Competition and Pricing on Retail Gasoline Markets

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Preface

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List of Abbreviations

ACCC	Australian Competition and Consumer Commission
ADAC	Allgemeiner Deutscher Automobil-Club
BBR	Bundesamt für Bauwesen und Raumordnung
BMI	Bundesministerium des Inneren
BTG	Bundesverband Tankstellen und Gewerbliche Autowäsche Deutschland
CNG	Compressed Natural Gas
EBV	Erdölbevorratungsverband
EID	Energie Informationsdienst
FOT	Free on Tank-Lorry
GDP	Gross Domestic Product
GLS	Generalized Least Square
KMK	Kultusministerkonferenz
LPG	Liquified Petroleum Gas
MPE	Markov Perfect Equilibrium
MSA	Metropolitan Statistical Area
MTS-K	Markttransparenzstelle für Kraftstoffe
NRW	North Rhine-Westphalia
OECD	Organisation for Economic Co-operation and Development
O.M.R.	Oil Market Report
RON	Research Octance Number

Chapter 1

Introduction

Competition and pricing on retail gasoline markets are frequently discussed topics among consumers, in the media, and at authorities alike. Specifically in times of record-breaking price levels or price volatility, consumers and the media regularly express their suspicion of anti-competitive practices conducted by market-dominating players. Typically, the behavior of major-brand gas stations is vigorously discussed, associated with debates on potential policy interventions in order to assure an adequate level of competitiveness on gasoline retail markets.[1]

Consequently, gasoline retail markets around the globe are frequently subject to in-depth inquiries by competition authorities and research organizations (see, e.g., ACCC 2007 for a report of the Australian authority or Conference Board of Canada 2001 for a Canadian report). The OECD (2013) collated investigations conducted by competition authorities in 31 member countries and acknowledged that gasoline retail markets are considered competitive in some countries. At the same time, however, competitiveness is threatened by the presence of a few vertically integrated players and high entry barriers in a number of countries. On top, typical pricing patterns such as "rockets and feathers" pricing or Edgeworth-type price cycles found on many local markets are considered as signs of imperfect competition. In light of extensive evidence on implicit collusion among gas station operators, the OECD report, eventually, admits that distinguishing lawful from unlawful conduct is a key challenge for many authorities (see OECD 2013, pp. 5-8 for a summary of findings across member countries).

In some cases, authorities' investigations have led to policy measures with varying degrees of market intervention, from increased transparency through an online price database (e.g., in Austria, Western Australia), price pre-notifications and a limit on

[1] In a report for the German automobile association ADAC, Dewenter, Haucap, and Heimeshoff (2012), for example, examine possible information policy, competition policy, and price regulation measures, informed by experimental results and international experiences.

the frequency of price changes (e.g., in Western Australia) or price increases (e.g., in Austria), a price ceiling (e.g., in Luxembourg), to even a price fixing mechanism (e.g., in the Canadian Province Nova Scotia).[2] In Germany, the most comprehensive inquiry into the sector was conducted by the Federal Cartel Office from 2008 until 2011. In their final report, the German authority substantiates its suspicion of a market-dominating oligopoly – comprising the five players BP (Aral), Shell, Total, ExxonMobil (Esso), and Jet – and documents behaviors suggesting implicit collusion among those players. Furthermore, pricing in four model regions (with 407 gasoline stations) have been empirically observed, revealing the presence of recurring price cycles (see Bundeskartellamt 2011a,b). In 2012, the German parliament passed a law, which included the set-up of a market transparency unit for fuels. Thereby, the legal basis for the introduction of a nationwide price database was created (also see Monopolkommission 2012).

Given its market structure, gasoline retail markets are an interesting field for empirical studies (compare Bundeskartellamt 2011a, pp. 20-21; Dewenter, Haucap, and Heimeshoff 2012, pp. 5-10; OECD 2013, pp. 9-30). Amongst relevant market characteristics, which to a large extent foster parallel conduct, are

- High mutual market shares of a few vertically integrated oil companies with largely similar interests and repeated interactions (e.g., through joint ventures)
- High degree of market transparency (in a local market area), together with low station operators' menu costs and low consumers' switching costs
- High level of product homogeneity, with product differentiation being primarily a result of locational advantage, brand recognition, or by-products
- Low level of product innovation (exceptions include "premium fuels"), and
- Relatively low (product-specific) price elasticity of demand.

A wide range of empirical studies have been published in the area of gasoline retailing. Byrne (2012), Eckert (2013), and Noel (2016) contribute extensive literature reviews citing more than 100 empirical papers in total. Early studies focused on gasoline markets in the U.S. or Canada (e.g., Castanias and Johnson 1993; Shepard 1993; Slade 1987, 1992), while several contributions from Australia (e.g., Wang 2008, 2009) and a few European countries (e.g., Asane-Otoo and Schneider 2015;

[2]See Dewenter, Haucap, and Heimeshoff 2012, pp. 11-15 for an overview of international experiences, Dewenter and Heimeshoff 2012 for empirical evidence, or Haucap and Müller 2012 for experimental findings on policy interventions.

Dewenter, Heimeshoff, and Lüth 2017; Foros and Steen 2008, 2013; Frondel, Vance, and Kihm 2016; Kihm, Ritter, and Vance 2016) have been added more recently, largely as a result of better data availability.

Numerous papers discuss questions related to price dynamics, specifically focusing on the two areas "rockets and feathers" pricing and Edgeworth price cycling (Noel 2016). The rockets and feathers phenomenon explores the dynamic relationship between input and retail prices under the hypothesis of an asymmetric response of gasoline prices to oil price shocks (i.e., a quick, rocket-like increase as a reaction to oil price increases and a slow, feather-like decrease as a reaction to oil price decreases; see, e.g., Bacon 1991; Borenstein, Cameron, and Gilbert 1997; Frondel, Vance, and Kihm 2016; Noel 2009). Edgeworth cycles, formalized by Maskin and Tirole 1988, in turn, refer to a repeated retail pricing pattern characterized by stepwise price undercuttings among (local) competitors until prices converge to costs, followed by a substantial price increase, which restarts the cycle (see, e.g., Doyle, Muehlegger, and Samphantharak 2010; Isakower and Wang 2014; Noel 2007b). While both rockets and feathers pricing and Edgeworth cycles describe asymmetric pricing phenomena, they differ as price changes are either caused by cost shocks or happen independent of costs. Empirical studies in this area typically focus on identifying either of the two dynamic pricing patterns, search for reasons why and where they exist, and describe their main features (e.g., cycling cities are found to be characterized by a higher share of independent retail stations; see Noel 2007a). While several authors are able to provide evidence of Edgeworth-type cycles in numerous cities and market areas, their competitive impact is largely unclear, albeit recent studies suggest that cycling markets tend to result in lower average price levels (see, e.g., Doyle, Muehlegger, and Samphantharak 2010; Noel 2011, 2015).[3] There are also studies combining the two concepts of rockets and feathers pricing and Edgeworth cycles in the sense that cost increases trigger a cycle restoration, while cost decreases allow for leeway to conduct price undercuttings (see, e.g., Eckert 2002; Lewis 2009; Lewis and Noel 2011; Noel 2009).

Another stream of empirical literature on gasoline retailing focuses on identifying price determinants (see, e.g., Barron, Taylor, and Umbeck 2004; Hosken, McMillan, and Taylor 2008). Within this stream, a number of studies specifically investigate price dispersion and price differentials among stations (see, e.g., Lewis 2008; Pennerstorfer et al. 2015). Often, variables reflecting brand association, station location and characteristics, or the competitive environment seem to have an impact on re-

[3] Assuming consumers are informed (e.g., as a result of price transparency through an online database) and adapt their purchase timing decision accordingly, unweighted average prices might be upward biased vis-à-vis realized prices (also see Noel 2012; Noel and Chu 2015).

tail prices or margins (Eckert 2013, p. 153). Beyond this, questions around merger evaluation, regulatory interventions, sales-below-cost, or vertical restraints have also attracted researchers' attention (see, e.g., Dewenter and Heimeshoff 2012; Dewenter, Heimeshoff, and Lüth 2017; Houde 2012; Simpson and Taylor 2008; Wang 2009).

With this dissertation, I contribute empirical investigations of pricing mechanisms and salient features of competition economics on retail gasoline markets in Germany to the existing literature. Most empirical studies use daily, weekly or even quarterly price data of specific cities or regions – either on a (city-)average basis or a station-by-station level – and partly include covariates such as the share of independent gasoline stations or the density of population in a given market area (Atkinson 2009). In contrast, studying competition and pricing on German gasoline markets in much more detail is enabled by a novel data set: Initiated by the German Federal Cartel Office, the so-called market transparency unit for fuel ("Markttransparenzstelle für Kraftstoffe", MTS-K) collects a census of price quotes from virtually all German gasoline stations since the end of 2013 (see Bundeskartellamt 2013 for information on the concept and Bundeskartellamt 2014, Bundeskartellamt 2015, as well as Bundeskartellamt 2017 for descriptive statistics on data collected by the MTS-K). For this thesis, I use price data between January 2014 and June 2016, which was provided by authorized consumer information provider "1-2-3 Tanken" and includes

- Exact station-level price quotes for gasoline (i.e., Super E5, Super E10) and diesel fuel types
- Basic information on each gasoline station's location (including address and geographical coordinates)
- Brand affiliation for numerous gasoline station chains, and
- Business hours per weekday and gasoline station.

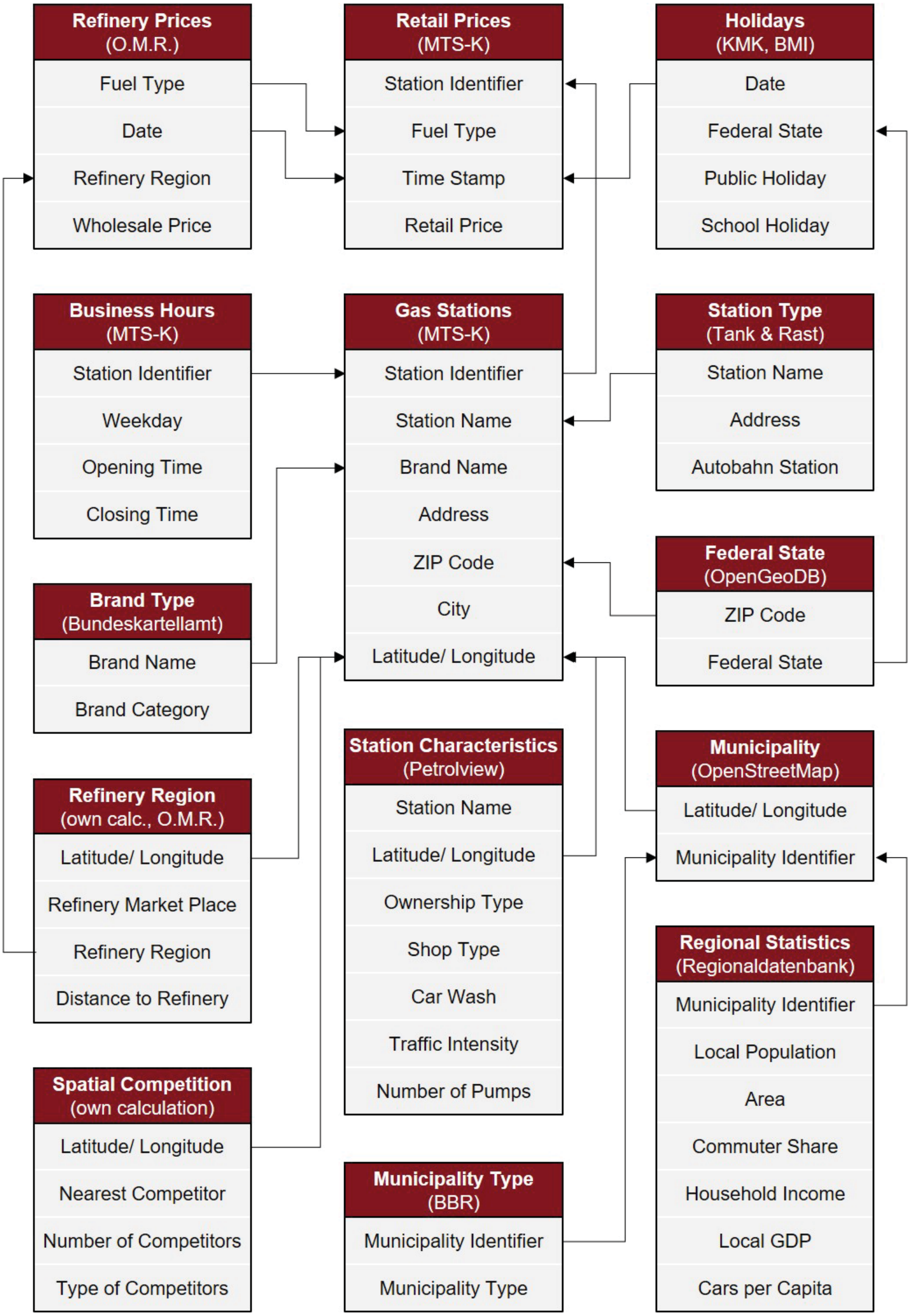
Moreover, in the course of this dissertation, a range of further data sources have been gathered and connected with MTS-K data to present a holistic view on competition and pricing on gasoline retail markets (see Figure 1.1 for a schematic overview of data sets, data fields, sources, and interconnections). Supplementary data includes

- "Ex-refinery" wholesale prices by refinery region (generated by independent service provider "Oil Market Report", O.M.R.)
- Various gasoline station characteristics such as size of shop or availability of car wash (generated by data provider "Petrolview")

- Identification of gasoline stations located at highway ("Autobahn") service areas (gathered from operator "Tank & Rast")
- Categorization of gasoline stations by brand groups (following Bundeskartellamt 2011b, pp. 13/21)
- Measures of spatial competition for each gasoline station (calculated as "orthodromic distance")
- Public holidays by federal state (published by the German Ministry of Internal Affairs, BMI)
- School holidays by federal state (published by the standing conference of the ministers of education, KMK)
- Unique municipality identifiers (through reverse geocoding, using "OpenStreetMap" data)
- Classification of municipality types (following "Bundesamt für Bauwesen und Raumordnung", BBR), and
- Local demand statistics such as population, cars, or commuter shares (published by the "Regionaldatenbank Deutschland").

