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Competition on the Fast Lane - The Price Structure of Homogeneous Retail Gasoline Stations

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January 2021

Abstract

This paper studies the relationship between retail gasoline pricing strategies and potential demand. Utilising detailed data on traffic on the German *Autobahn* and the special case of *Bundesautobahntankstellen*, the interaction between demand and price competition is studied, as are the changes in competition intensity across distances and road networks. The observed relationships match an Edgeworth cycling behaviour, whose steps appear to be determined by the changes in demand. Cycling intensity and undercutting increase with traffic, while relenting phases are timed to substantial changes in traffic flows. Thus, competition is found to intensify with rising potential demand, as that increases the incentives of undercutting.

JEL Classification: D22; D40; L11; L81; R12

Keywords: Retail gasoline prices; Edgeworth Cycles; Regional Infrastructure; Price Competition

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1 Introduction

Road transport remains the backbone of travel and logistics, accounting for three quarters of all passenger transports and over half of all freight transport within OECD countries (OECD, 2020a,b) in 2018. Consequently, the need and cost of refuelling road vehicles is an ubiquitous necessity - and annoyance - for both private and business drivers as well as a substantial cost factor for cargo transport. For the same reasons, fuel pricing and possible anti-competitive acts within the sector remain both in the public's eye and under investigation by economists and cartel agencies. While this interest has generated a series of regulations from enhanced transparency in Germany over limitations to price increases in Australia and Austria to outright price regulations in Belgium (Boehnke, 2017, Bundesministerium fr Wirtschaft und Energie, 2018, de Roos and Katayama, 2013), the underlying questions of the level competition among retail stations and its determinants remain open for discussion.

This analysis contributes to this discussion by utilising the special case of *Bundesautobahntankstellen* in the German market, which are regulated to have identical business hours, side products and services and which are accessible only from the *Autobahn* highway network. This allows isolating the competitive interactions between stations from their side-business and also integrating a reliable demand proxy, the traffic at the respective strip of highway. In effect, the stations are thus restricted to competing on price and their fixed location with regard to customers. Additionally, car parks (*Autohfe*), which are accessible by street and highway alike, but regulated to the same standards as *Bundesautobahntankstellen* otherwise, are used to gauge cross-network competitive effects.

Germany is well-suited for such an analysis for a number of reasons. Its *Markttransparenzstelle* and the *Bundesanstalt fr Straenwesen* provide detailed, publicly available data on highway traffic and station prices. Germany also has the fourth-most freight and the second-most passenger transport of all OECD members on its roads (OECD, 2020a,b), as its population is highly motorised and because of its position as a transit country at the heart of the European Union.[1]

Using price data of 428 *Bundesautobahntankstellen* and *Autohfe* as well as traffic information for all of 2018, price setting and competition are analysed in accordance with the Edgeworth cycle model commonly used in the analysis of retail gasoline prices. Therein, prices are raised rarely, but steeply and jointly by most players, and reduced sequentially in smaller, more numerous and disjointed steps. This is modelled accordingly by considering price increases and decreases separately for both the decision to change and the volume of any given change. In both steps, these decisions are related to demand and its dynamic in the period of question as well as the behaviour of local competitors.

[1] Transport volume is measured in millions passenger-kilometres and million ton-kilometres.

The results contribute specifically to the ongoing discussion on the collusive or competitive nature of Edgeworth cycling by providing support for the latter hypothesis: Cycling is initiated as traffic increases and ceases only as demand decreases again in the evening. Rising demand also increases the likelihood for price reductions more than for increases, while symmetrically affecting the volume of these changes. Hence, the chance for lower prices increases with demand. In the same competitive vein, *Bundesautobahntankstellen* respond to the pricing decisions of their local competitors despite their privileged location. They mirror price changes by stations of the same type to a large degree and to a smaller degree for similar *Autohof*-type stations, regardless of the price direction.

The remainder of the paper begins with an overview of the related and relevant literature in section 2, followed by an introduction into the network and thus the identification in section 3. In section 4, the data and its composition are introduced, followed by the empirical strategy in section 5 and the results in section 6. The paper concludes with a summarising evaluation of the results in section 7.

2 Literature

This paper is firmly routed in the literature on gasoline retail prices and the examination of the extensive data from German retail stations gathered by the *Markttransparenzstelle - Kraftstoffe* in particular. It contributes to this field in two related ways: First, by focussing on the role of demand for the pricing behaviour of retail stations, and second, by exploring the impact of more geographically dispersed competition in an otherwise densely populated market. Both of these are achieved by analysing a distinctive feature of the German market, the *Bundesautobahntankstellen* network, which is excluded from most other analysis of the market for the same reasons causing its usefulness here. BAT stations constitute a separate network of homogeneous stations located at pre-defined intervals and sharing the same types of customers, reducing their competitive variables to prices only. These features permit a more distinct examination of the interaction between price and demand.

The standard theory for gasoline retail pricing is the Edgeworth price cycle, based on Maskin and Tirole (1988) and introduced to fuel retail by Eckert (2002, 2003, 2004). In that model, pricing is dynamic and consists of two states: the relenting pahse and the undercutting phase. The former is, typically, a singular increase, which both follows and is followed by the undercutting phase, wherein the competitors within a market sequentially and repeatedly undercut one another with price decreases. These reductions, in theory, continue down to marginal costs and are both more frequent and significantly smaller in volume than the initial (and subsequent) increase.

Edgeworth cycling has been identified for the Canadian market (Eckert, 2002, Noel, 2007), parts of the

US (Lewis, 2012), Western Australia (de Roos and Katayama, 2013), Chile (Luco, 2019), Austria (Boehnke, 2017) and Germany (Boehnke, 2017, Eibelshuser and Sascha, 2018, Haucap *et al.*, 2017). In most of these cases, cycling is found to be an outcome of competition, with larger firms leading the relenting phases and smaller firms the undercutting (de Roos and Katayama, 2013, Lewis, 2012, Noel, 2007). Stronger competition is also associated with quicker cycles (Haucap *et al.*, 2017) and more heterogeneous firms are seen as beneficial to the existence of cycling (Eckert, 2003). This paper follows the interpretation of cycling as a competitive outcome.[2]

As stated, these studies are focused on the supply side of the market, as time-exact volume data is not accessible for researchers. At best, search data - e.g. Noel (2018), Luco (2019) - or manually collected demand data for a handful of stations - e.g. Boehnke (2017) - can be acquired to approximate demand. In other cases, consumer behaviour is found to be important but cannot be accurately traced due to the lack of data. Examples include Haucap *et al.* (2017) and Atkinson *et al.* (2014), who find that supermarket chains selling gasoline as a by-product enhance competition or Bantle *et al.* (2018) and Pennerstorfer *et al.* (2020) who find consumer routes to be important for market delineation. This paper aims to alleviate this lack of data by focussing on Germany's highway stations, which have more homogeneous customers than street stations and whose customer potential can be more accurately gauged using traffic data.[3]

Secondly, market delineation is a recurring complication in the literature. At times, restrictions of the data determine the market, as in Lewis (2012) or Noel (2007) who use cities as local markets, while in other cases (e.g. Haucap *et al.* (2017)) markets are defined locally as a circle around each station or according to computational restrictions (e.g. de Roos and Katayama (2013)). Other papers specifically investigate the competitive relationship between stations so as to improve market delineation and its conditions: Bergantino *et al.* (2018) observe for Italian data that stations are spatially related, with competition spilling over across larger distances as each station affects the next, though the effect decreases with distance. Kvasnika *et al.* (2018) similarly find that station density negatively impacts prices, but decreases in effect size and significance with increasing distance. Bantle *et al.* (2018) analyse price correlations between stations to define local markets according to the stations' price interdependence and find that these relationships are driven not solely by proximity, but also and especially by commuter routes. This paper expands these delineation analyses by using highway and highway-adjacent stations, for whom commuter routes and distances are

[2]Note that Byrne and de Roos (2019) and de Roos and Smirnov (2020) have defined conditions for which intertemporal pricing differences can be used in a collusive strategy. Under this regime, price differences and the resulting market share changes would be tolerated for a certain period of time to compel smaller market players to follow the overall collusive strategy instead of deviating further. Their model hinges on inattentive consumers and price dispersion serving to further obscure prices from these consumers. Similarly, Clark and Houde (2013) have investigated a Canadian cartel case and found such a strategy to have played out in service of the cartel in question. In terms of BAT stations, this model is unlikely, because BAT stations are known to be more expensive than regular stations even during their price minima.

[3]Boehnke (2017) has also used highway traffic data to approximate demand, but matched the traffic information to street stations as well. As these can be accessed locally, too, the data loses accuracy and becomes more of a density measure.

effectively identical.

3 *Bundesautobahntankstellen* Network & Identification

From its conception, the German highway network, the *Autobahn*, included dedicated rest areas alongside the actual highway, the *Autobahnraststtten*, to provide necessary infrastructure for the efficient operation of the motorways. The *Raststtten* typically include restaurants, parking for cars and trucks, service areas, a hotel, and fuel stations - the *Bundesautobahntankstellen* (BAT).

Originally a state enterprise, the BAT have been privatised under the umbrella of *Tank&Rast*, but remain heavily regulated with regards to their services and the provision thereof. The mandate includes 24 hours and seven days a week of service, but also the aforementioned restaurant and hotel areas. Truck parking and accommodation - while not a concern of the original design before the Second World War or the Fifties - have become a priority and are also required, if not expanded in cooperation with the federal government (Bundesministerium fr Verkehr und Infrastruktur, 2020). Additionally, the concessions for both the *Raststtten* and their fuel stations are administrated by *Tank&Rast* (Bundeskartellamt, 2011), who sell them to independent or vertically-integrated fuel station operators, which implies a common cost for these concessions across all stations.

This similarity also applies to their location, as the federal government's guidelines - rules, prior to privatisation - define a regular distance of fifty to sixty driving kilometres between two stations; permitting a higher driving distance of eighty kilometres for areas with little long-distance traffic (Bundesministerium fr Verkehr und Infrastruktur, 2020). It extends to their connection with the road network, as they can only be accessed from the *Autobahn* and only from one direction of travel[4]; a second BAT is usually built for the opposing direction.

In conclusion, BAT are, by virtue of regulation, mostly homogeneous in all relevant aspects of competition, from by-products to location and access. This makes them an ideal subject of study for price competition in general and in gasoline retail specifically, as they cannot compete with one another by any other means except their brand. Furthermore, entry is impssible except for an expansion of the BAT network by the regulator (the BMVI) and the administrator (Tank & Rast).

This suitability is increased by their relationship to their consumers. On the one hand, their location on and along the *Autobahn* potentially allows a customer to refuel without existing the highway and without having to search for a station outside of the BAT network, saving him time. On the other hand, BAT typically

[4]The only exception is a local access road for delivery of the station's own supply and fuel, which may not be used by other private vehicles.

charge significantly higher prices than standard road stations, which could be seen as the operators' premium for the customer's saved time, but is more likely a result of their contracts with Tank&Rast and a strategy of focussing on business travellers and truckers. Both of these groups have higher time costs and might have access to fleet cards guaranteeing them a certain rebate per liter (see Bundeskartellamt, 2011), thus rendering them less price-sensitive.[5][6] Regardless of the exact cause, the result of their higher prices must be a greater reliance on price-insensitive customers who would have no choice but to use these stations, e.g. truckers at the edge of their legally mandated rest times. Moreover, this customer base again renders the stations more homogeneous, further reducing their strategic options outside of price competition.

