***	-0.1***	-0.099	-0.264***
	(0.003)	(0.054)	(0.012)	(0.003)	(0.056)	(0.015)
Price difference * duration; measured in machine hours	-0.01***	-0.011	-0.008***	-0.029***	-0.029***	-0.018***
	(0.001)	(0.006)	(0.002)	(0.002)	(0.004)	(0.003)
In sight?	-1.528***		-1.509***	-1.551***		-1.572***
	(0.095)		(0.096)	(0.097)		(0.1)
Located near Motorway?	-0.648**		-0.638**	-0.930***		-0.852***
	(0.211)		(0.212)	(0.239)		(0.239)
Located at Federal Road?	2.300***		2.361***	2.268***		2.299***
	(0.082)		(0.083)	(0.083)		(0.085)
Stations in rural area?	-1.798***		-1.824***	-1.736***		-1.734***
	(0.075)		(0.076)	(0.077)		(0.078)
Price observation occurred Tuesday?	0.013	0.013		0.003	0.003	
	(0.036)	(0.026)		(0.036)	(0.023)	
Price observation occurred Wednesday?	0.003	0.003		0.018	0.018	
	(0.036)	(0.022)		(0.035)	(0.032)	
Price observation occurred Thursday?	-0.012	-0.012		-0.000	-0.001	
	(0.036)	(0.043)		(0.035)	(0.032)	
Price observation occurred Friday?	-0.005	-0.005		0.001	-0.000	
	(0.036)	(0.058)		(0.035)	(0.027)	
Price observation occurred Saturday?	0.022	0.020		0.02	0.019	
	(0.036)	(0.045)		(0.036)	(0.035)	
Price observation occurred Sunday?	0.034	0.032		0.039	0.038	
	(0.036)	(0.023)		(0.036)	(0.032)	
Lower Saxony school holidays extended	0.029	0.031		0.022	0.022	
	(0.020)	(0.046)		(0.020)	(0.035)	
Opening hours Saturday?	0.489***		0.492***	0.489***		0.491***
	(0.026)		(0.026)	(0.019)		(0.019)
Opening hours Sunday/Public Holiday?	-0.243***		-0.237***	-0.248***		-0.245***
	(0.023)		(0.024)	(0.018)		(0.018)
Aral	3.061***		3.311***	3.202***		3.533***
	(0.094)		(0.096)	(0.092)		(0.095)
Shell	3.554***		3.631***	3.702***		3.925***
	(0.1)		(0.102)	(0.099)		(0.101)
ESSO	1.321***		1.535***	1.302***		1.503***
	(0.192)		(0.194)	(0.203)		(0.204)
LTG	-0.023		0.063	-0.268		-0.166
	(0.271)		(0.272)	(0.310)		(0.311)
HEM	-1.833***		-1.828***	-1.729***		-1.670***
	(0.360)		(0.360)	(0.360)		(0.360)
STAR	-0.626*		-0.514	-0.793**		-0.690*
	(0.314)		(0.315)	(0.282)		(0.282)
BFT	3.295***		3.345***	3.293***		3.341***

Appendix Table 6: Different Fuel Types - Pooled Poisson and Fixed Effects Poisson

	Pooled E10	FE E10	Time FE E10	Pooled Diesel	FE Diesel	Time FE Diesel
	(0.099)		(0.101)	(0.098)		(0.101)
BLG	-0.179		-0.133	-0.088		0.022
	(0.110)		(0.111)	(0.106)		(0.107)
Freie Tankstelle	0.599***		0.683***	0.991***		1.228***
	(0.103)		(0.104)	(0.102)		(0.104)
Consumer satisfaction?	0.092		0.093	-0.114		-0.314***
	(0.058)		(0.061)	(0.059)		(0.064)
Number of services offered	-0.341***		-0.343***	-0.376***		-0.402***
	(0.016)		(0.016)	(0.016)		(0.016)
Constant	-8.857***			-7.899***		
	(0.357)			(0.352)		
Observations	269878	269878	247054	270689	270689	249025
AIC	301265.9	292493.5	248105.6	303101.1	294332.8	249496.4
BIC	301549.6	292588.0	248303.5	303384.8	294427.4	249694.5
chi2type	Wald	Wald	Wald	Wald	Wald	Wald
chi2	9966.704	76.936	10410.047	10150.586	74.295	11048.821
p	0.000	0.000	0.000	0.000	0.000	0.000

Robust standard errors in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$; gasoline stations "Hoyer", "Raifeisen", and "Freie Tankstelle Salewski" omitted because of collinearity and "JET" as base.

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