Enabled by the sound database described above, the aim of this thesis is to provide a comprehensive perspective on price level determinants, to analyze competition dynamics in local market areas, and to explore high-frequency, intraday price cycles. The following Chapter 2 on *Fuel Prices and Station Heterogeneity on Retail Gasoline Markets* (co-authored by Justus Haucap and Ulrich Heimeshoff), therefore, starts with a large-scale investigation into how and why price levels and the number of price changes differ across gasoline stations in Germany. Using both daily average prices as well as specific point-in-time prices allows to analyze pricing behaviors at different times of the day, by brand, location, and station characteristics, across different fuel types and in varying competitive environments.

Chapter 3 with the title *Selling Gasoline as a "By-Product": The Impact of Market Structure on Local Prices* (co-authored by Justus Haucap and Ulrich Heimeshoff) presents a rare, plausibly causal analysis on pricing patterns in local market areas (compare Noel 2015 for another causal analysis, investigating the exogenous shock of a refinery fire on price cycling). We explore a salient feature of competition on local markets, namely the influence of market structure on local price competition. Our identification strategy focuses on stations selling gasoline as a "by-product" (e.g., as



Note: Data sources in parentheses; arrows indicate links among data sets; not all data fields shown.

Figure 1.1: Schematic Overview of Data Sets

an add-on to supermarket or car wash operations) with varying, exogenously determined opening hours. We are first to present an analysis using hourly prices across numerous market areas.

Chapter 4 on *Characteristics, Causes, and Price Effects: Empirical Evidence of Intraday Edgeworth Cycles*, hereafter, establishes a link between Edgeworth cycle theory and empirically observed, high-frequency price cycles. In this chapter, I present unique evidence of the presence, causes, and price effects of price cycles on an intraday level, described by statistical indicators for both cycle asymmetry and cycle intensity. While the two previous chapters relied on the first full year of price data from the MTS-K, Chapter 4 investigates an enlarged period of observation from mid-2014 to mid-2016. Thereby, I specifically analyze a structural change in the intraday price equilibrium (with the introduction of a minor price increase around noon across the majority of gas stations) first observed in June 2015 (see Bundeskartellamt 2015, pp. 20-23).

In sum, this thesis presents a comprehensive empirical view on competition and pricing on retail gasoline markets in Germany. Chapter 5, eventually, concludes with a summary of findings, a discussion of policy implications, and specific ideas for further research in the field of gasoline retailing.

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Chapter 2

Fuel Prices and Station Heterogeneity on Retail Gasoline Markets[1]

Price levels and movements on gasoline and diesel markets are heavily debated among consumers, policy-makers, and competition authorities alike. In this paper, we empirically investigate how and why price levels differ across gasoline stations, using the first full year from a novel panel data set including price quotes from virtually all stations in Germany. Our analysis specifically explores the role of station heterogeneity in explaining price differences across gasoline stations. Key determinants of price levels across fuel types are found to be ex-refinery prices as key input costs, a station's location on roads or highway service areas, and brand recognition. A lower number of station-specific services implies lower fuel price levels, as does a more heterogeneous local competitive environment.

[1]This chapter, co-authored by Justus Haucap and Ulrich Heimeshoff, is forthcoming in *The Energy Journal* (Haucap, Heimeshoff, and Siekmann 2017).

2.1 Introduction

Competition and pricing on retail gasoline and diesel markets are highly debated topics among consumers, media as well as regulatory and antitrust authorities in many countries around the globe (see OECD 2013). Gasoline and diesel markets, and their retail segments in particular, have also been a field of intensive empirical research, around (asymmetric) pass-through of wholesale prices, evaluation of market power, or the effects of regulatory interventions, to name just a few examples (see Houde 2011; Noel 2007a,b, 2009). In particular, studies focusing on dynamic pricing behavior and characteristics of price cycles as well as studies analyzing (station-level) price dispersion and determinants of price levels have received substantial attention (see Eckert 2013; Noel 2011; Noel and Chu 2015). In addition, numerous competition authorities have conducted in-depth inquiries into the sector (see ACCC 2007; Bundeskartellamt 2011a; OECD 2013).

In order to understand competition processes in these markets and to evaluate potential market interventions, it is important to gain a solid understanding of the factors that affect prices. So far, hardly any attention has been paid to the fact that gas stations and their competitive environments are rather heterogeneous. While the physical product itself (i.e., gasoline or diesel) is fairly homogenous, stations' location, brand name, and service facilities are elements of product differentiation that should impact pricing. A major difficulty for such analyses has been limited data availability. In fact, comprehensive pricing data sets for empirical investigations have been very difficult to obtain, as gasoline and diesel are sold through numerous local gas stations. Several existing empirical studies, primarily for regional areas in the U.S. and Canada, hence, have relied on city-level data or survey data from a small sample of stations (e.g., Borenstein and Shepard 1996; Lewis 2009; Noel 2007a, 2015; Shepard 1993), in part with self-collected price observations (e.g., Atkinson 2009; Noel 2007b; Slade 1987, 1992). Recently, however, regulatory requirements on price transparency in some regions have led to more comprehensive and centrally collected databases. As an example, Wang (2009a) uses a census of daily prices for the city of Perth in Western Australia, collected by a regulatory body, to document oligopoly pricing strategies in a time-controlled market environment.[2] None of these studies, however, has accounted for the heterogeneity of gas stations.

A fascinating opportunity to learn more about retail gasoline pricing and the particular effect of station heterogeneity has recently emerged, as a major OECD country, namely Germany, introduced a gasoline price transparency platform. Since

[2]This represents a census of price data as Western Australian stations are restricted to a single price change per day.

December 2013, virtually all gas stations are required to notify all price changes to Germany's competition authority, the Federal Cartel Office, which collects the data and makes it available to internet price comparison platforms. This data set allows us to analyze retail gasoline pricing in a market without pricing regulations.[3] The advantage of our data set, in contrast to large portions of the existing literature, is that it includes data for all fuel stations and corresponding price changes in Germany, presenting a comprehensive picture of competition within fuel markets for an entire, major OECD country. As a result, we obtain a representative view of competition in German fuel markets, in urban as well as rural regions. These results are much easier to generalize than results obtained from empirical studies based on limited data sets covering a small subset of cities or regions, which will typically not provide a representative picture of competition in nationwide fuel markets. By combining price data with various stations characteristics (e.g., amenities such as shop offerings or car wash facilities) and measures for spatial competition, we are able to identify key factors determining station-level prices at different times of the day (e.g., day- and nighttime), in different segments (e.g., road and highway stations) and in different product markets.[4]

Our empirical investigation, thus, specifically looks at how and why price levels as well as the number of price changes differ across stations. Using average and point-in-time price metrics, we explore the impact a range of variables has on prices, subject to different levels of competition intensity across the day. We find that a significant part of the distribution of prices can be linked to observable station characteristics and wholesale price shocks. Ex-refinery prices are a good predictor of input cost changes, while stations located at highway service areas or associated with premium brands charge significantly higher prices. Analyzing brand categories as well as individual brands, we find that certain brands have distinctly different day- and nighttime pricing strategies in response to local competition intensity. Moreover, additional service offerings positively affect price levels, while heterogeneity among local competitors appears to lead to lower prices. Finally, stations offering gasoline as a by-product (e.g., supermarket-owned stations) have distinctly lower prices, albeit opening hours are structurally different.

The rest of this paper is structured as follows: We will start with an overview of

[3]Station operators in Germany are neither restricted in the frequency nor in the direction or magnitude of price changes.

[4]Road and Autobahn (i.e., highway service area) stations are considered distinct business segments (with a distinct competitive environment) as the single player "Tank & Rast GmbH" is responsible for leasing out all Autobahn stations. Gasoline (i.e., Super E5 and Super E10) and diesel represent non-substitutable product markets in the short- to medium-term due to technical characteristics of engines. For more details, see section 3.3.1.

related empirical literature in the following section. Section 2.3 then describes the German gasoline and diesel market as well as our data set, which includes (retail and wholesale) price data as well as station characteristics. Section 4.5 follows with the empirical analysis and results. Finally, section 4.6 summarizes main findings, highlights limitations and provides ideas for further research.

2.2 Related Literature

Much of the literature on gasoline retail markets focuses on price dynamics, by either looking at how upstream costs such as oil prices are passed through to retail prices or by linking (elements of) what is known as Edgeworth cycles to empirically observed price patterns (see Eckert 2013 or Byrne 2012 for an overview). Studies of the latter group analyze patterns resembling asymmetric price cycles, based on theoretical work formalized by Maskin and Tirole (1988).[5] These recurring cycles are characterized by a phase of fast and large price increases, in theory to a level slightly above the monopoly price ("relenting phase"), and a longer sequence of small step-wise price cuts, down to the level of marginal cost ("undercutting phase").

Another stream of empirical research focuses instead on identifying key determinants of station- or market-level prices, for instance, as a result of mergers (e.g., Simpson and Taylor 2008) or regulatory interventions (e.g., Carranza, Clark, and Houde 2015; Dewenter and Heimeshoff 2012). Within this stream, there are also studies that focus on price dispersion and price differentials (e.g., Barron, Taylor, and Umbeck 2004; Lewis 2008).

Most of the empirical studies on gasoline retail pricing focus on U.S. markets (e.g., Borenstein and Shepard 1996; Doyle, Muehlegger, and Samphantharak 2010; Lewis and Noel 2011; Shepard 1993; Zimmerman, Yun, and Taylor 2013), Canada (e.g., Atkinson 2009; Byrne, Leslie, and Ware 2015; Noel 2009, 2015; Slade 1987, 1992), and Australia (e.g., Valadkhani 2013; Wang 2008, 2009a,b; Wills-Johnson and Bloch 2010b). For European countries, fewer empirical studies are available. For the Norwegian market, Foros and Steen (2013) use a (consumer-submitted or self-observed) unbalanced panel data set of gasoline prices at Norwegian stations to estimate a fixed-effect model. Controlling for regional, brand, and weekday effects, among others, the model supports their observation of implicit price control

[5]The basic model of Maskin and Tirole (1988) has been refined over the last years, for example, by Eckert (2003), Noel (2008), and Wills-Johnson and Bloch (2010a). See Noel (2011) for a non-technical introduction to Edgeworth cycle theory. Numerous empirical studies focus on elements of Edgeworth cycles on gasoline markets, among them are Doyle, Muehlegger, and Samphantharak (2010), Isakower and Wang (2014), Noel (2007b), and Zimmerman, Yun, and Taylor (2013).

mechanisms at the headquarters of leading companies. The authors find evidence of a significant "day-of-the-week" effect, where prices seem to regularly "jump up" on Mondays. Applying a difference-in-differences model with weekly nationwide price data from 27 European countries, Dewenter, Heimeshoff, and Lüth (2017) find evidence for price increases in Germany as a result of increased transparency.[6] Moreover, in a recent paper, Pennerstorfer et al. (2015) look at quarterly diesel prices of Austrian stations to study the relationship between information (approximated by the fraction of commuters) and measures of price dispersion to generate routing-based measures for spatial competition and market area delineation. For Germany, a largely descriptive pricing investigation was conducted by the Bundeskartellamt (2009, 2011a,b) as part of its sector inquiry on fuels. The analysis of pricing in four German cities revealed the existence of recurring Edgeworth-type cycles, which the authority interpreted as evidence for collusive behavior.[7] In a recent paper, Kihm, Ritter, and Vance (2016) examine how crude oil price increases are passed through by major brands vis-à-vis other brands. The authors use large-scale customer-submitted price data from January 2012 to February 2013 and find heterogeneity in the extent of cost pass-through as well as a statistically significant but economically small impact of competition metrics.[8]

In our empirical analysis, we will specifically look at how and why price levels differ across various stations in Germany. Hosken, McMillan, and Taylor (2008) is related to this analysis. The authors use station-specific, weekly gasoline prices from a sample of 272 stations around Washington, D.C. from 1997 to 1999 to investigate the existence and dynamics of price dispersion as well as the impact of supplier and market characteristics on retail price levels. They find frequently changing (relative) price positions (i.e., stations do not apply simple pricing rules) and substantial differences in the impact of various brands.

For our analysis, we rely on a large-scale price data set and various station-specific characteristics to study price distribution as well as the influence of local competition, supply characteristics and demand-side effects on price levels. After a brief introduction to the German gasoline market and to the data used in the following section, we will present empirical findings on what affects station-specific price levels in section 4.5.

[6] In an earlier study, Dewenter and Heimeshoff (2012) compare the impact of Austrian pricing regulation on price levels, finding a significant price-lowering effect.

[7] The four cities were Cologne, Hamburg, Munich, and Leipzig; in total, price movements at 407 gasoline stations were analyzed with data from 1 January 2007 to 30 June 2010.

[8] Empirical studies on asymmetric pass-through of wholesale costs to retail prices in non-European countries include Bachmeier and Griffin (2003), Bacon (1991), Borenstein, Cameron, and Gilbert (1997), Eckert (2002), Lewis (2009), Noel (2009), and Radchenko (2005).

2.3 German Retail Gasoline Markets and Data

2.3.1 Market Characteristics

Gasoline and diesel are both fairly homogeneous products (in terms of their physical characteristics) and are sold exclusively via retail gasoline and diesel stations. Product differentiation results primarily from the spatial location of a specific station, its brand recognition and additional services such as shop offerings, while product innovation does not play a significant role (see, e.g., OECD 2013, pp. 9-30).[9] Most common fuel types sold at German stations are gasoline – specifically "Super E5", with a minimum research octane number (RON) of 95 and up to 5% of ethanol or "Super E10", with 95 RON and 10% ethanol – as well as diesel.[10] Gasoline and diesel constitute different product markets in the short- to medium-term, as consumers cannot substitute between the two fuel types given different technical specifications of engines (see, e.g., Bundeskartellamt 2011a).[11] Notwithstanding the above, most consumers may freely choose between the two gasoline products Super E5 and Super E10; only very few (older) cars are not designed or not recommended to use Super E10.

Only five vertically integrated oil companies have both a large nationwide network of stations (and, thus, comparably high market shares), and substantial direct access to refining capacities in Germany. These players have been argued to have fairly similar interests and to be well-connected (e.g., through joint ventures for refineries, tank farms, or pipelines; Bundeskartellamt 2011b, pp. 20-21, 2009, pp. 9-11). As these companies also supply competitors' retail stations, their influence is larger than reflected by the sheer number or market share of branded retail sites. In general, brand affiliation and ownership of a station are not contingent on each other. It is, therefore, helpful to distinguish between oil company and dealer ownership of stations next to brand affiliation (see Shepard 1993, pp. 60-66 or Bundeskartellamt 2011b, pp. 166-171). Apart from "major" players, gasoline and diesel stations are operated either by other integrated oil companies with a rather regional footprint and without substantial access to refinery capacities, or by a large number

[9] Several large retail players in Germany offer customer loyalty programs as a means of differentiation (e.g., Aral with Payback, Shell with ClubSmart, or Esso with DeutschlandCard).