At the same time, these characteristics lower the overall intensity of competition. The stations are placed fifty kilometres apart and designed as a local quasi-monopoly on the BAT network - notably reflected in their higher prices. Their locations and characteristics are fixed, new entry is mostly impossible and they target a price-insensitive customer base. However, the consequence of these restrictions is this: if even these stations competed, other types of fuel stations could only be more likely to do so.

More importantly, their similarity allows to investigate a comparatively pure case of price competition. Aiding in that identification is another unique feature of the BAT station network: the ability to more accurately approximate and include demand in the analysis. Traffic on the German *Autobahn* is counted by a set of 1124 counting stations operated by the *Bundesamt fr Straenwesen* (BAST) on the *Autobahn* for active traffic management and analysis purposes. These data differentiates vehicle types and is provided on an hourly basis, permitting a detailed tracing of all traffic at a given BAT station. This traffic must contain all customers of the BAT because it cannot be accessed any other way. Since the customers are more homogeneous due to the higher price levels disincentivizing all but the most price-insensitive customers, these flows should include a similar share of potential customers across the entire network. Thanks to traffic data matching demand flows for BAT stations, the effect of demand on price can be evaluated more accurately and price competition observed more clearly.

Lastly, the only equivalent alternative to BAT stations, the *Autohfe* (AH) can be used to measure price competition more accurately and across networks. AH stations are subject to similar regulations as BAT stations: around the clock service, sanitary installations, ample parking space for trucks and a maximum distance to the nearest highway access of one kilometre at the most (VwV-StVO (2017), Zu Zeichen 448.1). If they fulfil these conditions, they may be advertised on road signs, as BAT stations are, too. Therefore,

[5] Fleet cards are usually billed directly to the employer, which causes a principal-agent-problem further reducing employee incentives to search for a cheaper alternative.

[6] The extended service hours or low fuel reserves following traffic jams might also guide consumers towards refuelling at BAT.

they are the closest possible competitors and a viable alternative to trucks and business customers with a low price-sensitivity compared to their time-sensitivity. This potential is highlighted by the fact that AH stations are located on the regular road network and thus have to compete with road stations which charge significantly lower prices than BAT stations.

While their entrance can, unfortunately, not be observed, they are still a competitor intruding upon the tightly regulated and static competitive structures of BAT stations. Since they operate under a different demand and competitive structure, but are comparable in service to BAT stations, they are likely to provide competitive pressure on BAT, which will be analysed in this study to evaluate the level of competition amongst BAT and the response of fuel stations to an aggressive, lower-priced competitor.

In summary, BAT provide a set of around 340 relatively homogeneous stations with distinct, exogenous locations and a type-specific customer flow limited to a single access point, a BAT's *Autobahn* exit. These BAT stations differ significantly only in three dimensions along the *Autobahn* network: Traffic flow at their location, operator brand and the number of competitors, especially AH, in the vicinity. All of these dimensions can be controlled for, which permits observation of approximately pure price competition between these stations.

4 The Data

The data stems from two distinct sources, fuel station data from *Tankerknig UG*, as received from the *Markttransparenzstelle fr Kraftstoffe* (MTS-K), and traffic data from the *Bundesanstalt fr Straenwesen* (BAST). Additionally, information on infrastructure and distances was generated using Google and OSRM tools and sources. In the following section, the operations and resulting variables as well as their use will be summarised.

4.1 Traffic Data

Table 1: Summary Statistics for Traffic at BAT stations

Competing AH	Count	Unique Zst	$\mu(Pkw)$	$\sigma(Pkw)$	$\mu(Lkw)$	$\sigma(Lkw)$
No	91	52	1216	1051	201	186
Yes	212	118	1095	879	247	191

Notes: The table displays sample means and standard deviations for the hourly traffic at BAT stations with and without competing AH stations as measured by the nearest counting stations (Zst) to their location. Traffic is measured in single vehicles.

In 2018, the most recent year for which data is available, the BAST operated 1124 counting positions, called *Zhlstellen* (Zst), on the *Autobahn*. These Zst are automatic installations, either radar-, light- or induction-based, and provide a detailed, hourly summary of the traffic passing their location in both directions. Since Zst are meant to serve traffic flow analyses and as input for traffic management systems, they are typically located in relative proximity to highway junctions or exits, measuring the traffic on the stretch of highway before the junction. They can differentiate between up to nine different types of vehicle, including trucks and various types of cars. However, a significant number of Zst only collects data on trucks and all traffic (Bundesanstalt fr Straenwesen, 2020), restricting the analysis to these broader categories to avoid a loss of observations. Their geographic coordinates are also provided and used in this analysis to match BAT and AH stations to the closest Zst on the same Autobahn.

For this analysis, hourly data on the number of trucks (Lkw) and all other vehicles (Kfz) passing a given station in its direction of travel are used. Trucks are therein defined as trucks with or without trailers, but of at least 3.5 tons of weight; buses are also included in this measure. Thus, the variable includes all vehicle types that (almost) exclusively use diesel fuels and should influence prices directly for that fuel type only. *Kfz* on the other hand are defined as all cars with and without trailers, delivery vehicles and motorcycles as well as unclassified vehicles. They may use gasoline (E5) or diesel and should thus be a price determinant for both fuel types.

4.2 Fuel Station Data

Table 2: Average Prices and Competitive Position per Station Type

Prices:

	Competitors			P_{Type}		$N(\Delta P)$	
Type	AH	BAT	Count	E5	Diesel	E5	Diesel
BAT	No	Yes	90	1.59	1.44	1.2	1.2
BAT	Yes	Yes	211	1.61	1.47	1.2	1.2
AH	No	Yes	10	1.47	1.3	1.6	1.6
AH	Yes	Yes	88	1.47	1.31	1.6	1.6

Location:

	Competitors			No. of Competitors		Avg. Distance to:		Avg. Time to:	
Type	AH	BAT	Count	AH	BAT	AH	BAT	AH	BAT
BAT	No	Yes	90	0	7.67	-	45.87	-	31.14
BAT	Yes	Yes	211	2.98	5.96	41.17	42.96	27.37	28.35
AH	No	Yes	10	0	4.7	-	36.52	-	22.7
AH	Yes	Yes	88	3.57	6.91	40.11	41.46	26.22	26.19

Notes: The first table displays the yearly average of the hourly station prices and the hourly price changes of that station type. The second table displays the competitive situation of that station by listing the number of competitors per type, the average distance to these competitors and the average driving time required to reach them. Stations are divided into BAT and AH stations, with both categories subdivided depending on whether they have to compete with (other) AH and BAT stations.

The *Tankerknig* fuel station data encompasses the identities, locations and prices of all fuel stations in Germany since the creation of the MTS-K. Of these around 15,000 stations, 303 can be identified as BAT and 102 as AH.[7] For these stations, the dataset is restricted to observations from 2018, so as to fit the traffic data[8] and a further 21 stations have to be dropped as observation units due to a lack of suitable Zst[9]. These 21 stations are still used for competitor price calculations, since these do not require traffic information and dropping them would constitute a source of bias. Two additional BAT and four AH cannot be used in the main analysis as they lack BAT competitors; their summary statistics are displayed in Table 6 of the appendix.

For these competitor prices, a local market is defined around each BAT and AH station. This market is computed to include every other BAT or AH station within a linear distance of fifty kilometres, which reflects the guideline for BAT stations and consumer behavior in that use of BAT implies a time constraint, which would prohibit a long trip towards an alternative station. In a second step, all potential competitors located on a *Autobahn* running parallel to that of the station in question are dropped from the set of competitors, as drivers are unlikely to switch between parallel highways given the detour required.[10] For all remaining competitors - twelve on average -, driving distances and driving times to the observation unit station are calculated[11]. These yield an average distance of 47 kilometres and an average maximum distance of 76 kilometres, which fits both the aforementioned guideline and its relaxation to - at most - eighty kilometres for areas with low traffic. Driving times are 31.5 minutes on average, with an average maximum of 49.5 minutes.

Using these distances, a weighted average of competitor prices is calculated to express market price pressure on the station in question.[12] These averages and the prices for the observation unit station are calculated as hourly averages for alignment with the traffic data. Whenever price data for the observed station or any of its competitors is missing, that hour drops out. The MTS-K provides all price changes with an exact time stamp in seconds, which is used to calculate a duration-weighted price for every hour in 2018. All of these calculations are conducted for both diesel and e5 gasoline. Table 2 provides an overview over the average station prices and competitive characteristics for AH and BAT stations with and without AH competitors. This comparison also displays the price spread between BAT and AH stations assumed in

[7]Several stations cannot be identified or need to be dropped due to construction works at their location blocking access, them not having been opened within the observation period or issues with their reported prices. For AH stations, further concerns are undue distances to the *Autobahn* or insufficient truck parking space.

[8]Note that Zst are being added every year, whereas some are inoperable in certain years due to construction activity on the regular lanes. This restriction to the quality of fit between Zst and BAT stations impedes covering more than one year in the analysis.

[9]A Zst must be on the same highway and at most 50 kilometres distant from a fuel station to be considered suitable. On its 13,000 kilometres of *Autobahn* track, the network contains 213 junctions and 885 exits, corresponding to, on average, one change to traffic flows every twelve kilometres. Thus, a distance of more than fifty kilometres is already quite high.

[10]Specifically, German *Autobahnen* follow either a North-South or an East-West trajectory, with the former designated with odd numbers and the latter designated with even ones. Using these designations, all potential competitors on even-numbered *Autobahnen* are removed from the competitor set if the station in question is also along an even-numbered route. Stations along the same *Autobahn* are not dropped.

[11]The *Autobahnen* and driving directions are not extracted from the MTS-K data, but were generated by linking station locations to the nearest highways using OSRM tools and extrapolating the directions from station orientation to that highway.

[12]A simple, unweighted average is also calculated for robustness.

section 3.

4.3 Other Data

Aside from station and traffic data, information on official holidays, weekends and vacations within Germany and its federal states is used to account for potential one-off effects on pricing. *Holidays* include one dummy each for federal and state-level official holidays, which are separated to account for the difference in scale associated with a federal holiday. *Weekends* are divided into Saturday and Sunday, as both days will see reduced business travel, but Sunday also nearly prohibits truck traffic, which might change pricing behaviour at these days altogether. *Vacations* adds two dummies indicating the official start and end dates of the summer holidays in the federal state in question, both of which are defined as the actual date plus the two preceding and the two following days. This definition is chosen to account for the weekends often adjacent to the vacation start states, while the variable itself is included to account for the large waves of vacation trips starting and returning at the first and last days of the holidays, respectively.[13]

Lastly, data on diesel and e5 wholesale prices are included to account for macro-economic trends and potential oil price shocks. The underlying data is the daily FOB price from the Rotterdam spot market, as provided by OMJ, which is a price benchmark for the European market and thus sufficient to serve as a control for larger trends and shocks.