[10] Other fuel types offered at German stations include, most notably, different "premium" fuels, with higher octane ratings (for gasoline) or special additives (for gasoline and diesel). Furthermore, several stations sell liquefied petroleum gas (LPG, "Autogas") or compressed natural gas (CNG, "Erdgas") as alternative fuel types. Finally, numerous stations offer special truck diesel at high-speed pumps (see, e.g., `www.adac.de/infotestrat/tanken-kraftstoffe-und-antrieb`).

[11] In the long-run, gasoline and diesel may indeed be considered substitutes, as most cars are available with different engine types and most stations in Germany – as opposed to other countries – offer gasoline as well as diesel fuel types.

of small-to-medium sized retailers ("independents"), many of which cooperate via associations. Among the latter are also stations at major car wash facilities (e.g., "Mr. Wash") or supermarkets, where selling gasoline and diesel is considered a by-product. From the consumers' perspective, competition between gas stations takes place at the local level within a practically meaningful market area.[12] A special characteristic of the German market is, moreover, a different competitive environment for the small number of so-called Autobahn stations (i.e., stations integrated in highway service areas) as opposed to the majority of road stations. This is a result of assigning responsibility for construction, operation, and leasing of Autobahn stations (almost) exclusively to "Tank & Rast GmbH" after a privatization effort of formerly state-owned Autobahn gasoline station companies in 1998 (see Bundeskartellamt 2011b, pp. 213-218).

In contrast to other markets (e.g., in Austria or Western Australia), gasoline and diesel pricing in Germany is not subject to pricing regulations. German gasoline and diesel station operators are, thus, free to choose at which time, in which direction and by which amount they change prices for all fuel types offered. While station operators' menu costs are low, so are consumers' switching costs (Noel 2007a, p. 7). With product homogeneity and the chance to easily compare prices (within a regional market area), market transparency is, at least in theory, fairly high. The recent emergence of several mobile gasoline price comparison platforms in Germany has further helped to increase actual transparency for consumers (and suppliers) as prices can be retrieved from an up-to-date price database provided by the German Federal Cartel Office free of charge (e.g., via smartphones). Our empirical analysis largely builds on this novel database, which will be described in the next section.

2.3.2 Price Data

Empirical studies on gasoline and diesel retail pricing have largely utilized daily, weekly or quarterly price data of larger cities, on an average city-level basis or on a station-by-station level (see Eckert 2013). Price observations are often collected at specific daytimes and cover a sample of stations. Only more recently, with the emergence of larger data sets, more comprehensive investigations have become possible. Within this study, we make use of a rich panel data set comprising a census of gasoline (Super E5, Super E10) and diesel retail price quotes covering virtually all German gasoline stations. This novel data set is collected by the German market transparency unit for fuel ("Markttransparenzstelle für Kraftstoffe", MTS-K). Since

[12]While there is no single dominant approach for local market delineation in the literature, we propose simple measures of spatial competition in section 2.3.3.

1 December 2013, gasoline stations are obliged to instantaneously report any price change (including a precise time stamp), resulting in a comprehensive price data set across the country.[13]

Given the novelty of the data source, accuracy might be a concern.[14] To ensure data quality, we analyze submitted price quotes along data validation rules defined in Bundeskartellamt (2011b, Appendix p. 3). We exclude the first month of data (i.e., December 2013), mainly as a number of active gasoline stations failed to submit prices in the first month. Looking at data from January 2014 onwards only, price quotes considered "invalid" (e.g., empty price quote or price change of 0.00 Euro/liter) are at an acceptable level of about 1% of total observations (see Appendix 4.A for an overview of data preparation steps). In our analysis, we rely on the first full year of price data, from January to December 2014. All retail prices are nominal end-customer prices in Euro(cents) per liter and include all taxes and duties (i.e., value-added tax, energy tax, and a fee for the Petroleum Stockholding Assocation "EBV").

In the empirical analysis in section 4.5, we use station-level average price metrics (i.e., daily and daytime prices) as well as point-in-time prices (i.e., morning, evening, and midnight prices). The first requires an aggregation of precise price quotes to average prices per station and day with the help of two routines. First of all, we compute 24-hour average "daily prices" on a station-level by weighting all prices charged throughout the day with the length of their validity. Secondly, to compute "daytime prices", we follow the same logic but restrict the aggregation to prices charged between 8 am to 8 pm. We, thereby, focus on the part of the day, where most stations are open and demand as well as the level of competition is presumably highest. We use these two average price metrics as they incorporate the full variety of price levels (and precise times of validity) over the day or during daytime, and are arguably more accurate and unbiased with regard to a (random) time of observation as used in several earlier studies.[15] We, moreover, look at three point-in-time prices per station and day – namely morning prices (at 8 am), evening prices (at 8 pm), and midnight prices (at 12 am) – as they exemplarily represent different levels of competition dynamics across a typical daily price cycle (see section 2.4.1).

[13]For more information on the market transparency unit for fuel, please visit `www.bundeskartellamt.de/DE/Wirtschaftsbereiche/Mineral%C3%B6l/MTS-Kraftstoffe/mtskraftstoffe_node.html`. The data set was kindly provided by authorized consumer information provider "1-2-3 Tanken" (on 18 February 2015).

[14]The technical infrastructure itself was tested by the MTS-K during a three-month testing phase before launching standard operation phase ("Regelbetrieb") on 1 December 2013.

[15]Note, however, that we do not observe varying intraday demand levels and do not incorporate opening hours differences at individual stations.

To account for main input cost variations, we, furthermore, use daily wholesale prices “ex-refinery” for Super E5, Super E10 and diesel products. These prices are generated by Oil Market Report (O.M.R.), a widely used, independent information service provider, with the help of daily interviews of active market participants. We make use of the fact that this price data is available at a regional level, reflecting eight major refinery regions in Germany.[16] Individual stations are assigned to one of the eight refinery regions based on minimum linear distance to the region’s market place (see section 2.3.3 for details on calculation methodology). Ex-refinery wholesale prices are nominal and quoted in Euro(cents) per liter free on tank-lorry (fot) as of German refinery or storage including energy tax and fees for the Petroleum Stockholding Assocation “EBV”.[17]

2.3.3 Station Data

Apart from retail prices, the MTS-K data set includes station-specific data on virtually all gasoline stations across Germany, including geographical coordinates, detailed information on opening hours and brand affiliation. Similar to price data, we also check MTS-K station data for quality and exclude inactive entries and stations without submitted price quotes (per fuel type). Beyond this, we do not impose further threshold levels regarding, for instance, a minimum required number of price quotes per station and allow the data set to be unbalanced (see Appendix 4.A).

In total, stations are allocated to around 70 single brands. On top of this, we group brands into two “brand categories” to reflect and comment on a proposal by the Bundeskartellamt (2011b, pp. 13/21). In the first categorization, based on its brand, a station is classified into one of the three groups: oligopolistic player, other integrated player, or independent player. The first group includes all stations branded as Aral (BP), Shell, Total, Esso (ExxonMobil), and Jet (ConocoPhilipps), as proposed by the Bundeskartellamt (2011b). Apart from a nationwide network of gasoline stations, these oil companies are vertically integrated with substantial direct access to refinery capacities in Germany. Therefore, the Federal Cartel Office has classified these five vertically integrated oil companies as oligopoly players.

[16]Refinery regions are North (with market place Hamburg), East (Berlin), Seefeld, South-East (Leuna), West (Duisburg, Gelsenkirchen, Essen), Rhine-Main (Frankfurt), South-West (Karlsruhe), and South (Neustadt, Vohburg, Ingolstadt).

[17]Wholesale prices might differ depending on whether they are sold “branded” or “unbranded”, which, however, is not reflected in the data set. Price quotes are, moreover, not available on weekends and public holidays. We, therefore, assume prices to remain constant on previous-day levels in these cases. Some studies use crude oil prices instead of wholesale (rack) prices to control for input costs (e.g., Chouinard and Perloff 2007). We argue, however, that regional ex-refinery prices more precisely reflect input costs of stations.

We use this classification for our analysis. The second group consists of all brands of other, typically regional, integrated oil companies, mainly Star (Orlen), Agip (ENI), HEM (Tamoil), and OMV. The third group is made up of several small- to medium-sized retail stations ("independents"), many of which operate under common brands such as AVIA, bft, or Raiffeisen. The second additional classification on the basis of brand information, in turn, focuses specifically on brand value: Here, the Bundeskartellamt (2011b) distinguishes "premium brands" (e.g., Aral, Esso, Shell, Total, Orlen, OMV, Agip, AVIA, Westfalen), "established brands" (e.g., Jet, Star, HEM, Q1, avanti24), and other brands or independent suppliers (e.g., bft). For both characteristics, ownership structure is not included in MTS-K data, but only the branding of stations. Oligopolistic players may potentially also influence other retail sites through contractual partnerships though. In addition to the stations' brand affiliation, MTS-K data includes weekday-specific opening hours. We mainly use this information to distinguish stations, which are closed on Sundays from stations that are open every day as well as stations opening 24 hours per day and seven days per week from stations with more restrictive opening hours.

Furthermore, we combine three other data sources with MTS-K station data in order to present a comprehensive picture of station characteristics beyond brand affiliation and differences in opening hours. First, as a relevant control variable, we distinguish between two segments, road and Autobahn stations (almost all of the latter owned by Tank & Rast GmbH). To separate the two groups, we link information on highway service stations available on the Tank & Rast website[18] with MTS-K station data. All stations listed on the Tank & Rast website are identified within the MTS-K station data set; additionally, a small number of other Autobahn stations not operated by Tank & Rast are identified on the basis of a keyword search (e.g., "A*" or "BAB*") of the MTS-K address field. Secondly, we apply a rich data set of station characteristics collected by "Petrolview", a data provider for gasoline and diesel stations across Europe. By connecting Petrolview's individual station characteristics to MTS-K's station and price data, we are able to account for several observable variables influencing station heterogeneity.[19] Station-specific variables used in this study include the type of station ownership, the presence and type of a shop, the presence of a car wash facility, the intensity of traffic around the station, and the number of gasoline and diesel pumps (also the presence of truck diesel, CNG, or LPG pumps). While some station characteristics are represented by discrete or binary variables (e.g., number of pumps), others are clustered into

[18] See `www.tank.rast.de`.

[19] We are able to connect around 98% of MTS-K stations with Petrolview station characteristics (see Appendix 4.A for details).

meaningful groups (e.g., traffic intensity from very high to low).[20] Thirdly, to test for price differences during public and school holidays, we include information on the state of each gasoline station with the help of MTS-K's ZIP code data.[21] This is a prerequisite to include time series data on regionally different public and school holidays. An overview of public holidays by state is available on the website of the German Ministry of Internal Affairs.[22] School holidays, which also differ by state, are published by the standing conference of the ministers of education.[23]

Finally, we include measures reflecting a station's exposure to local competition. Several empirical studies implicitly assume (larger) cities to represent distinct market areas. While using cities as a measure for market delineation allows to incorporate other available city-level data (such as population density), it remains an arbitrary view on competitive dynamics. Similar to Pennerstorfer et al. (2015), we, hence, propose a different logic of local market delineation, enabled by geographical coordinates (latitude, longitude) of all registered stations included in the MTS-K data set. Based on this information, we calculate simple distance measures of the level of spatial competition by comparing a station's spatial relationship to each other station in three ways: (1) linear distance ("as the crow flies"), (2) minimum driving distance, and (3) shortest driving time. Linear distance, on the one hand, is computed as the shortest distance between two geo-coded locations ("orthodromic distance").[24] Retrieving minimum driving distance and time, on the other hand, requires road network data and corresponding routing algorithms. Therefore, these two measures are calculated with professional geocoding software. We report each station's distance to its single closest competitor as well as the number of competitors within a surrounding area defined by different critical values (e.g., 1, 2, or 5 km distance). Moreover, we look at the specific type of competitors by calculating

[20] The number of (gasoline, diesel) pumps is an integer variable, representing full pump installations with one or more slots and plugs for different fuel types. The presence of pumps for truck diesel, CNG, or LPG, and the presence of a car wash are binary variables. Regarding ownership, company-owned (i.e., brand and ownership are in line), dealer-owned, or other (e.g., supermarket-owned) can be distinguished. Categories for traffic intensity include very high (traffic levels >25,000 vehicles per day), high (15,000 to 25,000), medium (5,000 to 15,000), or low (<5,000). Categories for shop type include none, kiosk (i.e., small shop), standard store (offering, e.g., oil, cigarettes, confectionery products, some food and drinks), or convenience store (with a wide range of items).

[21] Here, we make use of a comprehensive list of ZIP code and federal state combinations available via the "OpenGeoDB" website (see `www.opengeodb.org`).

[22] In Germany, there are no further local holidays. The only exception is "Friedenfest" on 8 August, which is a public holiday in the city of Augsburg only (see `www.bmi.bund.de/SharedDocs/Downloads/DE/Lexikon/feiertage_de.html`).

[23] See `www.kmk.org/ferienkalender.html`.

[24] Using $dist = arccos(sin(lat1) * sin(lat2) + cos(lat1) * cos(lat2) * cos(lon2 - lon1)) * earthradius$ to compute "arc length" distances in kilometers, with $(lat1, lon1)$ and $(lat2, lon2)$ as coordinates of start and end point given in radians (converted from degrees by multiplying with $2\pi/360$), and $earthradius = 6,378km$.

shares of different brand categories (e.g., Federal Cartel Office's classification of oligopoly vs. independent players) within a surrounding area. With a similar logic, we calculate each station's distance to the first and second closest refinery region's market place.

In the following sections, we will present empirical findings based on combining all sources described above. A summary of variables used in the analysis and corresponding data sources can be found in Table 2.8 in Appendix 4.B.

2.4 Empirical Analysis

2.4.1 Descriptive Findings

Let us know briefly present relevant descriptive statistics on price levels, station characteristics, and measures of spatial competition. Underlying, granular data sets will afterwards be used to estimate the impact of station heterogeneity on price levels and price volatility (in section 2.4.2).