5 The Model

Using *Autobahntankstellen* (BAT) and *Autohfe* (AH) to abstract from non-fuel activities and thus observe price competition for homogeneous goods among highly homogeneous stations, the empirical strategy addresses three consecutive questions. First, which are the overall, static determinants of competition between homogeneous fuel stations? Second, in what manner does demand, measured by traffic as a proxy, impact competition and price-setting, and what is the effect of the composition of that competition? The third question also addresses the distinction between BAT and all other stations, as originally defined by the *Bundeskartellamt.* For the first question, station characteristics and prices at a specific hour of the week are assessed. The interaction between demand, competition and prices is investigated using hourly data of the binary decision to change prices and the volume of a price change, if executed.

[13]The Easter holidays - associated with price hikes in German popular opinion - included via the Easter vacations. The start and end points of the summer vacations are included because of the large vacation-based traffic jams they typically cause, which might induce price regime changes.

5.1 Static Determinants of BAT & AH Station Prices

The variable of interest in the static analysis are the price for *Super E5* gasoline and diesel, respectively, at a specific hour and day of every week in the year 2018. Specifically, the main analysis uses prices at Monday, 08:00 o'clock, while afternoon and weekend price moments are displayed in the appendix.[14] This choice allows comparison and identification of pricing determinants and regimes at a time of relatively high traffic - i.e. the commute to work. Given the restrictions of the approach, this identification serves primarily to test the assumptions made in section 3 and as support for the specifications used in the dynamic analysis. Price relationships, for example, are affected by homogeneous input costs, overstating their intensity in this static perspective.[15]

Stations are subdivided into three types: AH stations, BAT stations with AH competitors, and BAT stations competing only with other BAT. Price levels for the stations of each type are compared to the price levels of their intra-type and, if applicable, extra-type competitors. The hypothesis is that the price response increases with competitive pressure: lowest for BAT stations without AH competition and highest for AH stations, which have to compete with normal road stations also. The number of prices of BAT and AH competitors in the given hour is also included to account for price regime effects related to Edgeworth cycling, i.e. faster cycles leading to lower minimum prices[16] and higher volatility. Both the price level and the number of changes are summarised as *CptD*, the dynamic competition effects.

The competitive structure is further gauged by including static competition effects (*CptS*). These are the average travel time from one station to its local competitors, the number of competitors (of both types) and brand dummies covering the four oil majors on one side and the smaller market participants as *Other* brands on the other side.[17] The number of competitors notably does include other stations of the same brand. The reasoning behind this decision is twofold. First, while brands can theoretically coordinate prices for their stations, these stations are still exchangable from a consumer's perspective if they were to offer lower prices or benefit his route planning. Second, if a brand operates more than one station in a market, these stations are seen as different competitors by stations of other brands.

The models for the three station types and the fuel types $F = [E5, Diesel]$ are defined as:

[14] See Table 7 and Table 8.

[15] The non-stationarity of the data, which necessitates the use of first differences in the dynamic analysis to avoid bias, might also remain an issue despite the choice of a specific point in time to avoid it.

[16] Siekmann (2017) has observed this pro-competitive effect of cycling in his supply-side analysis of the German street stations.

[17] For robustness, the competitive measures were augmented by a measure of brand density, the share of competing stations belonging to the same brand as the observed station, and by dividing the number of competitors into types. Neither changed the results.

$$P^F_{AH} = c + CptD^F_{BAT}\beta + CptD^F_{AH}\gamma + CptS^F_{BAT}\delta + CptS^F_{AH}\zeta + \text{brand}\zeta \quad (1)$$

$$P^F_{BAT} = c + CptD^F_{BAT}\beta + CptD^F_{AH}\gamma + CptS^F_{BAT}\delta + CptS^F_{AH}\zeta + brand\zeta \quad (2)$$

$$P^F_{BAT_{AH.comp}} = c + CptD^F_{BAT}\beta + CptD^F_{AH}\gamma + CptS^F_{BAT}\delta + CptS^F_{AH}\zeta + \text{brand}\zeta \quad (3)$$

5.2 Determinants of Price Changes

Expanding on the static analysis, dynamic pricing behavior is analysed first by observing changes in station prices and regressing them on demand and competitor pricing. Pricing decisions are split into increases (relenting) and decreases (undercutting). This choice is modelled after the Edgeworth model for gasoline prices, wherein relenting phases are rarer and steeper than the steps of the undercutting phase and thus would plausibly result from different considerations. The decisions are further split into *E5* and *diesel*, the two most common fuels in Germany, because the latter is more regularly used for business travellers and almost exclusively for trucks. The control variables include wholesale costs (Δc^{E5}_{it}) and potential demand ((d_{it})). The latter includes the present car and truck traffic as well as their trends, which are included to account for differences in responding to rising and falling traffic and defined as follows.

$$\Delta d^{Type} = \frac{(d_t - d_{t-1})}{\sigma d}, \qquad \text{Type} = [Pkw, Lkw]$$

Information on BAT competitor pricing behaviour ($\Delta cptD_{id}$) is included by their distance-weighted average price and a dummy evaluating whether they changed prices or not. The same information is included for AH competitors ($\Delta cptDAH_{id}$), provided that at least one AH station is sufficiently close. This definition is summarized in Equation 4 and follows from the use of fixed effects, which capture the existence of competitors already, leaving only the interaction for analysis. This inclusion serves to expand the analysis beyond the centrally-planned structure of BAT.

While AH cannot be considered a treatment of entirely exogenous shock, since their entry is not observed, they are still an intrusion into the BAT system, permitting customers - including truck drivers - to eschew BAT for AH stations. Moreover, BAT stations cannot adjust their location in response to this competition, while AH location is based primarily on truck traffic, which provides their main revenues through night stops and maintenance. Their impact on BAT competition is therefore not their primary intent, but meaningful to gauge the intensity of competition across networks, i.e. when the customer has to divert from his route to benefit from a lower price.

$$p^{w\_avg,AH} = \begin{cases} 0 & if AH.comp = 0 \\ p^{w\_avg,AH} & if AH.comp = 1 \end{cases} \tag{4}$$

For the price variables, first differences are used instead of levels for three reasons. First, prices are relatively homogeneous across stations due to them being dependent on common supply factors, which would inflate coefficients. Second, prices are non-stationary due to this dependence, which would bias results if left unaddressed. Third, as stations can only compete with one another by adjusting prices, the change in price is the variable of interest for gauging competitive pressure.

Hence, the analysis observes the determinants of the linearised probability for a price change in a given hour, using first differences of all price ($cptD$) variables. Present demand (d) variables are included in level, because the relevant information for price-setting is the amount of potential consumers at a given point in time. Station fixed effects (α) are included to capture remaining location and station anomalies - e.g. construction measures restricting access, location near a national border - and abstract away from static components analysed in the first step. The resulting models are estimated using OLS with robust standard errors following Arellano's 1987 method.[18] They are defined as follows for both fuel types $F = [E5, Diesel]$:

$$Prob(P^F > 0|c, d, D, \alpha) = f(\Delta c_{it}^F \beta, d_{it}^F \gamma, \Delta cptD_{it}^F \zeta, \Delta cptDAH_{it}^F \theta, \alpha_i) \tag{5}$$

$$Prob(P^F < 0|c, d, D, \alpha) = f(\Delta c_{it}^F \beta, d_{it}^F \gamma, \Delta cptD_{it}^F \zeta, \Delta cptDAH_{it}^F \theta, \alpha_i) \tag{6}$$

These models are also estimated for AH stations to analyse divergences from BAT in their competitive structure. In both cases, it is assumed that rising demand should cause an undercutting phase as the potential gain from undercutting competitor's prices is increased; and vice versa. For competitor prices, a consistently positive relationship is assumed.

5.3 The Volume of Price Changes

Once the decision to change prices is made, the question of the volume of that change needs to be addressed. The determinants of this second decision are modelled in this second stage. Analogous to the

[18]Note that OLS is used instead of a Probit or Logit model because the simultaneity of price moves in the market and the inclusion of fixed effects prevents the algorithm from converging. An exclusion of competitors' price moves is, however, impossible as it would bias results while using lagged price changes would be a mis-specification due to the fast-moving nature of the German retail gasoline market. Hence, OLS is more robust and accurate despite the risk of expected probabilities with values above 1.

previous approach, relending relenting and undercutting are analysed separately. This also better reflects the Edgeworth model assumptions, in that relenting phases are typically much higher in volume than undercutting moves.

The model is defined using the same categories as the equation from subsection 5.2, but swaps competitors' decision to change prices with the average number of their hourly price changes. It also includes a binary variable for large price changes by AH stations defined as $|\overline{\Delta P^F_{AH}}| \upuparrows = |\overline{\Delta P^F_{AH}}| > \sigma_{\Delta p^F_{it} \neq 0}$, i.e. a price change of above one standard deviation of BAT stations' price changes.[19] According to empirical findings on Edgeworth cycles in gasoline retail, faster cycles would be associated with higher competitive pressure, more price changes and thus, potentially, lower prices, which is why the variable is added. As before, BAT and AH competitors are included separately. Wholesale prices are excluded because they are set daily and therefore unlikely to influence intra-day pricing behaviour outside of the first response when wholesale markets open. Aside from these alterations, the models are identical, and the volume equations are defined as follows:

$$\Delta p^F_{it} = d_{it}\gamma + \Delta cptD^F_{it}\zeta + \Delta cptDAH^F_{it}\theta + \alpha_i, \qquad \text{F} = [\text{E5, Diesel}] \tag{7}$$

6 Results

6.1 Static

The static analysis in Table 3 provides support for the assumption of three separate price regimes for the three station types. On the one hand, AH stations, which are on the standard road network and have to compete there as well, match their AH competitor's prices by about 94 percent for both fuel types.[20] Their prices are related to BAT competition as well, but weakly at 4 cent for every euro of the average of the competitors' prices and only at the 10% significance level.

On the other hand, BAT stations facing only intra-type competition match the prices of these competitors by 40 cent per euro and liter for gasoline and by 51.45 cent for diesel. This differences hints at the assumed competitive relationships, but is not statistically significant. Meanwhile, BAT stations facing both types of competitors react symmetrically. Regardless of fuel or competitor type, they raise their prices by 30 cent for every euro of the competitors' prices. Of all three station types, only BAT stations without AH competition respond to the number of price changes by their competitors. For every additional change by their intra-type competitors, they reduce their prices by 2.2 to 2.5 cent.

[19]This corresponds to a change of at least 4.7 cent for E5 gasoline and at least 4.97 cent for diesel.

[20]To be precise, for every euro of the distance-weighted average price of their competitors, the given station's prices increases by almost 94 cent.

Table 3: Static Analysis of BAT & AH Station Price Determinants: Monday, 08:00 - 09:00 AM

	Endog. Var	Price in Level					
	Fuel Type	E5 gasoline			Diesel		
	Station Type	AH	BAT		AH	BAT	
	Competitor Types	AH, BAT	BAT	BAT, AH	AH, BAT	BAT	BAT, AH
	(Intercept)	4.70*	91.40***	56.83***	4.50*	56.78***	42.47***
		(2.38)	(25.07)	(10.41)	(2.10)	(16.95)	(8.94)
Wholesale	FOB_E5	0.14	1.23**	0.69			
		(0.10)	(0.42)	(0.58)			
	FOB_Diesel				0.36*	2.83**	1.28
					(0.17)	(1.00)	(0.86)
BAT Competitors	$\overline{P_{BAT}^{E5}}$	3.47·	40.04*	32.25**			
		(1.92)	(17.65)	(10.21)			
	$\overline{N(P_{BAT}^{E5})}$	−0.47	−2.21***	−0.52			
		(0.36)	(0.62)	(0.42)			
	$\overline{P_{BAT}^{Diesel}}$				3.68·	51.45**	33.21***
					(1.98)	(16.44)	(9.61)
	$\overline{N(P_{BAT}^{Diesel})}$				−0.53	−2.51***	−0.68
					(0.41)	(0.64)	(0.47)
AH Competitors	$\overline{P_{AH}^{E5}}$	93.40***		31.74***			
		(1.59)		(5.59)			
	$\overline{N(P_{AH}^{E5})}$	0.16		0.10			
		(0.14)		(0.26)			
	$\overline{P_{AH}^{Diesel}}$				92.79***		35.20***
					(1.99)		(7.66)
	$\overline{N(P_{AH}^{Diesel})}$				−0.09		0.13
					(0.15)		(0.30)
Location	Time to BAT Comp.	0.00	0.09	−0.06	−0.04	0.07	−0.05
		(0.03)	(0.06)	(0.08)	(0.04)	(0.07)	(0.08)
	Time to AH Comp.	0.02		0.08	0.02		0.07
		(0.02)		(0.05)	(0.02)		(0.05)
	No. of Comp.	−0.00	0.04	0.22	0.03	0.04	0.24
		(0.05)	(0.08)	(0.14)	(0.06)	(0.08)	(0.15)
Brand	Other	−0.94·	−7.56***	−3.17*	−1.31*	−8.43***	−3.43*
		(0.55)	(2.19)	(1.61)	(0.64)	(2.20)	(1.62)
	ESSO	−2.58***	−2.67·	−1.01	−2.65***	−2.64·	−1.28
		(0.62)	(1.50)	(0.92)	(0.73)	(1.39)	(1.11)
	Shell	−1.37**	−1.63*	−1.75**	−0.88	0.22	−0.31
		(0.50)	(0.72)	(0.67)	(0.58)	(0.88)	(0.86)
	TOTAL	−2.34***	−4.95**	−4.79***	−2.81***	−6.35***	−6.31***
		(0.49)	(1.53)	(1.25)	(0.62)	(1.64)	(1.46)
	Adj. R^2	0.86	0.43	0.21	0.88	0.58	0.29
	Num. obs.	4295	4138	10216	4295	4138	10216

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Static Analysis for the prices of AH and BAT stations at all Mondays of 2018 for the period from 08:00 to 09:00 AM, in the latter case subdivided into those without and with AH competitors. Stations without BAT or AH competitors are excluded. The first three columns depict results for gasoline, the latter three for diesel. Average Competitor prices are provided in Euro per liter, wholesale prices as $100\$/t$. The number of average price changes by the competitors within that hour is also included. Average time to BAT or AH competitors is the average travel time to the local competitors. Regarding the brand dummies, Aral serves as the base category because its stations have, on average, the highest prices and because it is the largest operator alongside Shell. Outside of these two, Esso and Total also have their own categories, as they are major players in the market. All other owners of BAT and AH stations are subsumed under the *Other* label. Standard errors are clustered on the station level.

In contrast, The coefficients for wholesale prices appear small at 1.23 cent for gasoline and 2.83 for diesel per additional 100$/$t$. However, this effect is likely understated due to the correlation between retail and wholesale prices, but also reflects contracts and insurances against price volatility by station operators.

These results support several assumptions regarding the identification. First, AH stations do not appear to view BAT stations as their primary competitors, yet BAT stations operate a different pricing regime when facing AH competition. Secondly, the static location parameters (i.e. distance to competitors and number thereof) are non-significant given the lack of variation in them due to the network design. Thirdly, BAT stations - especially when facing only intra-type competition - appear somewhat more sensitive to competitor's diesel prices than to gasoline prices. This asymmetry is not visible for AH stations, but also not statistically significant and thus at best a preliminary interpretation. Nonetheless, these results point towards a competitive relationship, but also to barriers imposed on that competition by network design and location.[21]

Notably, the brand effects, too, attest to type-specific regimes: Their spread is highest for BAT facing only intra-type competition and lowest for AH stations. Aral - also the base category - and Shell, the two largest single operators in the set always have the highest brand premia, although Shell marginally underbids Aral for gasoline by 1.37 to 1.75 cent per liter (c.p.). Total and Esso, the other two major operators, on the other hand differentiate their premia by station type. Total underbids Aral for every station type, but the difference is twice as high for BAT stations: between 5 and 6 cent for BAT to 2 or 3 cent for AH. In the case of Esso, only its AH stations underbid Aral and Shell significantly. Minor players, subsumed under the *Other* label follow the opposite strategy to Esso and underbid strongly at their BAT stations, but weakly (to non-significant) at AH stations.

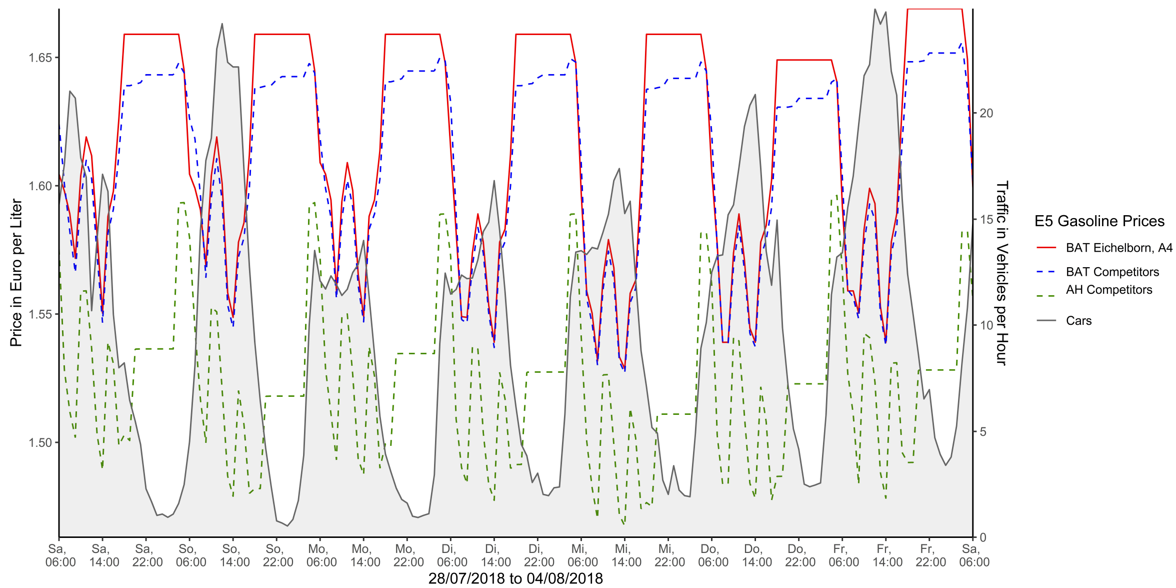
6.2 Price Changes

Table 4 depicts BAT hourly pricing decisions for the entirety of 2018. A characteristic example for the pricing process is provided in Figure 1. BAT operators' pricing decisions appear to be influenced by traffic, competitor behaviour, holidays and weekends (see also Table 9). [22]

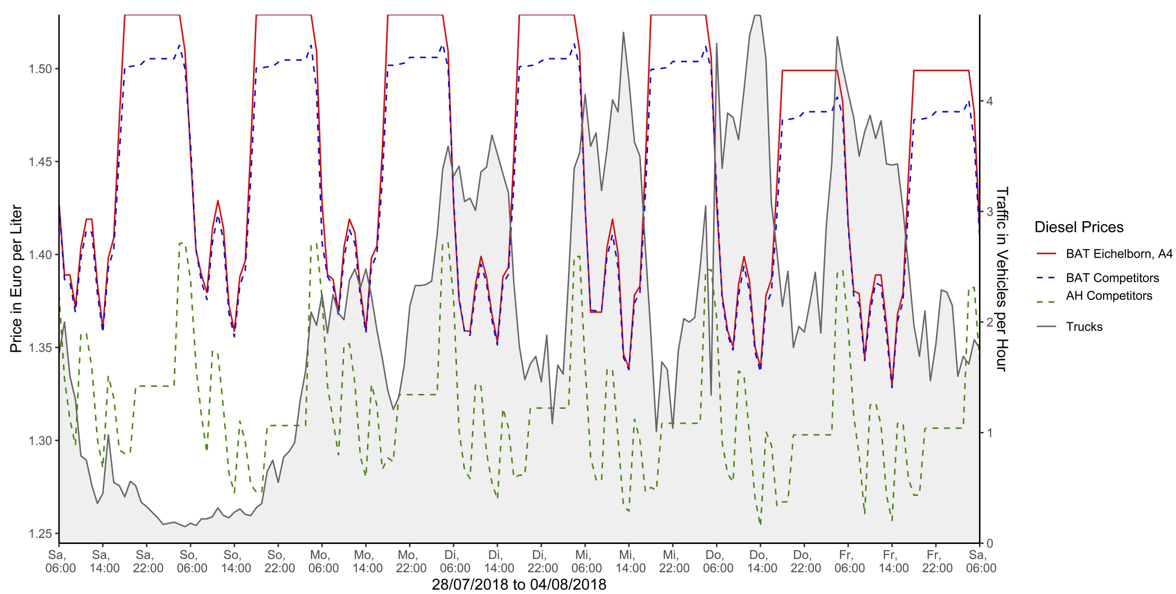
[21] The variation in intercept size between the fuel and station types also indicates different regimes: The constant is highest for BAT stations facing only intra-type competition and lowest for AH stations on the road network, which fits the higher price levels for BAT and their lesser exposure to competition. Similarly, the intercept is higher for gasoline than diesel, which reflects its higher price, but potentially also a stronger competition for diesel amongst the observed stations.

[22] Changes in the wholesale price appear to be weakly relevant for the decision to increase prices and irrelevant for intra-day price reductions. The effect is very small even when significant - a 2 percent increase in the likelihood to raise diesel prices given an (unlikely) increase of wholesale prices by 100$ per ton.It should be noted that this effect might be understated, as the wholesale prices - *free on board* prices for Rotterdam - are set daily, not hourly. Hence, their variation is by definition much lower than that of the gasoline prices, as it can only be accounted for once a day while the average station posts 7.6 prices per day. This change is defined as occurring at 09:00 o'clock, the opening of the exchange. Insurance policies and intra-company transfer prices are also not considered in this analysis.

Figure 1: Characteristic Cycling & Traffic



Notes: This figure depicts hourly E5 gasoline prices for the period from Saturday, 28/07/2018 06:00 AM, to Saturday, 04/08/2018 06:00 AM, for the BAT station Eichelborn located along the A4 *Autobahn*. Also shown are the prices of that station's local BAT and AH competitors as well as the hourly car traffic at the station.