Across the period of observation, daily prices for fuel type Super E5 are highest with an average of 1.541 Euro/liter, followed by Super E10 with 1.502 Euro/liter, and diesel with 1.359 Euro/liter, taking 24-hour averages. Daytime prices (i.e., prices between 8 am and 8 pm) are lower, on average, across all three fuel types with 1.520 Euro/liter Super E5, 1.480 Euro/liter Super E10, and 1.336 Euro/liter diesel, respectively. Average daytime prices are lower because the vast majority of stations set rather constant and high price levels at night, but stepwise cut prices over the day, to restore price levels (in the evening hours), often with a single large price increase.[25] As a consequence, our three point-in-time price metrics exhibit the highest average price levels at midnight, only slightly lower values in the morning (where a few stations have already started to cut prices), but substantially lower levels in the evening (shortly before prices jump up again). On average, stations change their prices between four and five times per day (with a corresponding average validity of each price of around five hours). While some stations do not change their prices over several days, there are other stations with 15 or more price changes on certain days. Figure 2.1 shows the average daily price path (averaged over all stations and all days), which provides a stylized result of observed price patterns.

Daily ex-refinery wholesale prices across the whole period and across regions are at an average level of 1.202 Euro/liter Super E5, 1.168 Euro/liter Super E10, and 1.043 Euro/liter diesel, respectively. Across refinery regions, average prices vary

[25] Figure 2.4 in Appendix 4.B shows an exemplary station's pricing over a week, illustrating the typical pattern of high prices during nighttime and several price cuts throughout the day.

Table 2.1: Summary Statistics: Retail & Wholesale Prices

Variable	Super E5	Super E10	Diesel
Daily average price (24-hour, in Euro/liter)	1.541	1.502	1.359
Daytime average price (8 am to 8 pm, in Euro/liter)	1.520	1.480	1.336
Average midnight price (12 am, in Euro/liter)	1.574	1.536	1.395
Average morning price (8 am, in Euro/liter)	1.558	1.519	1.376
Average evening price (8 pm, in Euro/liter)	1.499	1.459	1.315
Average intraday price spread (in Euro/liter)	0.089	0.091	0.095
Price changes per day (in number)	4.7	4.8	4.7
Wholesale price “ex-refinery” (in Euro/liter)	1.202	1.168	1.043

Note: Averages across all stations’ or regions’ daily metrics.
Source: MTS-K data (Jan-Dec 2014), O.M.R. data, own calculation.

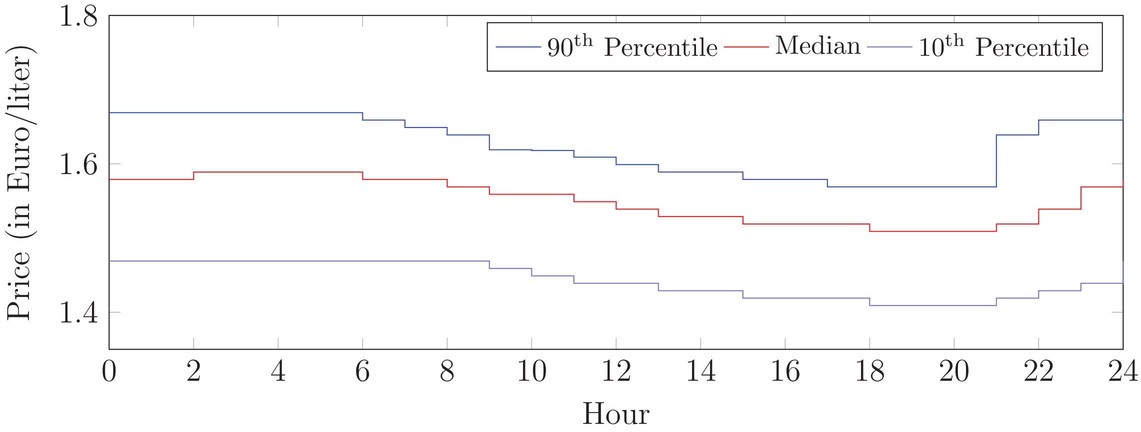
by up to 2 Eurocents/liter, with South-West (gasoline) or North (diesel) offering lowest and South-East offering highest average price quotes.[26] Differences between ex-refinery prices and retail prices (“at the pump”) are driven by the value-added tax of 19%, transport costs (from refinery to retail site), sales costs of the station operator, and, eventually, the retail margin. Table 2.1 shows summary statistics of price data by fuel type across all stations included in the data set and Figure 2.2 presents a time series of average daily retail and wholesale prices across all stations or regions. While prices of gasoline fuel types slightly increased during the first half of the year, we see a sharp price decline across fuel types in the last quarter of 2014.[27]

In the MTS-K data set slightly less than 15,000 stations are registered. Excluding inactive stations as well as stations with a new brand or ownership and focusing on stations with a complete set of station characteristics provided by Petrolview leaves us with 14,135 stations to be used for our empirical analysis. Except for just below 400 stations located at the Autobahn, all other retail sites are classified as road stations. Interestingly, almost all stations offer diesel as a fuel type, reflecting the fact that diesel-fueled engines are widespread among passenger cars in Germany (in contrast, for instance, to the U.S. market).[28] Only a very few stations do not offer Super E5, while around 5% of all stations do not sell Super E10, a recent fuel type introduced in 2011. In the data set, about 70 single brands can be identified. With 2,346 stations and 1,858 stations, respectively, Aral (BP) and Shell are the two

[26]Based on shortest linear distance to a refinery region’s market place, we assign between 910 (East) to 3,147 (West) stations to any single refinery region.

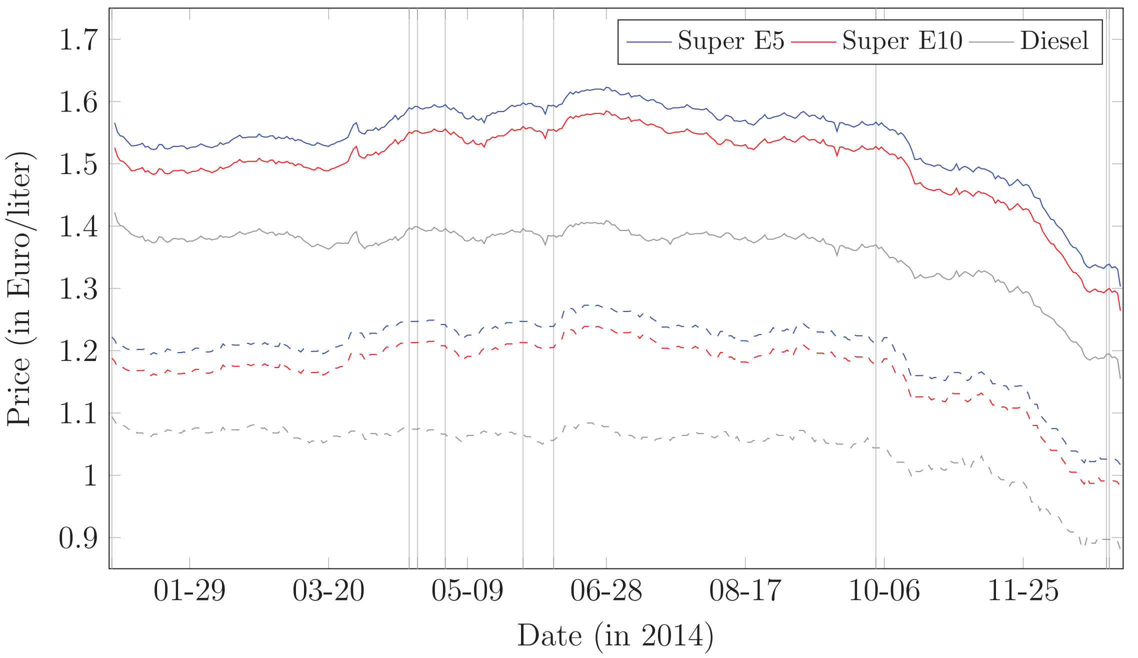
[27]An Augmented Dickey Fuller test on average prices suggests that retail and wholesale price series of all fuel types are individually integrated of order one and pairwise cointegrated.

[28]According to the Kraftfahrtbundesamt (German Federal Motor Transport Authority), about 30% of all passenger cars in Germany are diesel-powered vehicles (see `www.kba.de/DE/Statistik/Fahrzeuge/Bestand/Umwelt/2014_b_umwelt_dusl_absolut.html`).



Note: Hourly point-in-time prices averaged over all stations and all days.

Figure 2.1: Average Daily Retail Price Path



Note: Retail prices (i.e., average across all German stations' daily average prices) of indicated fuel type shown with solid lines, wholesale prices (i.e., average across all refinery regions' daily prices) with dashed lines. Vertical lines represent public holidays in majority of states.

Figure 2.2: Average Daily Retail & Wholesale Price Series

largest single brands, together accounting for more than a quarter of all stations. Within the small segment of Autobahn stations, Aral and Shell even operate more than half of all stations. Following Aral and Shell, six other brands (Esso, Total, Avia, bft, Jet, and Star) can be found with more than 500 stations each. Classifying brands into the categories introduced in section 2.3.3 shows that the five supposed oligopoly-player brands and the non-integrated independent brands both operated around 6,000 stations. In total, 40% of stations are open "24/7", among those are 54% oligopoly-branded stations, compared to a smaller share of 47% oligopoly-branded stations in the overall market. While this classification based on MTS-K data merely reflects branding of stations and not ownership structure, a look at Petrolview's station characteristics shows that almost two thirds of all stations are owned by dealers. The remaining part is largely owned by the company also owning the brand.[29] Nowadays, most stations have a shop offering, while size and variety differ. With the data at hand, we can distinguish between stations with a convenience store (41%), a standard store (46%) and a smaller kiosk-type store (4%). More than 90% of all stations have between one and four gasoline and diesel pumps. Individual station data shows a maximum of 16 pumps. Beyond gasoline and diesel pumps, almost half of all stations have at least one additional truck pump and a corresponding bay, while a third offers LPG and no more than 5% offer CPG pumps. Regarding traffic at the (primary) street of a station's location, stations with very high (9%), high (36%), medium (43%), and low (12%) traffic intensity can be distinguished. Furthermore, 4,619 stations also benefit from traffic of a secondary road (e.g., at a crossing). Table 2.2 shows summary statistics on the number of stations across various characteristics.

In Germany, the density of gasoline stations varies significantly across regions, with a high density, for instance, in the Rhine-Main area and a considerably lower density, for instance, in the Eastern part of the country. As an example, the distance to the closest competitor – irrespective of segment, product offering, or brand – ranges from virtually zero to around 25 km. Across the entire country, there is, on average, a station every 1.6 km (linear distance), 2.2 km (driving distance), or six minutes (driving time). Within a circular surrounding area of 1 km linear distance around a given station, there are, on average, 0.9 competitors. Within 2 km and 5 km, this number increases to 2.6 and 10.5, respectively. In line with intuition, driving distance measures show higher values, as the road network virtually never represents the shortest possible connection between a pair of stations. For driving distance, there are 0.5, 1.5, and 6.9 competitors within a (non-circular) area of 1, 2, and 5

[29] Other ownership types include supermarket-owned stations.

Table 2.2: Summary Statistics: Gasoline and Diesel Stations

By type			By brand			By characteristics			By local competition	
Segment			*Brands (>500 stations)*			*Amenities*			*Linear distance*	
Road station	13,769	97%	Aral	2,346	17%	Convenience store	5,761	41%	Closest comp.	1.58 km
Autobahn station	366	3%	Shell	1,858	13%	Standard store	6,455	46%	Comp. in 1 km	0.92
Ownership type			Esso	1,048	7%	Kiosk	563	4%	Comp. in 2 km	2.64
Company-owned	5,455	39%	Total	834	6%	Car wash	10,432	74%	Comp. in 5 km	10.45
Dealer-owned	8,269	59%	Avia	738	5%	*Traffic intensity*			*Driving distance*	
Other	411	3%	bft	601	4%	Very high	1,266	9%	Closest comp.	2.21 km
Product offering			Jet	583	4%	High	5,054	36%	Comp. in 1 km	0.52
Super E5	14,005	99%	Star	536	4%	Medium	6,118	43%	Comp. in 2 km	1.54
Super E10	13,435	95%	*Brand category 1*			Low	1,697	12%	Comp. in 5 km	6.85
Diesel	14,130	100%	Oligopoly	6,669	47%	Secondary road	4,619	33%	*Driving time*	
Business hours by day			Other integrated	1,565	11%	*Number of pumps*			Closest comp.	6.07 min
Monday-Saturday	14,116	100%	Independent	5,901	42%	1 to 2 pumps	4,345	31%	Comp. in 2 min	0.40
All week	13,481	95%	*Brand category 2*			3 to 4 pumps	8,482	60%	Comp. in 5 min	1.19
Business hours by time			Premium	7,705	55%	5 to 6 pumps	1,196	8%	Comp. in 10 min	3.77
8 am to 6 pm	12,038	85%	Established	1,518	11%	>6 pumps	112	1%		
8 am to 8 pm	11,729	83%	Other	4,912	35%	Truck pumps	6,627	47%		
24 hours, 7 days	5,623	40%				LPG pumps	4,617	33%		
						CNG pumps	759	5%		

Note: Included are 14,135 active stations with price quotes (MTS-K) and all station characteristics (Petrolview); closest comp(etitor) stated in kilometers or minutes, all other variables in number of stations.
Source: MTS-K data, Petrolview data, own calculations.

km.[30] In terms of driving time, averagely 3.8 stations are not more than ten minutes away (without traffic congestion). The type of local competition, subsumed by brand category, varies across areas between 0 and 100%, but, on average, reflects overall category shares of 47% oligopoly-branded players and 42% independent players. Finally, across the country, the closest refinery market place is averagely around 80 km in linear distance away from gasoline stations, with approximately another 90 km to the second closest refinery market place.

2.4.2 Impact of Station Heterogeneity

In this section, we will focus on the impact of time-variant refinery prices and demand-side controls as well as various time-constant station characteristics on retail price levels. While not visible for customers, (region-specific) refinery prices for gasoline and diesel products are an obvious determinant of retail price variation as they represent the major source of input costs (Hosken, McMillan, and Taylor 2008). Moreover, we include controls in form of weekday, state, and (school, public) holiday dummies to incorporate demand-side effects. Albeit gasoline and diesel are both fairly homogenous products, a simple two-way fixed effects estimation (see Appendix 2.C) suggests that price dispersion is induced by station heterogeneity rather than physical product characteristics. We, therefore, test for the impact of a wide range of (observable) station characteristics on price levels, informed by existing studies (Eckert 2013). Specifically, we control for variables representing brand and ownership structure, station location and amenities, and spatial competition metrics[31] in a random effects model setup. We are aware of the potential omitted variable bias of such a model (e.g., due to unobserved station characteristics). However, we assume a robust specification in light of the variety of control variables included, similar to other empirical studies on gasoline markets estimating random effects models (e.g., Pennerstorfer et al. 2015). The specified model is described below in equation (4.2),

$$p_{it} = \alpha + \beta c_{it} + \boldsymbol{x}_i \boldsymbol{\gamma} + \boldsymbol{d}_{it} \boldsymbol{\delta} + u_{it} \tag{2.1}$$

with p_{it} as station i's average or point-in-time retail price at day t, $\boldsymbol{x}_i$ representing a vector of all time-invariant, station-specific control variables, c_{it} as region-specific refinery prices, and $\boldsymbol{d}_{it}$ as a vector of dummy variables to control for weekdays, states, as well as public and school holidays (varying by the state of a station's

[30]Routing-based algorithms do not show a direct competitor for a few stations (e.g., from an island to mainland Germany).

[31]Similar to Eckert and West (2005), we focus on count and type of local competitors within a 2 km surrounding area. The local competition metric used for all estimations is linear distance.

location). Table 2.3 presents results for a number of specifications of the generic model introduced in equation (4.2) for fuel type Super E5. Specifically, we estimate the model with two daily average price metrics (specification (1) with 24-hour daily and (2) with 8 am to 8 pm daytime prices) and three point-in-time price metrics (specification (3) with 8 am morning, (4) with 8 pm evening, and (5) with 12 am midnight prices) as the dependent variable (see section 2.3.2 for details on calculation routine).[32] All coefficients are denoted in Eurocents/liter of fuel. Similar to empirical findings in Kihm, Ritter, and Vance (2016), using a large-scale gasoline price panel data set, we find most regressors to be statistically highly significant, influenced by the sheer number of observations.[33] Most coefficients affect prices in the expected way (i.e., coefficients' signs are in line with expectations, cf. Eckert 2013, pp. 152-156). Moreover, the direction of price impact of all (significant) covariates is largely robust with regard to using different price metrics. In turn, the economic impact of individual variables is, ceteris paribus, significant for some variables, while being negligible for others. As expected, some coefficients vary in magnitude between daily and daytime average price and different point-in-time price specifications. This is due to the fact that pricing behavior of stations is, to a large extent, simply different across the day (e.g., more dynamic during the day than at nighttime, cf. section 2.4.1), as a result of varying competition intensity and different levels of demand. While daily and daytime price specifications are arguably more robust, looking at different points-in-time yields additional insights, which we will comment where reasonable.[34]

First of all, ex-refinery prices appear to be a good predictor of (daily) input price changes, with coefficients slightly above one across all specifications. Note that a coefficient value of 1.19 would represent perfect pass-through considering a value-added tax of currently 19% in Germany. Values smaller than 1.19, as found across specifications, indicate imperfect pass-through and suggest that competition is also less than perfect. Cost pass-through, however, exceeds 90% in all specifi-

[32]The number of observations slightly differs among specifications (1) to (4) as, for example, some "partial" days are not considered for daily (24-hour) prices, while they are considered for daytime prices. In specification (5) with midnight prices, in turn, we only include stations with 24/7 opening hours (and also use the nearest competitor with 24/7 opening). We provide results for the same specifications for fuel types Super E10 and diesel in Tables 2.9 and 2.10 in Appendix 4.B. As a robustness check, we estimate equivalent models with time-fixed effects instead of region-specific ex-refinery prices (and all covariates, except for weekdays), showing largely similar results.

[33]Exceptions include primarily traffic intensity and distance to the nearest competitor in certain specifications. The latter variable, for many stations, varies only marginally.

[34]In addition, varying coefficient values can, to a limited extent, be associated to diverse opening hours across stations. While we account for such differences with two dummy variables (i.e., 24/7 opening and Sunday opening) in all but the last specification, this might not filter out the entire station- and weekday-specific granular opening hour variety.

Table 2.3: Regression of Retail Prices (Super E5)

Dependent variable:	Average prices		Point-in-time prices		
Super E5 price	Daily	Daytime	Morning	Evening	Midnight
	(1)	(2)	(3)	(4)	(5)
Station type					
Autobahn station	5.669	6.475	5.690	9.243	3.517
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
24/7 business hours	0.285	0.274	0.113	0.457	-
	(0.00)	(0.00)	(0.01)	(0.00)	
Brand categories					
Oligopoly player brand	2.522	1.139	1.676	1.066	4.180
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Integr. player brand	0.834	0.574	0.977	0.882	1.567
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Station characteristics					
Convenience store	0.261	0.125	0.259	*0.019*	0.802
	(0.00)	(0.00)	(0.00)	*(0.58)*	(0.00)
Kiosk-type store	-0.347	*-0.093*	-0.413	0.150	-1.112
	(0.00)	*(0.20)*	(0.00)	(0.08)	(0.00)
No store	-0.908	-0.320	-1.254	*-0.001*	-1.198
	(0.00)	(0.00)	(0.00)	*(0.99)*	(0.00)
Car wash	0.424	0.172	0.229	0.165	0.264
	(0.00)	(0.00)	(0.00)	(0.00)	(0.04)
Traffic intensity	*0.032*	*-0.012*	*0.012*	*-0.039*	0.195
	(0.18)	*(0.55)*	*(0.64)*	*(0.11)*	(0.00)
Number of pumps	-0.116	-0.097	-0.088	-0.100	-0.063
	(0.00)	(0.00)	(0.00)	(0.00)	(0.09)
Truck pumps	0.202	0.146	0.109	0.177	0.273
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Local competition					
Distance to nearest comp.	0.024	*0.010*	*0.004*	0.045	*0.015*
	(0.02)	*(0.25)*	*(0.71)*	(0.00)	*(0.35)*
# of competitors in 2 km	-0.099	-0.083	-0.113	-0.077	-0.053
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Share of oligopoly brands	0.724	0.561	0.676	0.509	0.717
	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Share of independents	0.423	0.508	0.328	0.630	*-0.023*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.93)*
Demand-side controls					
School holiday	0.281	0.032	0.240	-0.046	0.697
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Public holiday	0.368	0.672	0.676	0.880	-0.264
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Input costs					
Ex-refinery price	1.104	1.095	1.113	1.084	1.087
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to refinery	0.013	0.016	0.010	0.016	0.007
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	16.939	17.098	17.987	16.405	20.656
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	4,989,486	5,001,061	5,003,332	5,000,986	1,955,103
Number of groups	14,005	14,005	14,005	14,005	5,504
R^2	0.875	0.874	0.815	0.838	0.773

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics.
Included but not shown: Weekday dummies, state dummies, LPG/ CNG pump, ownership type, secondary road, additional distance to 2^{nd} refinery, and open on Sundays dummy (see Table 2.11).
Omitted variables: Road station, independent brand, standard store.

cations (assuming a coefficient of 1.19 to represent 100%). Moreover, the distance of a station to the nearest refinery has a significant positive impact on prices. For example, another 100 km to the nearest refinery leads to a rise in retail prices by 1.3 Eurocents/liter, on average. Secondly, driven by a restricted competitive environment and, potentially, a lower price elasticity of consumers, Autobahn stations carry a surcharge of around 6-7 Eurocents/liter during the day, and even close to 10 Eurocents/liter in the evening. For a typical consumer, this price premium at otherwise identical stations is equivalent to extra costs for filling up of around 4-6 Euro per fuel tank or 100-150 Euro in the course of a year.[35] The price difference between Autobahn and road stations is smaller at night, where most stations retain high price levels irrespective of other factors. Third, comparing the Bundeskartellamt's brand categories reveals that oligopoly-type players charge significantly higher prices than other stations. While the gap is largest for the midnight price specification, it diminishes to around 1 Eurocent/liter over the course of the day. Fourth, regarding station amenities, results are largely in line with the expectation that a wider range of services for the customer, and, therefore, a "one-stop shopping" offering, is associated with higher price levels. Between no shop offering and a convenience store is a range of about 0.4 to 2.2 Eurocents/liter (or 0.2 to 1.3 Euros per fuel tank), while having a car wash facility, ceteris paribus, is associated with a price increase of close to another 0.2 to 0.6 Eurocents/liter. Fifth, we analyze the role of spatial competition on prices, where a major advantage of our data set is that, in contrast to other existing studies, we can obtain representative results for urban as well as rural regions. We find the distance to the nearest competitor to be statistically significant but negligible in magnitude. Furthermore, as expected, an additional station within a local area, on average, slightly decreases price levels. Interestingly, both variables reflecting the share of a brand category in the local market have a positive sign.[36] We infer from this finding that in market areas that comprise a homogenous group of stations, price competition is less intense, while a larger heterogeneity of local competition appears to induce lower prices. Using variables reflecting shares of individual oligopoly-player brands (instead of a single group variable) shows that the effect more than doubles in all specifications for Aral and Shell, suggesting higher price levels in local environments with particularly a higher share of these two brands. Finally, school and public holidays, as relevant demand-side controls, largely have the expected positive impact on price levels. The extent of price effects from school holidays differs, however, as coefficient values are

[35] Assuming 60 liter per fuel tank and 20,000 km driving distance per year with an average consumption of 8 liter per 100 km.

[36] An exception is specification (5), where the share of independents is insignificant.

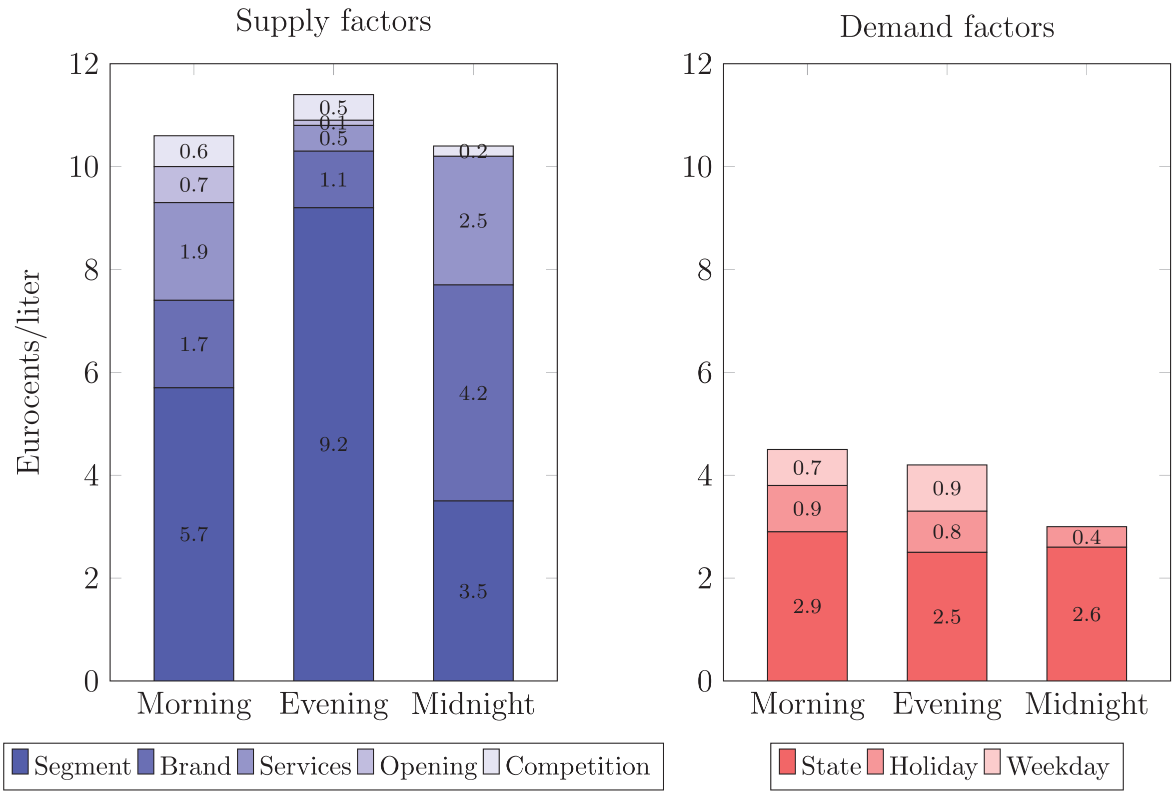
either low or even negative in some specifications (especially for diesel fuel). Also, the price increase associated with public holidays cannot necessarily be observed for midnight prices. As the magnitude of price effects on both public and school holidays is limited, drastic price increases, as sometimes reported by customers and the media, are, if present, either limited to a subset of stations or limited to specific holiday periods.[37]

Figure 2.3 summarizes average price spreads of stations along supply and demand categories investigated in this study at different points-in-time of the day.[38] We find price spreads for supply factors of 10.4 to 11.4 Eurocents/liter in total while demand factors vary by 3.0 to 4.5 Eurocents/liter. The left-hand side of Figure 2.3 compares supply-side driven spreads between a "premium" and a "no-frills" station. We define a "premium" station as oligopoly player-branded, in the Autobahn station segment, with 24/7 opening hours, a full-service offering (i.e., convenience store, car wash, truck pump) and a single other competitor (integrated player-branded) in a 2 km surrounding. We further define a "no-frills" station as independent player-branded, in the standard road station segment, with restricted opening, no services, and five other competitors in the surrounding area.[39] As discussed in this section (cf. Table 2.3), differences in segment (i.e., Autobahn vs. road location), brand (i.e., oligopoly vs. independent), and service offerings (i.e., full vs. no services) account for a significant share of price spreads. Competition effects are measurable but, on average, rather limited. While the overall spread remains fairly constant across the day, its structure varies. For the majority of fuel stations, which are located on the road, price competition intensity significantly increases in the evening hours (as indicated by tight spreads across all categories, except segment). In turn, the small segment of stations located at the Autobahn is hardly affected by this price pressure. Instead, a higher segment-specific spread in the evening more than offsets the decline of all other categories. At midnight, brand-specific difference become most relevant. On the right-hand side of Figure 2.3, we illustrate the effect of different (time-

[37]Regressing single, nationwide public holidays and a set of covariates on Super E5 price levels shows, ceteris paribus, significantly higher price levels on Whitmonday (+1.7 Eurocents/liter for daily prices, +1.7 Eurocents/liter for daytime prices), Unity Day (+1.3, +1.4), Labor Day (+1.1, +1.5), and Ascension Day (+0.9, +0.8). Contrary to public opinion, coefficients are ambiguous or even negative (in 2014) on dummy variables for Good Friday (-0.3, +0.4) and Christmas (-1.0, -0.6). Only a few existing studies specifically investigate this question, among them, Hall, Lawson, and Raymer (2007), who find no holiday effect.