Notes: This figure depicts hourly diesel prices for the period from Saturday, 28/07/2018 06:00 AM, to Saturday, 04/08/2018 06:00 AM, for the BAT station Eichelborn located along the A4 *Autobahn*. Also shown are the prices of that station's local BAT and AH competitors as well as the hourly truck traffic at the station.

Table 4: Determinants of Price Change Decisions

	Endog. Var	$Prob(P^F > 0)$		$Prob(P^F < 0)$	
	Fuel Type	E5 Gasoline	Diesel	E5 Gasoline	Diesel
Demand	Pkw	0.003^{***}	0.003^{***}	0.003^{***}	0.003^{***}
		(0.000)	(0.000)	(0.000)	(0.000)
	Lkw	0.005^{***}	0.006^{***}	0.012^{***}	0.012^{***}
		(0.001)	(0.001)	(0.001)	(0.001)
	ΔPkw	-0.037^{***}	-0.037^{***}	-0.023^{***}	-0.024^{***}
		(0.007)	(0.007)	(0.005)	(0.005)
	ΔLkw	-0.008^{*}	-0.008^{*}	-0.016^{***}	-0.013^{**}
		(0.004)	(0.004)	(0.004)	(0.005)
BAT Competitors	$\overline{\Delta P^{E5}_{BAT}}$	0.032^{***}		-0.025^{***}	
		(0.002)		(0.002)	
	$\Delta P^{E5}_{BAT} > 0$	0.233^{***}			
		(0.011)			
	$\Delta P^{E5}_{BAT} < 0$			0.223^{***}	
				(0.011)	
	$\overline{\Delta P^{Diesel}_{BAT}}$		0.029^{***}		-0.023^{***}
			(0.002)		(0.002)
	$\Delta P^{Diesel}_{BAT} > 0$		0.240^{***}		
			(0.011)		
	$\Delta P^{Diesel}_{BAT} < 0$				0.232^{***}
					(0.012)
AH Competitors	$\overline{\Delta P^{E5}_{AH}}$	0.000		-0.005^{***}	
		(0.001)		(0.001)	
	$\Delta P^{E5}_{AH} > 0$	0.051^{***}			
		(0.010)			
	$\Delta P^{E5}_{AH} < 0$			0.056^{***}	
				(0.008)	
	$\overline{\Delta P^{Diesel}_{AH}}$		-0.000		-0.005^{***}
			(0.001)		(0.001)
	$\Delta P^{Diesel}_{AH} > 0$		0.053^{***}		
			(0.010)		
	$\Delta P^{Diesel}_{AH} < 0$				0.057^{***}
					(0.008)
Dummies	Wholesale Δ	yes	yes	yes	yes
	Station-FE	yes	yes	yes	yes
	Vacation	yes	yes	yes	yes
	Holiday	yes	yes	yes	yes
	Weekend	yes	yes	yes	yes
	Adj. R^2	0.201	0.200	0.209	0.217
	Num. obs.	2,410,109	2,410,109	2,410,109	2,410,109

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Analysis of the determinants of hourly price change decisions for all BAT stations in 2018. Standard errors are corrected for autocorrelation and heteroskedasticity using Arellano's method with clustering on the station level. Hence, the R^2 is not informative. Columns (1) and (2) depict the determinants of the decision to raise prices for a given station in a given hour for gasoline and diesel, respectively. Columns (3) and (4) depict the same for the decision to lower prices. The control variables include hourly truck and car traffic, in 100 vehicle steps, as well as its trend. First differences of distance-weighted competitor prices and dummy variables indicating their pricing decisions are included for each fuel and station type. Information on AH competitors must be understood as an interaction term of the variable itself and the existence of AH competitors. Holidays, the start and end of summer vacations and weekends are demarked by dummies. Fixed effects and wholesale prices in first differences are included. Results for the dummies and wholesale prices are shown in Table 9.

Demand Increasing demand - measured as present traffic of both trucks (*Lkw*) and all cars (*Pkw*) - is associated with higher likelihoods of price changes in both directions.[23] The relationship with undercutting is slightly stronger than that for relenting. This observation is in line with Edgeworth cycling in that higher potential demand would increase the incentives of undercutting by promising a larger share of the demand. Once undercutting begins, the cycle would accelerate as competitors join in.

Specifically, for each additional 100 trucks passing a station per hour the probability to undercut increases by 1.2 percentage points for diesel. This is twice the effect size of the same increase on the likelihood of a relenting move. At the peak rush hour in the network (2280 trucks), it translates to a 25 percentage point increase. Given the relative importance of trucker demand to BAT stations, it is unsurprising that these effects are larger than those for car traffic: For every 100 vehicles, the likelihood of a price change in either direction raises by 0.3 percentage points.[24] Notably, the effects are almost identical for gasoline and diesel pricing decisions, which reflects the high correlation between the two prices and indicates that most stations and brands appear to prefer a static difference between them.[25]

The dynamic of traffic ($\Delta Pkw/Lkw$) also informs on stations' pricing behaviour, suggesting a persistence in cycling intensity. If car traffic was one standard deviation lower in the previous hour (935 cars less), the probability of relenting moves in the given hour is reduced by 3.7 percentage points and that of undercutting by 2.3 percentage points. If traffic had been higher the period before, the probability would increase by the same margin instead. The coefficients are overall lower for truck traffic, but relatively stronger for undercutting (1.3 to 1.6 percentage points) than for relenting (0.8). As undercutting is the more relevant measure for the intensity of competition, this underlines the importance of truck traffic for BAT price competition. Car - and thus commuter - traffic progression on the other hand appears to shape relenting decisions.[26]

Given that high present traffic is linked with more intense cycling and low traffic with the relative lack

[23] This finding is in line with Boehnke (2017) who also postulate that pricing and demand need not move in the same direction. Note also that these regressions have also been conducted using unweighted average prices instead of the distance-weighted ones used in the main specifications, but were only marginally changed by that change due to the relative homogeneity of competitor locations.

[24] For the maximum car traffic observed in the *Autobahn* network (6818 vehicles), this still corresponds to a 27.2 percentage point increase in the undercutting and relenting probabilities.

[25] The model was also estimated for AH stations, as displayed in Table 10. There, the effects for present demand are similar overall, but stronger for car traffic and undercutting. This result supports the assumption from section 3 that *Autohfe* compete more with street stations and are thus more interested in car drivers than BAT stations. However, as AH stations can be accessed from the regular road network as well, the *Autobahn* traffic flows lose some of their accuracy as demand approximations when used for non-BAT stations.

[26] The results for AH stations (see Table 10) differ here. A steep increase in car traffic to the last period actually raises the linearised probability of price increases by 5.5 percentage points. This reflects a difference in cycling behaviour, as can be observed in Figure 1: BAT stations tend to steeply raise their prices in the evening, keeping them at level until commencing traffic causes them to cycle again. AH stations also raise their prices overnight, but not to the same degree. Instead, they tend to perform a larger price hike just as traffic increases again. This may be designed to extract higher profits from early commuters who cannot afford a detour. At the same time, steep increases in truck traffic reduce the probability of a price increase by 4.3 to 4.7 percent - five times the effect observed for BAT stations. This once again signals the relevance of trucker demand for the AH business model.

thereof, these results then imply that Edgeworth cycling behaviour can neither be stopped immediately when traffic declines nor does it commence immediately as traffic mounts. Instead, it is caused by ensuing competition for an increasing demand following (nightly) periods of little traffic, as can be observed for the exemplary case shown in Figure 1. Once cycling has intensified, this behaviour continues for as long as potential demand remains high, until traffic declines for a longer period of time, allowing pro-competitive cycling behaviour to wind down.

Competition If at least one BAT competitor to a given station changes its prices, this corresponds to a 23 to 24 percentage point increase in probability of a price change in the same direction for that station. For AH competitors, this relationship is almost five times smaller (5.1 to 5.7 percentage points), but significant. The latter result is of particular interest because AH stations compare primarily with normal road stations, not BAT, as the divergence in price levels indicates (see Table 2 and Figure 1). Thus, their pricing behaviour cannot result from simultaneous price setting, as is potentially the case amongst BAT stations.

It then implies that BAT stations have to respond to the prices of their competitors despite the large distances between them both within and without the *Autobahn* network. Since station fixed effects are included, this relationship cannot be attributed to brand affiliation, but can instead be interpreted as an attempt to avoid being undercut by too large a margin, which might otherwise affect even relatively price-insensitive customers.

This interpretation is supported by the effects for the volumes of competitors' price changes on station price setting decisions: Each cent by which competing BAT raise their gasoline (diesel) prices on average corresponds to a 3.2 (2.9) percentage point increase in the probability of a given station raising prices as well. For price decreases, this effect is slightly weaker at 2.5 (2.2) percentage points. If competing AH stations exist and raise prices, however, the volume by which they do so is irrelevant for the BAT response, while the volume of AH price decreases does affect BAT station responses. The likelihood to lower prices increases by 0.5 percentage points (for both fuel types). While this effect is comparably small, it is nonetheless significant and in line with the interpretation of BAT stations reacting primarily when having to avoid being undercut.

6.3 The Volume of Price Changes

Table 5 shows the determinants of the volume changes in gasoline and diesel prices, divided by fuel types and the direction of change. The changes are measured in absolute numbers and denoted in cents per liter. Again, both competitor behaviour and demand factors appear to influence the pricing decisions asymmetrically with stronger effects observed for relenting than undercutting.

Table 5: Determinants of the Absolute Volume of Price Change Decisions

	Endog. Var	$\lvert\Delta p_{it}\rvert$			
	Fuel Type	E5 Gasoline		Diesel	
	, if:	$\Delta p_{it} > 0$	$\Delta p_{it} < 0$	$\Delta p_{it} > 0$	$\Delta p_{it} < 0$
Demand	Pkw	-0.03^{***}	-0.03^{***}	-0.03^{***}	-0.03^{***}
		(0.00)	(0.00)	(0.00)	(0.00)
	Lkw	-0.05^{***}	-0.07^{***}	-0.06^{***}	-0.08^{***}
		(0.01)	(0.01)	(0.02)	(0.01)
	ΔPkw	0.12^{*}	-0.10^{**}	0.10	-0.15^{***}
		(0.05)	(0.03)	(0.06)	(0.04)
	ΔLkw	0.14^{**}	0.04	0.16^{**}	0.04
		(0.05)	(0.03)	(0.06)	(0.04)
BAT Competitors	$\overline{\Delta P^{E5}_{BAT}}$	0.65^{***}	-0.62^{***}		
		(0.04)	(0.04)		
	$N(\Delta P^{E5}_{BAT} \neq 0))$	0.25^{*}	-0.15^{***}		
		(0.10)	(0.04)		
	$\overline{\Delta P^{Diesel}_{BAT}}$			0.68^{***}	-0.65^{***}
				(0.04)	(0.04)
	$N(\Delta P^{Diesel}_{BAT} \neq 0))$			0.19	-0.18^{***}
				(0.12)	(0.04)
AH Competitors	$\overline{\Delta P^{E5}_{AH}}$	-0.03^{*}	0.01		
		(0.01)	(0.01)		
	$\lvert\overline{\Delta P^{E5}_{AH}}\rvert \upuparrows$	0.64^{***}	0.63^{***}		
		(0.07)	(0.07)		
	$N(\Delta P^{E5}_{AH} \neq 0))$	0.02	-0.04		
		(0.06)	(0.03)		
	$\overline{\Delta P^{Diesel}_{AH}}$			$-0.03^{\cdot}$	0.02
				(0.01)	(0.01)
	$\lvert\overline{\Delta P^{Diesel}_{AH}}\rvert \upuparrows$			0.60^{***}	0.71^{***}
				(0.08)	(0.09)
	$N(\Delta P^{Diesel}_{AH} \neq 0))$			-0.02	-0.03
				(0.07)	(0.03)
Dummies	Station-FE	yes	yes	yes	yes
	Vacation	yes	yes	yes	yes
	Holiday	yes	yes	yes	yes
	Weekend	yes	yes	yes	yes
	Adj. R^2	0.26	0.23	0.29	0.27
	Num. obs.	360,998	411,937	372,167	424,801