[38]For the purpose of this analysis, we focus on gas station-specific supply factors. Overall, as was to be expected, refinery prices (i.e. input costs) account for the largest part of explained price variance (coefficient of determination of 63 to 76%, depending on the point in time specification), while station-specific supply factors add between 5 and 11% and demand factors explain another 1 and 3% of price variance across stations and time.

[39]Competitors are three oligopoly players, one integrated player, and one independent.



Note: Relevant coefficients from specifications (3) to (5) in Tables 2.3 and 2.11. Only station-specific supply factors considered (without input costs).

Figure 2.3: Average price spreads determined by supply and demand factors

constant and time-variant) demand-side factors. We compare a higher-priced station located in the Southwest of Germany (in the state of Baden-Württemberg) on a Sunday with a holiday price mark-up to a lower-priced station in Berlin on a regular Monday.[40] Overall, demand category-driven price spreads are much smaller. Time-invariant spreads from being located in different states contribute most, while time-varying holiday and weekday effects are, on average, not larger than 1 Eurocent/liter each, everything else being equal.

As a next step, we specifically investigate the impact of approximately 70 single brand dummies in a model also including all covariates discussed so far. While other coefficients not explicitly shown remain comparable in magnitude, Table 2.4 shows brand-specific estimates for the same (average, point-in-time) price metrics. On a high-level, significant differences in magnitude across specifications for several brands are obvious, with prices being less dispersed during daytime for most brands. We interpret this primarily as a distinct day- versus nighttime pricing strategy of certain brands (e.g., Aral, Shell, OMV) in light of a higher competition intensity,

[40]Please note that we omit the weekday effect for midnight specifications in this illustration as it then shows the opposite direction (cf. Table 2.11).

which is, however, not common to all brands (cf. Agip). Moreover, findings across all specifications support the Federal Cartel Office's (Bundeskartellamt 2011a) classification of "premium brands" (such as Aral, Shell, Esso, Total, OMV, Agip, or Avia), which are able to charge the highest prices. Coefficients on "established brands" (e.g., Star or HEM) are ambiguous in direction. Among the independents, associations (e.g., bft or Raiffeisen) show slightly higher price levels than other independents.

Two further findings are noteworthy: First, Jet's pricing neither seems to resemble other established brands nor other oligopoly-type player brands. Removing Jet from the group of oligopoly players consequently increases the coefficient for the remaining four-player group considerably. This finding is especially noteworthy because the Federal Cartel Office considers Jet as part of a jointly-dominant oligopoly, while the Düsseldorf Higher Regional Court did not share this view in a recent merger case (see, e.g., Monopolkommission 2014). Secondly, among the brands with most negative coefficients (based on the mean of all Super E5 specifications) and 15 or more active stations are, next to regional Bavarian player Deutscher Brennstoff Vertrieb (DBV) and independent player ED Mineralölhandels KG (ED), three chains, whose primary business is not selling gasoline (namely, the car wash chain Mr. Wash and the two supermarket chains Globus and V-Markt). For these players, selling gasoline can be considered a by-product of their car wash or supermarket business offer used for marketing purposes. By setting low gasoline prices, these chains intend to lure customers to their car wash or supermarket business, respectively. Common for these stations, however, are in many cases structurally different business hours, matching those of their primary business (e.g., "24/7" or Sunday opening is rare). Therefore, next to examining the robustness with regard to daytime, morning, or evening price specifications, which are less prone to a potential opening hour bias, we perform an additional robustness check by estimating a set of specifications including a subset of stations with 24/7 opening hours only (see Table 2.12 in Appendix 4.B). Results are largely comparable, which suggests that there is no structural difference induced by varying opening hours. Thus, while daytime price regressions carry smaller coefficients, specifically for the group of other selected independents, significant negative values remain in all specifications.[41]

Finally, we investigate drivers of price volatility to analyze how and why gaso-

[41]When interpreting results in Table 2.12 in Appendix 4.B, please note, however, that for the group of other selected independent brands, a focus on stations with 24/7 opening hours quite dramatically reduces the number of observations, for reasons stated above. Specifically, Mr. Wash has no station (out of 19 in total), which is always open, while DBV, V-Markt, Globus, and ED operate 10 (of 16), 5 (of 28), 38 (of 41), and 4 (of 106) stations on a 24/7 basis, respectively. Mr. Wash's highly negative coefficients, thus, cannot be tested within a 24/7 opening hour setup.

Table 2.4: Regression of Retail Prices (Single Brands, Super E5)

Dependent variable:	Average prices		Point-in-time prices		
Super E5 price	Daily	Daytime	Morning	Evening	Midnight
	(6)	(7)	(8)	(9)	(10)
Oligopoly player brand					
Aral	3.966	1.825	3.340	1.345	6.262
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Shell	4.310	1.480	2.668	1.499	8.103
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Esso	2.861	0.906	2.123	0.301	6.524
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Total	2.560	0.797	2.025	0.174	5.522
	(0.00)	(0.00)	(0.00)	(0.05)	(0.00)
Jet	*-0.063*	-0.377	*0.067*	-0.648	1.687
	(0.40)	(0.00)	*(0.42)*	(0.00)	(0.00)
Other integrated player					
star	0.728	-0.179	1.014	-0.741	3.706
	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)
Agip	1.965	1.922	2.447	1.274	1.572
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
HEM	0.207	-0.236	0.711	-0.725	2.406
	(0.01)	(0.00)	(0.00)	(0.00)	(0.00)
OMV	3.998	1.227	3.190	4.090	7.235
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Independent brands (associations)					
AVIA	2.198	0.973	2.182	0.296	4.233
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
bft	0.504	0.171	0.439	0.175	0.674
	(0.00)	(0.02)	(0.00)	(0.06)	(0.05)
Raiffeisen	0.434	0.167	0.582	*-0.090*	1.238
	(0.00)	(0.05)	(0.00)	*(0.38)*	(0.00)
Other selected independent brands					
Mr. Wash	-4.067	-3.131	-4.620	-1.964	no obs.
	(0.00)	(0.00)	(0.00)	(0.00)	
DBV	-2.201	-1.347	-1.499	-1.838	-2.974
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Globus	-1.688	-0.548	-2.273	0.402	-4.144
	(0.00)	(0.01)	(0.00)	(0.08)	(0.00)
ED	-1.624	-1.568	-1.513	-1.803	-3.719
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)
V-Markt	-1.531	*-0.133*	-3.084	*0.010*	-4.035
	(0.00)	*(0.61)*	(0.00)	*(0.97)*	(0.00)
Input costs					
Ex-refinery price	1.104	1.095	1.113	1.084	1.087
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	16.851	17.259	17.690	16.910	19.478
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	4,989,486	5,001,061	5,003,332	5,000,986	1,955,103
Number of groups	14,005	14,005	14,005	14,005	5,504
R^2	0.900	0.882	0.831	0.851	0.816

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics.
Included but not shown: Other single brands; all station characteristics and demand-side controls.
Omitted variables: “Unbranded” stations and other omitted variables as in previous specifications.

Table 2.5: Regression of Daily Price Changes (Super E5)

Dependent variable: # of daily price changes	GLS (11)	Poisson (12)
Station type		
Autobahn station	-2.060	-0.532
	(0.00)	(0.00)
24/7 business hours	-0.105	-0.033
	(0.00)	(0.00)
Brand categories		
Oligopoly player brand	0.265	0.061
	(0.00)	(0.00)
Integr. player brand	-0.279	-0.061
	(0.00)	(0.00)
Station characteristics		
Convenience store	0.080	0.021
	(0.01)	(0.04)
Kiosk-type store	-0.445	-0.110
	(0.00)	(0.00)
No store	-0.917	-0.253
	(0.00)	(0.00)
Car wash	0.076	*0.006*
	(0.03)	*(0.59)*
Traffic intensity	0.093	0.022
	(0.00)	(0.00)
Local competition		
Distance to nearest comp.	-0.053	-0.013
	(0.00)	(0.00)
# of competitors in 2 km	0.017	0.004
	(0.00)	(0.03)
Share of oligopoly brands	-0.209	*-0.039*
	(0.00)	*(0.16)*
Share of independents	-0.596	-0.136
	(0.00)	(0.00)
Demand-side controls		
Monday	1.251	0.288
	(0.00)	(0.00)
Saturday	0.619	0.153
	(0.00)	(0.00)
School holiday	0.039	0.008
	(0.00)	(0.00)
Public holiday	-1.239	-0.289
	(0.00)	(0.00)
Constant	8.214	2.220
	(0.00)	(0.00)
Number of observations	4,989,486	4,989,486
Number of groups	14,005	14,005
R^2	0.162	

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics. Included but not shown: Weekday, state, pumps, ownership, and open on Sundays dummy. Omitted variables: Road station, independent brand, standard store, Sunday.

line prices differ across regional markets. To approximate volatility, we choose the number of price changes per day as the dependent variable and regress again on a full set of control variables (see Table 2.5 for estimation results). Given that our dependent variable in this case comprises count data, we also estimate a Poisson random-effects model (see Wooldridge 2010, p. 760) in addition to a generalized least square estimation. Both models indicate a consistent direction of effects.[42] First of all, daily price changes are influenced by the segment: Autobahn stations change prices about two times less often during the day. Secondly, among station-specific characteristics, the type of shop, particularly the absence of a shop, is of relevance. This suggests less volatility in light of less sophisticated operations (e.g., with few employees or automated stations, fewer price changes can be assumed). Third, volatility is also driven by two demand-side factors, namely weekends (specifically Sundays) and public holidays, both inducing one or more price changes less over a typical day.

2.5 Conclusion

In this paper, we have presented a large-scale analysis of price determinants on retail gasoline and diesel markets, using a census of price quotes of virtually all stations in Germany. In contrast to many studies on competition in retail fuel markets, our empirical study is not restricted to few regions or cities, but instead presents extensive findings for an entire country. As a result, our study helps to better understand the nature of competition and pricing in retail fuel markets in a major OECD country. While there are differences in institutional environments and local market structures between fuel markets in OECD countries, there are also many similarities so that our results should be generalizable to a certain degree. Specifically, we have been able to compare pricing at different times of the day (e.g., day- and nighttime) and on different market segments (i.e., Autobahn and road stations), and to assess the impact of a rich set of station characteristics and measures of spatial competition on price levels. For this purpose, we have computed average daily and daytime retail prices (based on precise intraday price quotes) as well as daily point-in-time prices (in the morning, evening, and at midnight), which we tested for price distribution and regressed on various supply- and demand-side controls in (station-)random effects models. To account for differences between stations and brands as well as differences in costs and location is of major importance to understand the competitive dynamics in a market with an otherwise homogeneous

[42] Coefficients of Poisson model estimations can, however, not be linearly interpreted.

product. Competition authorities and policy makers often fail to account for these differences that effectively lead to product differentiation.

We find that a large part of the daily distribution of prices observed "at the pump" can be associated with observable station characteristics as well as price shocks affecting all stations. In all of our regressions, we have estimated a pass-through rate of wholesale prices between 90 and 100%, suggesting that there is a fair degree of competition even though it is less than perfect due to product differentiation resulting from stations' location, facilities, and brands. Among the observable variables, distinguishing between the two segments Autobahn and road stations is critical. Furthermore, brand recognition has a crucial impact on price levels in line with existing classifications of premium brands, but also with varying strategies regarding day- and nighttime pricing. Interestingly, Jet's position within the group of established brands and oligopoly-type players is ambiguous. This is an important finding in the German context, where the role of Jet has been heavily debated between the Federal Cartel Office on the one hand as well as market participants and courts on the other hand. Our findings suggest that Jet's pricing is rather different from the other four so-called oligopoly brands. Moreover, stations that sell gasoline and diesel as a by-product are among the cheapest gasoline stations. More generally, the type of local competition is found to be more relevant than the sheer number of players. Lower price levels can be expected the more heterogeneous the group of brands within a local area is. This implies that a concentration on market shares alone is insufficient to explain competitive dynamics, even at the local level. Finally, service offerings tend to increase prices, but in some instances also volatility. As an example, the absence of a shop and, thus, likely less sophisticated operations, implies fewer price changes. Results are comparable across fuel types and largely support expectations on price determinants (Eckert 2013), while specific impacts naturally vary.

These findings are extremely relevant for the policy debate. Retail gasoline pricing is often poorly understood by policy-makers and, therefore, viewed with great suspicion. Often, an overly simplistic idea of competition is applied, not accounting for product differentiation that results from station heterogeneity. In our paper, we have managed to identify a number of factors that affect price levels as well as the frequency of price changes. Parts of the price differences among stations can be explained by factors of product differentiation between stations such as the type of shop, the presence of a car wash facility, or brand names. Furthermore, competition among stations plays a role, as prices tend to decrease with the number of competitors in the vicinity. Input costs as measured by ex-refinery prices and distance to refineries are also important, as are demand-side factors. Hence, we are able to draw a quite complex picture of the factors driving retail gasoline price levels and price changes. Most important from a policy perspective, however, is the finding that competitive forces are, at least to a measurable degree, working, in contrast to suspicions sometimes voiced in policy circles. Cost pass-through rates between 90 and 100% suggest that competition is alive, even though the model of perfect competition may not be the most applicable.

The findings presented in this paper are, of course, subject to certain assumptions and limitations. Among others, areas close to the border are subject to cross-border competition, which cannot be considered in our analysis (see, e.g., Banfi, Filippini, and Hunt 2005). Moreover, the method of calculating average daily and daytime prices is necessarily imperfect. Further research in the area of retail gasoline pricing may investigate specific aspects associated with intraday pricing patterns (compare Figure 2.4), for example, in the context of Edgeworth cycle theory. Furthermore, the impact of opening hours and other competition-related variables on local pricing as well as the price pass-through from refineries to retail gasoline stations (cf. rockets-and-feathers literature) may be interesting aspects for future research.

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Appendix

2.A Preparation of Raw Data

In this appendix, we will describe the process of data validation including any corrections made to MTS-K raw data with respect to both price and station data.