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Analysis of the determinants of the volume of all price change decisions in 2018 for all BAT stations. Standard errors are corrected for autocorrelation and heteroskedasticity using Arellano's method with clustering on the station level, hence the R^2 is not informative. The dependent variables are the absolute cent/liter changes in E5 gasoline and diesel prices for positive - columns (1) and (3) - and negative changes - columns (2) and (4). respectively. Gasoline is shown first, diesel second. Demand variables are the hourly truck and car traffic, in 100 vehicle steps, as well as their trends. Competitor behaviour is assessed by the first differences of distance-weighted competitor prices and the number of price changes in the given hour by BAT and AH stations. Information on AH competitors must be understood as an interaction term of the data itself and the existence of AH competitors. Holidays, the start and end of summer vacations and weekends are demarked by dummies and fixed effects are included. Results for the dummies are shown in Table 11

Demand The effects of present demand for the volumes of these price changes are negative. That is, per 100 cars passing a station, the volume of price changes is lowered by 0.03 ct/l, regardless of the change's direction. For trucks, this effect lies between 0.05 and 0.08 cent per 100 vehicles. Given the observed positive relationship between present traffic and price change decisions, these results are in accordance with Edgeworth cycling. Therein, undercutting steps would become more numerous - as observed - and individually smaller as competition increases.

However, the relenting moves should become larger in response, which is not immediately observable, but partially linked to the dynamic of traffic. For each standard deviation by which traffic increases from the last period to the current one ($\Delta Pkw/Lkw$), relenting steps increase by 0.1 to 0.16 ct/l for all type combinations but cars and diesel. This means that larger relenting steps manifest in periods of steeply increasing traffic. However, this effect is being countermanded by the negative impact of present demand on the size of relenting steps. This latter relationship also discloses the other situation in which larger price increases would occur: longer periods of extremely low traffic.[27]

Competition BAT stations strongly adhere to the price changes of their intra-type competitors. Stations match each cent of the average of their BAT competitors' changes by 0.62 to 0.68 cent in the same direction, if they also choose to change prices.[28] The number of BAT competitor's price changes, a measure of cycling intensity, has expected effects. For each additional gasoline price change competitors conduct in the given hour on average, a relenting move becomes 0.25 cent steeper and an undercutting one by 0.15 cent smaller. In the case of diesel, however, the number of changes only affect undercutting steps.

Again, these results fit a pro-competitive Edgeworth interpretation. As cycle intensity increases in the number of price changes, relenting steps become larger and undercutting ones smaller, because firms sequentially try to undercut one another. Given this, higher counts of price changes are more likely to occur in undercutting phases, which fits the non-significance of that count for diesel relenting.

The results for AH competition underscore this interpretation. If AH stations alter their prices substantially ($\overline{|\Delta P^F_{AH}|} \upuparrows$) BAT prices respond by increasing the volume of their own price alteration by 0.6 to 0.7 cent per liter. This effect is also, notably, strongest for price decreases of diesel fuels, where competition between the two station types should be highest. In the case of price increases, it is also countermanded by a small, weakly significant negative impact of the change in average AH prices, which lowers the price increase of the station in question by 0.03 cent per cent of competitor change. That is, BAT stations react

[27]The model was also estimated for AH stations, as displayed in Table 12. There, the effects for demand were weaker and less significant than for BAT. This result affirms the restriction and assumption from section 3 that *Autobahn* traffic flows would lose their accuracy as demand approximations when used for non-BAT stations as they can be accessed by other roads as well.

[28]Theoretically, if one station opts to lower prices while competitors raise theirs, the results indicate that this decrease would be reduced by 0.62 (0.65) cent per liter gasoline (diesel) for every cent of increase by their competitors; and vice versa.

to their competitors' volume changes especially when they are at risk of being undercut too substantially, but also relent alongside their competition.[29]

While a collusive interpretation based on price spreads as a means of distribution demand between stations could also be at play, it is unlikely for competition across networks. AH stations cannot select their prices according to their BAT competitors because of their location on the road network and their resulting competition with road stations for private customers. Therefore, BAT network stations could not channel sufficient demand towards AH stations as they do not compete for this non-*Autobahn* demand in the first place. For the same reason, AH stations are more likely to affect BAT pricing than for the reverse to occur. It is the BAT stations that must avoid being undercut too severely for their location advantages to prevent a demand drain.

6.4 Discussion of Results

The relationship between a BAT station's pricing behaviour and the average prices of its direct BAT competitors cannot be understood as a causal one. While brand-specific effects, including potential intra-brand coordination, are captured in the fixed effects, a similar motion across all stations cannot be ruled out based on this analysis. The construction of average prices, necessary for inclusion of the hourly demand variables, further complicates the issue as the exact timing of the pricing decisions within a market must remain unobserved to avoid a bias with regard to demand. Hence, this analysis cannot provide insight into the identity of price leaders and followers within the BAT market. However, the positive link between the likelihoods for price reductions and intra-network undercutting do imply a pro-competitive relationship. From a station operators' point of view, keeping prices high would be the superior option if competition and undercutting could be avoided.

Hence, this analysis of BAT stations and the AH stations on the edge of the formers' network implies the existence of competition across networks and larger distances, albeit lessened by either. It is also tied to the potential demand on the highway connecting these stations at the given time. While the overall price regime and levels of both station types are chosen primarily for intra-type competition, individual and intra-day price regimes take inter-type competition into account, especially and more consistently for price decreases and diesel fuels.[30] That is, AH stations attempt to undercut BAT competitors significantly, whereas BAT stations aim to preserve the price spread imposed by their contracts and sustained by their location.

[29]The analysis of determinants for the volume of price changes for AH stations (see Table 12) supports this argument: AH stations respond to the price changes of intra-type competitors in a manner similar to BAT stations. Their response to BAT station price setting is, by comparison, five to ten times weaker, while the strongest reaction occurs for diesel undercutting steps. There, for every additional cent of the decrease, the AH lowers its own price by an additional 0.08 cent.

[30]The stronger effects for price decreases are also a more reasonable result considering brand and firm perspectives because it is generally assumed that systematic price increases by larger brands are coordinated centrally, not executed independently by station operators. Hence, the decreases are more likely to be market outcomes.

Moreover, demand is confirmed as a major driver of competition and pricing regimes for fuel stations in accordance with the Edgeworth cycling model. Higher traffic is strictly associated with an increase in the likelihood for price changes of either direction and fuel type, with marginally stronger effects for undercutting and diesel fuels. The latter is in line with the focus of BAT stations on truckers and business travellers who are more likely to require diesel fuels. The former fits the model of Edgeworth cycles, which postulates quicker, but smaller consecutive price decreases as competition intensifies, followed by one large price increase. This relenting move is also observed and related to the dynamic of demand, i.e. BAT undertake it as traffic rapidly declines (in the evening) or during periods of low traffic. AH, meanwhile, conduct their relenting move as traffic initially mounts or as truck traffic declines.

The relationship between the volume of price changes and demand further supports an Edgeworth interpretation: As the likelihood of undercutting (and matching) increases with demand, the volume of each individual reduction becomes smaller. That is, stations engage in an accelerated undercutting and matching process of the Edgeworth cycle. Correspondingly, the size of price increases is negatively related to present traffic flows, but positively to steep increases in traffic. Timing and scope of the relenting phase are dependent on present demand and its trend. This result again underlines the relevance of controlling for demand when analysing fuel pricing and the competitive nature of even BAT stations: As demand rises, so does competition for it - even for BAT stations.[31]

7 Conclusion

Gasoline pricing remains a contentius topic between accusations of collusion by customers and governments on one side and assertions of competition by the retailers on the other side. Vertical integration of the retailers and local monopolies at more remote locations support the former interpretation, as do the synchronised relenting phases in the market. Yet, this analysis of *Bundesautobahntankstellen* suggests that even these homogeneous, spatially differentiated stations targetting relatively price-insensitive customers are forced to compete in periods of higher potential demand.

This competitive relationship is found to exist across networks - from BAT highway stations to AH road network ones -, but decreases in strength with that transition. It is also lessened by the higher distances between stations and highly related to the competitive pressure originating from rising potential demand. Strategically, the observed competition fits an Edgeworth cycle pattern once time-specific demand is taken into account: Price changes become more likely as demand increases, with more pronounced effects for price decreases. At the same time, the size of individual price changes declines with an exception for the rare price

[31] It should be noted that demand is likely being underestimated in this analysis as it would also impact the pricing decisions of a given station's competitors. This interdependency might not be fully captured by the model.

increases denoting the end of a cycle, which become larger and occur in periods of strong demand shifts. In summary, higher demand leads to stronger competition on prices, allowing for them to fall.

In terms of policy, this paper comes to the reassuring conclusion that even BAT stations cannot completely isolate themselves from competitive pressure. Their relationship with *Autohof* stations, which are their closest possible competitors, also implies a pro-competitive effect of market entries. While these entries cannot be observed in the study, the presence of AH stations appears to intensify cycling and thereby competition. On a more specific note, this analysis also cautions against the Bundeskartellamt's (2011) decision to exclude BAT from the regular retail gasoline market. While their connection is weak, it appears to exist nonetheless and could perhaps be intensified to the benefit of BAT customers. The construction of more AH stations to enhance competitive pressure or an alteration of the contracts between BAT operators and *Tank & Rast* to reduce the price spread could be means towards this end.

Lastly, this analysis does not provide a causal link and cannot exactly identify price leaders and followers due to the restrictions of the demand data. Improving upon these points would be a natural venue for future research. The observation of AH entries into the market or an analysis of network intersections (e.g. an unfinished *Autobahn* leading into into another type of road) would also be interesting expansions.

Appendix

Table 6: Average Prices and Competitive Position per Station Type

Prices:

	Competitors			P_{Type}		$N(\Delta P)$	
Type	AH	BAT	Count	E5	Diesel	E5	Diesel
BAT	No	No	1	1.52	1.35	1.29	1.29
BAT	Yes	No	1	1.5	1.36	1.17	1.17
AH	No	No	1	1.5	1.34	1.35	1.35
AH	Yes	No	3	1.49	1.33	1.52	1.52

Location:

	Competitors			No. of Competitors		Avg. Distance to:		Avg. Time to:	
Type	AH	BAT	Count	AH	BAT	AH	BAT	AH	BAT
BAT	No	No	1	0	0	-	-	-	-
BAT	Yes	No	1	1	0	57.15	-	46.66	-
AH	No	No	1	0	0	-	-	-	-
AH	Yes	No	3	2.67	0	37.59	-	21.5	-

Notes: This table provides summary statistics for those BAT and AH stations which cannot be used in the main analysis due to them lacking BAT competitors. The first table displays the yearly average of the hourly station prices and the hourly price changes of that station. The second table displays the competitive situation of that station by listing the number of competitors per type, the average distance to these competitors and the average driving time required to reach them.

Table 7: Static Analysis of BAT & AH Station Price Determinants: Sunday, 03:00 - 04:00 AM

	Endog. Var	Price in Level					
	Fuel Type	E5 gasoline			Diesel		
	Station Type	AH	BAT		AH	BAT	
	Competitor Types	AH, BAT	BAT	BAT, AH	AH, BAT	BAT	BAT, AH
	(Intercept)	$5.50^{\cdot}$	91.37^{***}	75.60^{***}	2.67	56.08^{**}	58.34^{***}
		(2.92)	(25.68)	(12.39)	(2.29)	(18.77)	(10.39)
Wholesale	FOB_E5	0.06	1.17^{**}	$1.00^{\cdot}$			
		(0.12)	(0.38)	(0.57)			
	FOB_Diesel				0.21	2.41^{**}	1.65^{*}
					(0.16)	(0.88)	(0.80)
BAT Competitors	$\overline{P_{BAT}^{E5}}$	3.44	39.60^{*}	23.16^{*}			
		(2.47)	(17.61)	(10.13)			
	$\overline{N(P_{BAT}^{E5})}$	-4.56^{*}	-1.84^{**}	-0.87			
		(2.18)	(0.71)	(0.76)			
	$\overline{P_{BAT}^{Diesel}}$				3.07	52.57^{**}	23.58^{*}
					(2.12)	(16.91)	(9.47)
	$\overline{N(P_{BAT}^{Diesel})}$				-4.66^{*}	$-1.21^{\cdot}$	-0.89
					(2.18)	(0.71)	(0.77)
AH Competitors	$\overline{P_{AH}^{E5}}$	93.58^{***}		28.12^{***}			
		(1.67)		(4.52)			
	$\overline{N(P_{AH}^{E5})}$	$3.94^{\cdot}$		0.69			
		(2.22)		(0.71)			
	$\overline{P_{AH}^{Diesel}}$				94.27^{***}		33.64^{***}
					(1.64)		(6.68)
	$\overline{N(P_{AH}^{Diesel})}$				$4.24^{\cdot}$		0.04
					(2.26)		(0.70)
Location	Time to BAT Comp.	0.01	0.08	-0.03	0.01	0.06	-0.01
		(0.03)	(0.07)	(0.08)	(0.04)	(0.08)	(0.08)
	Time to AH Comp.	0.01		$0.10^{\cdot}$	0.03		0.08
		(0.02)		(0.05)	(0.02)		(0.06)
	No. of Comp.	-0.02	0.06	0.14	-0.00	0.06	0.13
		(0.05)	(0.08)	(0.15)	(0.05)	(0.10)	(0.16)
Brand	Other	-4.42^{***}	-8.23^{**}	-3.40^{*}	-4.47^{***}	-9.59^{***}	-3.89^{*}
		(1.06)	(2.73)	(1.72)	(1.21)	(2.76)	(1.71)
	ESSO	$-1.36^{\cdot}$	-3.45^{*}	$-1.83^{\cdot}$	$-1.23^{\cdot}$	-4.02^{*}	-2.45^{*}
		(0.72)	(1.62)	(0.96)	(0.73)	(1.59)	(1.18)
	Shell	-1.88^{**}	-1.86^{*}	-2.47^{***}	-2.15^{***}	-0.64	-1.24
		(0.58)	(0.78)	(0.66)	(0.56)	(0.95)	(0.83)
	TOTAL	-1.88^{**}	-3.69^{*}	-3.89^{**}	-2.00^{**}	-5.07^{**}	-5.02^{**}
		(0.69)	(1.67)	(1.35)	(0.76)	(1.89)	(1.61)
	Adj. R^2	0.86	0.39	0.14	0.89	0.53	0.22
	Num. obs.	4291	4124	10202	4291	4124	10202

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Static Analysis for the prices of AH and BAT stations at all Sundays of 2018 for the period from 03:00 to 04:00 AM, in the latter case subdivided into those without and with AH competitors. Stations without BAT or AH competitors are excluded. The first three columns depict results for gasoline, the latter three for diesel. Average Competitor prices are provided in Euro per liter, wholesale prices as $100\$/t$. The number of average price changes by the competitors within that hour is also included. Average time to BAT or AH competitors is the average travel time to the local competitors. Regarding the brand dummies, Aral serves as the base category because its stations have, on average, the highest prices and because it is the largest operator alongside Shell. Outside of these two, Esso and Total also have their own categories, as they are major players in the market. All other owners of BAT and AH stations are subsumed under the *Other* label. Standard errors are clustered on the station level.

Table 8: Static Analysis of BAT & AH Station Price Determinants: Wednessday, 17:00 - 18:00

	Endog. Var	Price in Level					
	Fuel Type	E5 gasoline			Diesel		
	Station Type	AH	BAT		AH	BAT	
	Competitor Types	AH, BAT	BAT	BAT, AH	AH, BAT	BAT	BAT, AH
Wholesale	(Intercept)	2.31	76.65**	34.66***	1.23	36.62**	26.01***
		(1.89)	(23.37)	(8.55)	(1.64)	(13.40)	(7.84)
	FOB_E5	−0.01	1.02**	1.09*			
		(0.10)	(0.39)	(0.55)			
	FOB_Diesel				−0.00	2.90*	2.06**
					(0.13)	(1.23)	(0.77)
BAT Competitors	$\overline{P^{E5}_{BAT}}$	4.42*	46.86**	36.61***			
		(1.82)	(16.93)	(9.27)			
	$\overline{N(P^{E5}_{BAT})}$	−0.07	−1.25	0.72			
		(0.30)	(0.93)	(0.57)			
	$\overline{P^{Diesel}_{BAT}}$				4.31**	60.76***	37.86***
					(1.52)	(15.60)	(8.70)
	$\overline{N(P^{Diesel}_{BAT})}$				−0.07	−1.07	0.75
					(0.32)	(0.85)	(0.64)
AH Competitors	$\overline{P^{E5}_{AH}}$	94.43***		39.06***			
		(1.61)		(6.92)			
	$\overline{N(P^{E5}_{AH})}$	0.03		−0.38			
		(0.14)		(0.44)			
	$\overline{P^{Diesel}_{AH}}$				94.98***		37.86***
					(1.61)		(8.26)
	$\overline{N(P^{Diesel}_{AH})}$				−0.03		−0.38
					(0.13)		(0.48)
Location	Time to BAT Comp.	0.01	0.11	−0.07	0.02	0.12	−0.07
		(0.03)	(0.08)	(0.08)	(0.03)	(0.09)	(0.08)
	Time to AH Comp.	0.01		0.07	0.02		0.05
		(0.02)		(0.05)	(0.03)		(0.05)
	No. of Comp.	−0.01	0.04	0.23	−0.00	−0.01	0.27$^{\cdot}$
		(0.06)	(0.10)	(0.14)	(0.07)	(0.11)	(0.15)
Brand	Other	−2.82**	−4.54$^{\cdot}$	−1.92	−2.95**	−5.01*	−2.38
		(0.97)	(2.52)	(1.59)	(1.08)	(2.54)	(1.63)
	ESSO	−2.91***	−3.04*	−0.79	−2.88***	−4.24**	−1.69
		(0.55)	(1.53)	(0.94)	(0.58)	(1.50)	(1.11)
	Shell	−0.47	1.32	0.85	−0.71	3.33**	2.33**
		(0.47)	(1.03)	(0.69)	(0.46)	(1.20)	(0.89)
	TOTAL	−2.47***	−3.52*	−4.95***	−2.59***	−4.94*	−6.60***
		(0.61)	(1.77)	(1.25)	(0.66)	(1.93)	(1.42)
	Adj. R^2	0.90	0.35	0.27	0.93	0.61	0.37
	Num. obs.	4278	4122	10178	4278	4122	10178

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Static Analysis for the prices of AH and BAT stations at all Wednesdays of 2018 for the period from 17:00 to 18:00 o'clock, in the latter case subdivided into those without and with AH competitors. Stations without BAT or AH competitors are excluded. The first three columns depict results for gasoline, the latter three for diesel. Average Competitor prices are provided in Euro per liter, wholesale prices as $100\$/t$. The number of average price changes by the competitors within that hour is also included. Average time to BAT or AH competitors is the average travel time to the local competitors. Regarding the brand dummies, Aral serves as the base category because its stations have, on average, the highest prices and because it is the largest operator alongside Shell. Outside of these two, Esso and Total also have their own categories, as they are major players in the market. All other owners of BAT and AH stations are subsumed under the *Other* label. Standard errors are clustered on the station level.

Table 9: Determinants of Price Change Decisions: Wholesale & Dummy Details

	Endog. Var	$Prob(P^F > 0)$		$Prob(P^F < 0)$	
	Fuel Type	E5 Gasoline	Diesel	E5 Gasoline	Diesel
Wholesale	ΔFOB_E5	$0.0001^{\cdot}$		-0.000	
		(0.000)		(0.000)	
	ΔFOB_Diesel		0.0002^{**}		-0.000
			(0.000)		(0.000)
Vacation	Start Summer	-0.012^{***}	-0.010^{**}	-0.014^{***}	-0.007^{*}
		(0.003)	(0.003)	(0.003)	(0.004)
	End Summer	-0.026^{***}	-0.021^{***}	-0.035^{***}	-0.022^{***}
		(0.003)	(0.003)	(0.004)	(0.003)
Holiday	State	-0.009^{*}	-0.010^{*}	0.003	-0.000
		(0.004)	(0.004)	(0.004)	(0.004)
	National	0.008^{*}	0.012^{***}	0.031^{***}	0.030^{***}
		(0.003)	(0.003)	(0.004)	(0.004)
Weekend	Sunday	-0.001	0.002	0.014^{***}	0.013^{***}
		(0.003)	(0.003)	(0.003)	(0.003)
	Saturday	$-0.004^{\cdot}$	-0.001	0.008^{***}	0.009^{***}
		(0.002)	(0.002)	(0.002)	(0.002)

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

This table shows the parameters for wholesale prices, vacation, holiday and weekend dummies as used in the main regression of subsection 6.2 and displayed in Table 4. Wholesale prices are (weakly) significant for price increases only and have small coefficients. This implies a low relevance for intra-day pricing decisions, which is understandable as station operators will insure themselves against volatility and because wholesale prices are posted daily, not hourly.

It can be observed that both the start and the end of the state-specific summer vacations leads to a reduced probability of price changes. While the same applies to official state holidays, the opposite can be observed for national holidays which raise the probabilities for price changes in both directions and of both fuel types. Weekends increase the likelihood of price decreases for both fuel types, but barely effect the likelihood of price increases. Given the overall results of higher traffic prompting more intense cycles, national holidays could be considered predictable events of higher traffic, inducing a change in regime towards more fluctuation. Contrastingly, the start and end of state summer vacations would likewise indicate higher traffic volumes, but also presents a shift towards more time-sensitive consumers racing to reach their destinations, thus permitting higher price premiums and less cycling.