First, closely following validation rules suggested by the Federal Cartel Office (Bundeskartellamt 2011b, Appendix p. 3), retail price raw data as submitted to the market transparency unit for fuel is corrected for obvious errors. Broadly speaking, the Federal Cartel Office proposes to delete inaccurate data entries for one of three reasons: missing entries (i.e., empty price cells), most likely incorrect price levels (i.e., prices below a threshold level of 0.50 Euro per liter or above a threshold level of 2.00 Euro per liter), or most likely incorrect price changes (i.e., zero price change or price change below or above a threshold level of |0.20| Euro per liter). Given that we focus on the standard operation phase ("Regelbetrieb") starting 1 December 2013 and leave out the first month (i.e., December 2013) as several stations are not (yet) submitting prices to MTS-K in this period, necessary adjustments to raw data for the period January to December 2014 are, in total, on an acceptable level (of around 1% of total observations). Table 2.6 presents an overview of validation rules and affected data records. Please note that deleting a data entry due to an incorrect price change might create new instances of incorrect price changes. Therefore, we conduct corrections in as many iterations as required to eliminate all errors. Table 2.6 shows the sum of corrected price changes after all iterations. The empirical analysis presented in this paper relies on "total valid observations".

In a second step, we check MTS-K station data for activity status and submission of price quotes for each fuel type. In total, the MTS-K data set (as of mid-2014) includes 14,838 entries. A number of entries are, however, flagged as no longer active as, for instance, some stations were closed or changed their ownership structure and/ or brand name, leading to double entries. These inactive entries are, therefore, disregarded from the analysis. Some further stations do not submit price quotes at all or not for all three fuel types (e.g., a station does not offer all products). After

Table 2.6: Raw Price Data Preparation

Variable	Super E5	Super E10	Diesel
Total observations	24,284,499	23,636,582	24,816,236
Empty price cell	7,980	46,795	5,101
Price $<$ 0.50 Euro/liter	0	0	0
Price $>$ 2.00 Euro/liter	0	0	0
Change $=$ 0.00 Euro/liter	194,257	182,787	183,823
Change $>$ $\lvert 0.20 \rvert$ Euro/liter	6,500	4,529	6,021
Total invalid observations	208,737	234,111	194,945
Total valid observations	24,075,762	23,402,471	24,621,291

Source: MTS-K data (Jan-Dec 2014), own calculation.

excluding stations without price quotes, in total, 14,454 stations are considered valid and are used for pricing analysis. For fuel-type specific analysis, (different) subsets of active stations with (valid) price quotes are used. While we explicitly exclude stations without any (fuel-type specific) price quotes, we do not impose further (subjective) threshold levels regarding, for instance, a minimum required number of price quotes per station to be considered. As a consequence, we allow the data set to be unbalanced. Finally, we link various station characteristics from Petrolview to MTS-K station data on the basis of geographic coordinates as well as address information (i.e., street, ZIP code, city). In total, we are able to connect 14,135 or 98% of all valid MTS-K stations with Petrolview data and consequently use this data set to determine price level determinants. Table 2.7 presents the number of stations along the categories described above. The empirical analysis in this paper relies on "stations with all characteristics" or, more precisely, fuel-type specific sub-groups.

Table 2.7: Raw Station Data Preparation

Variable	Count
Total entries (MTS-K)	14,838
Active stations (MTS-K)	14,530
Active stations with price quotes (MTS-K)	14,454
Thereof: Offering Super E5	14,270
Thereof: Offering Super E10	13,673
Thereof: Offering Diesel	14,450
Stations with all characteristics (MTS-K, Petrolview)	14,135
Thereof: Offering Super E5	14,006
Thereof: Offering Super E10	13,436
Thereof: Offering Diesel	14,131

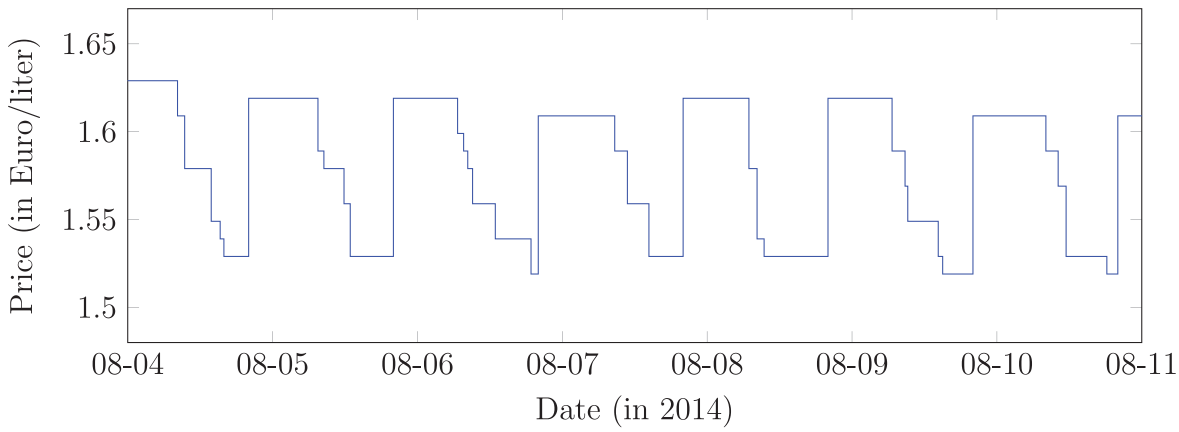
Source: MTS-K data, Petrolview data, own calculation.

2.B Figures and Tables

Table 2.8: Overview of Variables

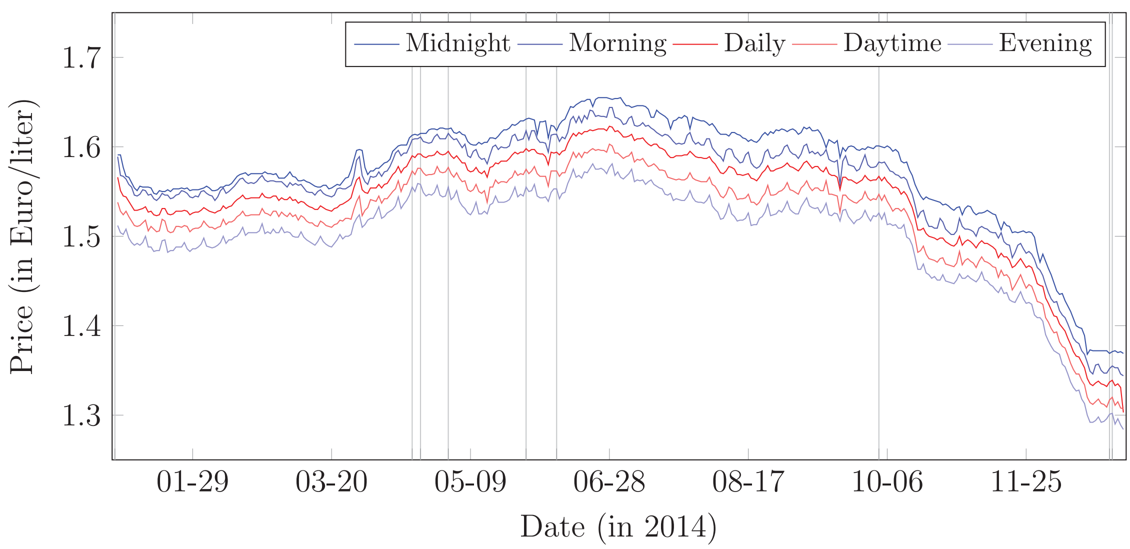
Variable	Type	Source
Station location:		
Station ID	Integer, constant	MTS-K
Latitude	Decimal, constant	MTS-K
Longitude	Decimal, constant	MTS-K
ZIP code	Integer, constant	MTS-K
Federal state	Cluster, constant	OpenGeoDB/ own calc.
Type:		
Brand name	String, constant	MTS-K
Brand category 1	Cluster, constant	Bundeskartellamt/ own calc.
Brand category 2	Cluster, constant	Bundeskartellamt/ own calc.
Ownership type	Cluster, constant	Petrolview
Autobahn station	Binary, constant	Tank & Rast/ own research
Station offering & amenities:		
Offering Super E5	Binary, constant	MTS-K/ own calc.
Offering Super E10	Binary, constant	MTS-K/ own calc.
Offering Diesel	Binary, constant	MTS-K/ own calc.
Shop type	Cluster, constant	Petrolview
Car wash facility	Binary, constant	Petrolview
Gasoline/ diesel pumps	Integer, constant	Petrolview
Truck pumps	Binary, constant	Petrolview
LPG pumps	Binary, constant	Petrolview
CNG pumps	Binary, constant	Petrolview
Traffic intensity	Cluster, constant	Petrolview
Secondary road	Binary, constant	Petrolview
Spatial competition:		
Nearest competitor	Decimal, constant	Own calculation
Competitors in 1/ 2/ 5 km	Integer, constant	Own calculation
Share of oligopoly players	Decimal, constant	Own calculation
Share of independents	Decimal, constant	Own calculation
Business hours:		
Open on Sundays	Binary, constant	MTS-K/ own calc.
Open "24/7"	Binary, constant	MTS-K/ own calc.
Retail prices:		
Fuel type	Integer, constant	MTS-K
Avg. daily/ daytime prices	Decimal, variant	MTS-K/ own calc.
Point-in-time prices	Decimal, variant	MTS-K/ own calc.
Wholesale prices:		
Refinery region	String, constant	O.M.R./ own calc.
Distance to closest refinery	Decimal, constant	O.M.R./ MTS-K/ own calc.
Add'l distance to 2^{nd} refinery	Decimal, constant	O.M.R./ MTS-K/ own calc.
Refinery price	Decimal, variant	O.M.R.
Weekday & holidays:		
Weekday	Integer, variant	Own calculation
Public holiday	Binary, variant	BMI
School holiday	Binary, variant	KMK

Note: BMI = Bundesministerium des Inneren, KMK = Kultusministerkonferenz, MTS-K = Markttransparenzstelle für Kraftstoffe, O.M.R. = Oil Market Report.



Note: Pricing of Aral station in Drolshagen, week commencing 4 August 2014.

Figure 2.4: Exemplary Weekly Price Pattern of Major-Brand Gasoline Station



Note: Super E5 retail price series (i.e., averages across all German stations' prices) of indicated metric (i.e., point-in-time metrics in blue, average price metrics in red). Vertical lines represent public holidays in majority of states.

Figure 2.5: Retail Price Series of Different Metrics (Example: Super E5)

Table 2.9: Regression of Retail Prices (Super E10)

Dependent variable:	Average prices		Point-in-time prices		
Super E10 price	Daily	Daytime	Morning	Evening	Midnight
	(13)	(14)	(15)	(16)	(17)
Station type					
Autobahn station	5.627	6.455	5.649	9.224	3.452
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
24/7 business hours	0.329	0.306	0.155	0.495	–
	(0.00)	(0.00)	(0.00)	(0.00)	
Brand categories					
Oligopoly player brand	2.490	1.140	1.647	1.085	4.063
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Integr. player brand	0.787	0.568	0.934	0.897	1.405
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Station characteristics					
Convenience store	0.255	0.125	0.260	*0.026*	0.780
	(0.00)	(0.00)	(0.00)	*(0.46)*	(0.00)
Kiosk-type store	-0.272	*-0.041*	-0.338	0.210	-0.980
	(0.01)	*(0.60)*	(0.00)	(0.03)	(0.01)
No store	-0.819	-0.243	-1.149	*0.072*	-1.106
	(0.00)	(0.00)	(0.00)	*(0.34)*	(0.00)
Car wash	0.417	0.176	0.215	0.189	*0.212*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.10)*
Traffic intensity	*0.026*	*-0.011*	*0.006*	*-0.036*	0.187
	(0.27)	*(0.61)*	*(0.81)*	*(0.15)*	(0.00)
Number of pumps	-0.122	-0.096	-0.098	-0.097	*-0.057*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.13)*
Truck pumps	0.202	0.141	0.098	0.175	0.280
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)
Local competition					
Distance to nearest comp.	0.026	*0.010*	*0.009*	0.040	*0.026*
	(0.01)	*(0.24)*	*(0.42)*	(0.00)	*(0.13)*
# of competitors in 2 km	-0.099	-0.083	-0.114	-0.075	-0.053
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Share of oligopoly brands	0.691	0.547	0.667	0.472	0.591
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)
Share of independents	0.389	0.481	0.340	0.549	*-0.104*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.71)*
Demand-side controls					
School holiday	0.267	0.012	0.231	-0.069	0.697
	(0.00)	(0.02)	(0.00)	(0.00)	(0.00)
Public holiday	0.370	0.683	0.714	0.874	-0.280
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Input costs					
Ex-refinery price	1.107	1.098	1.116	1.086	1.092
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to refinery	0.012	0.016	0.010	0.016	0.006
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	16.254	16.366	17.445	15.584	19.987
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	4,781,094	4,792,445	4,794,396	4,792,374	1,863,261
Number of groups	13,435	13,435	13,435	13,435	5,249
R^2	0.876	0.874	0.817	0.839	0.773

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics.
Included but not shown: Weekday dummies, state dummies, LPG/ CNG pump, ownership type, secondary road, additional distance to 2nd refinery, and open on Sundays dummy.
Omitted variables: Road station, independent brand, standard store.