Overall, the vacation, holiday and weekend effects have only small impacts.

Table 10: Determinants of Price Change Decisions for AH

	Endog. Var	$Prob(P^F > 0)$		$Prob(P^F < 0)$	
	Fuel Type	E5 Gasoline	Diesel	E5 Gasoline	Diesel
Demand	Pkw	0.003^{***}	0.003^{***}	0.008^{***}	0.008^{***}
		(0.000)	(0.001)	(0.000)	(0.000)
	Lkw	0.007^{***}	0.006^{***}	0.010^{***}	0.010^{***}
		(0.002)	(0.002)	(0.002)	(0.002)
	ΔPkw	0.055^{***}	0.055^{***}	-0.064^{***}	-0.070^{***}
		(0.009)	(0.009)	(0.009)	(0.010)
	ΔLkw	-0.047^{***}	-0.043^{***}	-0.033^{***}	-0.036^{***}
		(0.011)	(0.011)	(0.007)	(0.007)
Wholesale	ΔFOB_E5	-0.000		0.000	
		(0.000)		(0.000)	
	ΔFOB_Diesel		0.0002^{*}		-0.000
			(0.000)		(0.000)
BAT Competitors	$\overline{\Delta P^{E5}_{BAT}}$	-0.007^{***}		0.014^{***}	
		(0.001)		(0.001)	
	$\Delta P^{E5}_{BAT} > 0$	0.144^{***}			
		(0.010)			
	$\Delta P^{E5}_{BAT} < 0$			0.161^{***}	
				(0.009)	
	$\overline{\Delta P^{Diesel}_{BAT}}$		-0.007^{***}		0.014^{***}
			(0.001)		(0.002)
	$\Delta P^{Diesel}_{BAT} > 0$		0.145^{***}		
			(0.009)		
	$\Delta P^{Diesel}_{BAT} < 0$				0.165^{***}
					(0.009)
AH Competitors	$\overline{\Delta P^{E5}_{AH}}$	0.031^{***}		-0.037^{***}	
		(0.002)		(0.001)	
	$\Delta P^{E5}_{AH} > 0$	0.466^{***}			
		(0.015)			
	$\Delta P^{E5}_{AH} < 0$			0.348^{***}	
				(0.010)	
	$\overline{\Delta P^{Diesel}_{AH}}$		0.029^{***}		-0.035^{***}
			(0.002)		(0.001)
	$\Delta P^{Diesel}_{AH} > 0$		0.467^{***}		
			(0.015)		
	$\Delta P^{Diesel}_{AH} < 0$				0.343^{***}
					(0.010)
Vacation	Start Summer	-0.004	-0.002	0.002	0.001
		(0.004)	(0.004)	(0.005)	(0.006)
	End Summer	-0.003	-0.004	-0.007	-0.004
		(0.003)	(0.004)	(0.005)	(0.004)
Holiday	State	0.009^{*}	$0.009^{\cdot}$	0.018^{**}	0.022^{***}
		(0.005)	(0.005)	(0.006)	(0.006)
	National	0.015^{**}	0.012^{*}	0.012^{*}	0.013^{*}
		(0.005)	(0.005)	(0.006)	(0.006)
Weekend	Sunday	0.013^{**}	0.014^{**}	0.012^{*}	0.012^{*}
		(0.004)	(0.005)	(0.005)	(0.005)
	Saturday	0.007^{*}	0.008^{*}	$0.006^{\cdot}$	$0.006^{\cdot}$
		(0.003)	(0.003)	(0.004)	(0.003)
	Station-FE	yes	yes	yes	yes
	Adj. R^2	0.49	0.49	0.44	0.43
	Num. obs.	719,747	719,747	719,747	719,747

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Analysis of the determinants of hourly price change decisions for all AH stations in 2018. Standard errors are corrected for autocorrelation and heteroskedasticity using Arellano's method with clustering on the station level. Hence, the R^2 is not informative. Columns (1) and (2) depict the determinants of the decision to raise prices for a given station in a given hour for gasoline and diesel, respectively. Columns (3) and (4) depict the same for the decision to lower prices. The control variables include hourly truck and car traffic, in 100 vehicle steps, as well as its trend. First differences of distance-weighted competitor prices and dummy variables indicating their pricing decisions are included for each fuel and station type. Information on AH competitors must be understood as an interaction term of the variable itself and the existence of AH competitors. Holidays, the start and end of summer vacations and weekends are demarked by dummies. Fixed effects and wholesale prices in first differences are included.

Table 11: Determinants of the Absolute Volume of Price Change Decisions: Dummy Details

	Endog. Var	$\lvert\Delta p_{it}\rvert$			
	Fuel Type	E5 Gasoline		Diesel	
	, if:	$\Delta p_{it} > 0$	$\Delta p_{it} < 0$	$\Delta p_{it} > 0$	$\Delta p_{it} < 0$
Vacation	Start Summer	-0.34^{***}	-0.36^{***}	-0.09	-0.17^{**}
		(0.05)	(0.05)	(0.06)	(0.05)
	End Summer	-0.34^{**}	-0.24^{*}	-0.26^{***}	-0.26^{***}
		(0.12)	(0.11)	(0.06)	(0.05)
Holiday	State	-0.40^{***}	-0.44^{***}	-0.41^{***}	-0.45^{***}
		(0.07)	(0.06)	(0.09)	(0.07)
	National	0.00	-0.03	-0.13^{*}	-0.15^{*}
		(0.05)	(0.06)	(0.06)	(0.06)
Weekend	Sunday	-0.12^{**}	-0.16^{***}	-0.12^{**}	-0.18^{***}
		(0.04)	(0.04)	(0.04)	(0.04)
	Saturday	-0.11^{***}	-0.15^{***}	-0.09^{**}	-0.15^{***}
		(0.03)	(0.03)	(0.03)	(0.03)

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

This table shows the parameters for vacation, holiday and weekend dummies as used in the main regression of subsection 6.3 and displayed in Table 5.
Both the start and the end of the summer vacation periods have a contracting influence on price changes, i.e. smaller decreases and increases in cent per liter, especially for gasoline by 0.24 to 0.36 cent per liter. Both may reflect strategy changes reacting to holiday travellers in addition to the demand effects caused by their travel. State holidays similarly contract price changes by 0.4 to 0.45 ct/l, whereas national holidays interestingly only affect diesel prices, presumably through strategy changes in reaction to depressed truck traffic. Saturdays and Sundays similarly contract volume changes weakly. In general, these coefficients imply a reduction in price volatility over the tested days and periods, which might result from a more even and less commercial traffic distribution throughout the day. That would lead to fewer peak demand phases and as a result to fewer undercutting operations.

Table 12: Determinants of the Absolute Volume of Price Change Decisions for AH

	Endog. Var	$\lvert\Delta p_{it}\rvert$			
	Fuel Type	E5 Gasoline		Diesel	
	, if:	$\Delta p_{it} > 0$	$\Delta p_{it} < 0$	$\Delta p_{it} > 0$	$\Delta p_{it} < 0$
Demand	Pkw	-0.02^{***}	-0.03^{***}	-0.02^{***}	-0.03^{***}
		(0.00)	(0.00)	(0.00)	(0.00)
	Lkw	0.00	-0.04^{**}	0.02	-0.03^{**}
		(0.01)	(0.01)	(0.01)	(0.01)
	ΔPkw	0.31^{**}	0.06	0.40^{***}	0.12^{**}
		(0.10)	(0.04)	(0.11)	(0.04)
	ΔLkw	0.11	0.10^{*}	0.04	0.09^{*}
		(0.07)	(0.04)	(0.09)	(0.04)
BAT Competitors	$\overline{\Delta P_{BAT}^{E5}}$	0.05^{***}	-0.08^{***}		
		(0.01)	(0.01)		
	$N(\Delta P_{BAT}^{E5} \neq 0))$	0.13	$0.10^{\cdot}$		
		(0.10)	(0.05)		
	$\overline{\Delta P_{BAT}^{Diesel}}$			0.04^{**}	-0.08^{***}
				(0.01)	(0.01)
	$N(\Delta P_{BAT}^{Diesel} \neq 0))$			0.16	$0.11^{\cdot}$
				(0.13)	(0.06)
AH Competitors	$\overline{\Delta P_{AH}^{E5}}$	0.50^{***}	-0.42^{***}		
		(0.02)	(0.02)		
	$\lvert\overline{\Delta P_{AH}^{E5}}\rvert \upuparrows$	0.46^{***}	0.83^{***}		
		(0.07)	(0.07)		
	$N(\Delta P_{AH}^{E5} \neq 0))$	0.16^{**}	-0.14^{***}		
		(0.06)	(0.03)		
	$\overline{\Delta P_{AH}^{Diesel}}$			0.55^{***}	-0.45^{***}
				(0.02)	(0.02)
	$\lvert\overline{\Delta P_{AH}^{Diesel}}\rvert \upuparrows$			0.43^{***}	0.86^{***}
				(0.07)	(0.08)
	$N(\Delta P_{AH}^{Diesel} \neq 0))$			$0.10^{\cdot}$	-0.15^{***}
				(0.06)	(0.04)
Vacation	Start Summer	0.01	0.02	0.08^{*}	0.11^{**}
		(0.04)	(0.03)	(0.04)	(0.03)
	End Summer	0.01	-0.01	0.03	0.01
		(0.04)	(0.03)	(0.04)	(0.03)
Holiday	State	$0.12^{\cdot}$	0.06	0.16^{**}	0.06
		(0.06)	(0.05)	(0.06)	(0.05)
	National	-0.04	-0.10^{**}	0.06	$-0.07^{\cdot}$
		(0.05)	(0.04)	(0.06)	(0.04)
Weekend	Sunday	0.06	-0.03	0.11^{*}	-0.01
		(0.05)	(0.03)	(0.05)	(0.04)
	Saturday	0.05	$-0.05^{\cdot}$	0.09^{*}	-0.03
		(0.03)	(0.03)	(0.03)	(0.03)
	Adj. R^2	0.38	0.28	0.43	0.32
	Num. obs.	214,067	278,704	214,743	278,992
	Station-FE	YES	YES	YES	YES

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{\cdot}p < 0.1$

Analysis of the determinants of the volume of all price change decisions in 2018 for all AH stations. Standard errors are corrected for autocorrelation and heteroskedasticity using Arellano's method with clustering on the station level, hence the R^2 is not informative. The dependent variables are the absolute cent/liter changes in E5 gasoline and diesel prices for positive - columns (1) and (3) - and negative changes - columns (2) and (4). respectively. Gasoline is shown first, diesel second. Demand variables are the hourly truck and car traffic, in 100 vehicle steps, as well as their trends. Competitor behaviour is assessed by the first differences of distance-weighted competitor prices and the number of price changes in the given hour by BAT and AH stations. Information on AH competitors must be understood as an interaction term of the data itself and the existence of AH competitors. Holidays, the start and end of summer vacations and weekends are demarked by dummies and fixed effects are included.

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