Table 2.10: Regression of Retail Prices (Diesel)

Dependent variable:	Average prices		Point-in-time prices		
Diesel price	Daily	Daytime	Morning	Evening	Midnight
	(18)	(19)	(20)	(21)	(22)
Station type					
Autobahn station	5.900	6.723	6.097	9.642	3.527
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
24/7 business hours	0.293	0.262	0.117	0.451	–
	(0.00)	(0.00)	(0.01)	(0.00)	
Brand categories					
Oligopoly player brand	2.706	1.167	1.782	1.108	4.607
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Integr. player brand	0.822	0.534	0.983	0.863	1.630
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Station characteristics					
Convenience store	0.267	0.123	0.274	*0.008*	0.851
	(0.00)	(0.00)	(0.00)	*(0.83)*	(0.00)
Kiosk-type store	-0.447	-0.161	-0.504	*0.073*	-1.233
	(0.00)	(0.03)	(0.00)	*(0.42)*	(0.00)
No store	-0.897	-0.293	-1.245	*0.027*	-1.210
	(0.00)	(0.00)	(0.00)	*(0.70)*	(0.00)
Car wash	0.416	0.154	0.197	0.157	*0.168*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.21)*
Traffic intensity	*0.041*	*-0.005*	*0.014*	*-0.031*	0.213
	(0.11)	*(0.79)*	*(0.61)*	*(0.21)*	(0.00)
Number of pumps	-0.122	-0.098	-0.087	-0.107	-0.071
	(0.00)	(0.00)	(0.00)	(0.00)	(0.07)
Truck pumps	0.227	0.150	0.130	0.187	0.338
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Local competition					
Distance to nearest comp.	0.022	*0.009*	*0.001*	0.047	*0.008*
	(0.03)	*(0.32)*	*(0.94)*	(0.00)	*(0.64)*
# of competitors in 2 km	-0.108	-0.088	-0.127	-0.082	-0.060
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Share of oligopoly brands	0.839	0.606	0.859	0.526	0.933
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Share of independents	0.498	0.548	0.468	0.643	*0.092*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.76)*
Demand-side controls					
School holiday	0.068	-0.201	0.024	-0.255	0.493
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Public holiday	0.503	0.882	0.860	1.090	-0.270
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Input costs					
Ex-refinery price	1.075	1.087	1.089	1.072	1.004
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Distance to refinery	0.012	0.016	0.010	0.015	0.006
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	19.690	17.522	20.401	17.086	29.115
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	5,034,078	5,045,724	5,048,057	5,045,648	1,996,631
Number of groups	14,130	14,130	14,130	14,130	5,622
R^2	0.815	0.821	0.722	0.771	0.672

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics.
Included but not shown: Weekday dummies, state dummies, LPG/ CNG pump, ownership type, secondary road, additional distance to 2^{nd} refinery, and open on Sundays dummy.
Omitted variables: Road station, independent brand, standard store.

Table 2.11: Regression of Retail Prices (Super E5) – Further Variables

Dependent variable:	Average prices		Point-in-time prices		
Super E5 price	Daily	Daytime	Morning	Evening	Midnight
	(1)	(2)	(3)	(4)	(5)
Station-specific variables					
Open on Sundays	0.309	*0.033*	0.548	-0.367	-
	(0.00)	*(0.65)*	(0.00)	(0.00)	
Company ownership	0.104	*-0.013*	0.094	*0.007*	0.682
	(0.00)	*(0.69)*	(0.02)	*(0.86)*	(0.00)
Other ownership	-0.225	-0.509	-0.468	-0.660	*-0.478*
	(0.06)	(0.00)	(0.00)	(0.00)	*(0.22)*
Secondary road	0.188	0.095	0.122	0.109	0.245
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
LPG pumps	-0.177	-0.130	-0.080	-0.142	-0.349
	(0.00)	(0.00)	(0.03)	(0.00)	(0.00)
CNG pumps	*0.055*	0.200	*0.108*	0.166	*-0.051*
	(0.38)	(0.00)	*(0.13)*	(0.01)	*(0.70)*
Add'l distance to 2nd refinery	0.004	0.005	0.004	0.005	*-0.001*
	(0.00)	(0.00)	(0.00)	(0.00)	*(0.57)*
Demand-side controls (weekdays)					
Monday	-0.332	-0.583	-0.669	-0.929	0.160
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Tuesday	-0.194	-0.450	-0.638	-0.782	0.303
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Wednesday	-0.177	-0.440	-0.591	-0.756	0.363
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Thursday	-0.256	-0.544	-0.713	-0.787	0.339
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Friday	-0.297	-0.557	-0.758	-0.865	0.241
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Saturday	-0.201	-0.388	-0.114	-0.562	0.192
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Demand-side controls (states)					
Baden-Württemberg	2.219	2.109	2.338	2.190	2.564
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Bayern	1.677	1.699	1.515	2.286	1.195
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Berlin	-0.419	-0.437	-0.518	-0.302	*-0.305*
	(0.00)	(0.00)	(0.00)	(0.03)	*(0.27)*
Brandenburg	0.299	0.403	0.458	*0.240*	*0.370*
	(0.02)	(0.00)	(0.00)	*(0.12)*	*(0.14)*
Bremen	*-0.201*	-1.030	*-0.145*	-0.819	1.792
	(0.30)	(0.00)	*(0.46)*	(0.00)	(0.00)
Hamburg	*0.221*	-0.271	0.334	*-0.213*	1.111
	(0.17)	(0.03)	(0.04)	*(0.16)*	(0.00)
Hessen	1.227	1.254	1.444	1.187	1.152
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Mecklenburg-Vorpommern	-0.355	-0.538	*0.010*	-1.086	0.764
	(0.01)	(0.00)	*(0.94)*	(0.00)	(0.01)
Niedersachsen	0.839	0.594	1.202	0.314	1.372
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Nordrhein-Westfalen	0.869	0.555	1.251	0.313	1.657
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Rheinland-Pfalz	1.245	1.374	1.219	1.615	1.007
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Saarland	1.907	1.613	2.677	1.735	1.929
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Sachsen	*-0.157*	*-0.021*	-0.247	*-0.041*	*-0.065*
	(0.16)	*(0.83)*	(0.03)	*(0.75)*	*(0.79)*
Sachsen-Anhalt	*-0.174*	*-0.016*	-0.351	*-0.147*	*-0.127*
	(0.16)	*(0.88)*	(0.00)	*(0.28)*	*(0.63)*
Schleswig-Holstein	0.710	0.338	1.003	*-0.192*	1.414
	(0.00)	(0.00)	(0.00)	*(0.17)*	(0.00)
Constant	16.939	17.098	17.987	16.405	20.656
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	4,989,486	5,001,061	5,003,332	5,000,986	1,955,103
Number of groups	14,005	14,005	14,005	14,005	5,504
R^2	0.875	0.874	0.815	0.838	0.773

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics.
Only variables not included in Table 2.3 shown.
Omitted variables: Sunday (weekday), Thüringen (state), dealer ownership.

Table 2.12: Regression of Retail Prices (Single Brands, Open 24/7, Super E5)

Dependent variable:	Average prices		Point-in-time prices		
Super E5 price	Daily	Daytime	Morning	Evening	Midnight
	(23)	(24)	(25)	(26)	(27)
Oligopoly player brand					
Aral	4.126	1.765	3.463	1.068	6.262
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Shell	4.429	1.376	2.801	1.417	8.103
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Esso	2.909	0.705	2.049	*-0.250*	6.524
	(0.00)	(0.00)	(0.00)	*(0.10)*	(0.00)
Total	2.458	0.409	2.015	-0.735	5.522
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Jet	*-0.189*	-0.882	*0.099*	-1.428	1.687
	(0.24)	(0.00)	*(0.58)*	(0.00)	(0.00)
Other integrated player					
star	0.647	-0.505	0.971	-1.282	3.706
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Agip	2.648	2.239	2.806	1.249	1.572
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
HEM	0.555	*-0.211*	1.012	-0.810	2.406
	(0.00)	*(0.23)*	(0.00)	(0.00)	(0.00)
OMV	4.162	1.169	3.354	3.694	7.235
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Independent brands (associations)					
AVIA	2.070	0.723	2.219	*-0.175*	4.233
	(0.00)	(0.00)	(0.00)	*(0.17)*	(0.00)
bft	*0.258*	*0.114*	*0.221*	*0.014*	0.674
	(0.15)	*(0.42)*	*(0.34)*	*(0.93)*	(0.05)
Raiffeisen	0.446	*0.034*	0.613	-0.351	1.238
	(0.00)	*(0.76)*	(0.00)	(0.01)	(0.00)
Other selected independent brands					
Mr. Wash	no obs.	no obs.	no obs.	no obs.	no obs.
DBV	-2.294	-1.669	-1.203	-2.260	-2.974
	(0.00)	(0.00)	(0.10)	(0.00)	(0.00)
Globus	-1.835	*-0.495*	-2.222	*0.376*	-4.144
	(0.00)	*(0.11)*	(0.00)	*(0.25)*	(0.00)
ED	-2.334	-2.022	-0.663	-2.811	-3.719
	(0.00)	(0.00)	(0.01)	(0.00)	(0.02)
V-Markt	-1.781	*-0.292*	-3.447	*0.082*	-4.035
	(0.00)	*(0.56)*	(0.00)	*(0.90)*	(0.00)
Input costs					
Ex-refinery price	110.58	109.74	111.47	108.75	108.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	16.716	17.302	17.361	17.040	19.478
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Number of observations	1,955,127	1,959,479	1,960,544	1,959,454	1,955,103
Number of groups	5,504	5,504	5,504	5,504	5,504
R^2	0.897	0.880	0.825	0.847	0.816

Note: Robust p-values in parentheses; non-significance at 10% level denoted in italics.
Included but not shown: Other single brands; all station characteristics and demand-side controls.
Omitted variables: “Unbranded” stations and other omitted variables as in previous specifications.

2.C Distribution of Prices

In this appendix, we explore the distribution of prices across gasoline stations in Germany. Generally, price dispersion means that firms charge different prices for selling the same good at the same time (Lewis 2008, p. 654). Despite being fairly homogenous products, dispersed gasoline prices might still be present but induced by station-specific attributes rather than the physical characteristics of the fuel offered.

To provide evidence of price dispersion, following Lewis (2008), Hosken, McMillan, and Taylor (2008), and others, we propose a simple model using (time-invariant) station-fixed effects to control for the heterogeneity of stations (irrespective of whether characteristics are observed or unobserved) as well as time-fixed effects (in form of time dummies for all days considered) to account for price changes over time, which are common to all stations. Equation (2) below describes such a two-way fixed effects regression model (see Cameron and Trivedi 2005, p. 738),

$$p_{it} = \alpha + \theta_i + \gamma_t + u_{it} \tag{2}$$

with p_{it} as station i's (point-in-time) retail price at day t, θ_i representing station-fixed effects and γ_t representing time-fixed effects. Residuals u_{it} are considered deviations from the "clean" or "residual" price after controlling for station heterogeneity and (input) price variations equally affecting stations (Pennerstorfer et al. 2015).

Table 2.13 illustrates the retail price distribution for Super E5 using three point-in-time metrics and three distinct price series, namely (i) retail prices as listed at the pump, (ii) prices corrected for time-fixed effects, and (iii) clean prices as introduced above, estimated by the two-way fixed effects model. The table shows frequency distributions of residuals around the estimated price, rounded to the nearest Eurocent/liter of fuel. The estimated price in the center of the distribution thereby represents either (i) a simple average price across all stations and days, (ii) a day-specific average price across all stations, or (iii) the day-specific average price determined by a specific station's characteristics. Albeit intraday spreads might be considerably larger, distributions around (i) and (ii) represent maximum levels of price differences (at different points in time) a consumer could be exposed to over the year or on a typical day. While prices in (i) are obviously quite dispersed, including time fixed effects in (ii) leads to a higher concentration around the estimated price. Notably, at midnight, numerous stations offer prices slightly above the average, while stations pricing below the average are more dispersed. In (iii), we see evidence of a strong impact of station-specific characteristics on prices. The remaining distribution can be attributed to true price dispersion across stations.

Table 2.13: Distribution of Point-in-Time Prices

Price series	Period	−5	−4	−3	−2	−1	0	1	2	3	4	5
(i) Distribution of prices around mean: $u_{it} = \bar{p} - p_{it}$	Midnight	3%	3%	4%	5%	6%	8%	8%	6%	4%	4%	4%
	Morning	3%	3%	4%	5%	6%	7%	8%	9%	9%	7%	5%
	Evening	2%	3%	4%	6%	7%	8%	8%	8%	8%	8%	6%
(ii) Distribution of prices with time-fixed effects: $u_{it} = \hat{p}_t - p_{it}$	Midnight	2%	4%	5%	7%	7%	6%	8%	12%	12%	10%	8%
	Morning	3%	4%	6%	10%	15%	15%	12%	9%	7%	4%	3%
	Evening	2%	5%	11%	15%	17%	15%	11%	7%	5%	3%	2%
(iii) Distribution of "clean" or residual prices: $u_{it} = \hat{p}_{it} - p_{it}$	Midnight	1%	2%	4%	9%	20%	22%	21%	12%	5%	2%	1%
	Morning	1%	2%	5%	10%	18%	22%	18%	11%	6%	3%	2%
	Evening	1%	2%	5%	12%	22%	24%	17%	8%	4%	2%	1%

Note: Price distributions for Super E5 in Eurocents/liter (rounded to nearest cent); only illustrated for range of -5 and +5 Eurocents/liter.
Source: MTS-K data, own calculation.

Declaration of Contribution

Hereby I, Manuel Siekmann, declare that the chapter *"Fuel Prices and Station Heterogeneity on Retail Gasoline Markets"* is co-authored by Justus Haucap and Ulrich Heimeshoff. It is forthcoming in *The Energy Journal* (Haucap, Heimeshoff, and Siekmann 2017).

My contributions to this chapter are as follows:

- I was responsible for data gathering, preparation and analysis
- I wrote major parts of the introduction, the literature review, the section on market and data, the empirical analysis, and the conclusion

Signature of co-author 1 (Justus Haucap): ________________________

Signature of co-author 2 (Ulrich Heimeshoff): ________________________

Chapter 3

Selling Gasoline as a "By-Product": The Impact of Market Structure on Local Prices[1]

We use a novel data set with exact price quotes from virtually all German gasoline stations to empirically investigate how a temporary variance in local market structure – induced by restricted opening hours of specific players – affects price competition. We focus on stations selling gasoline as a "by-product" (i.e., as an add-on to a company's core product range) and find that, during their exogenously determined hours of opening, they have a significant negative price effect on nearby major-brand gas station competitors. Applying a difference-in-difference framework with hourly average prices, our findings explicitly account for counterfactual market scenarios.

[1]This chapter, co-authored by Justus Haucap and Ulrich Heimeshoff, is based on DICE Discussion Paper No. 240 (Haucap, Heimeshoff, and Siekmann 2016).

3.1 Introduction

Retail gasoline prices are a topic of significant public interest around the world (see OECD 2013). Consumers and regulators frequently observe significant inter- and intraday price volatility. While price volatility can, at least partly, be traced back to the associated volatility of crude oil or refinery prices (see, e.g., Frondel, Vance, and Kihm 2016; Haucap, Heimeshoff, and Siekmann 2017), intraday price fluctuations are mainly driven by demand factors and competition. The increasing extent of price fluctuations has raised public concerns in policy circles, the media, and at competition authorities alike. Only recently, the German Federal Cartel Office has observed an average price spread of seven to ten Eurocents/liter per gasoline station and day, and even a 15 to 20 Eurocents/liter average daily price spread within the same city in Germany (Bundeskartellamt 2014). Consumers face significant uncertainty resulting from four to five price changes per gasoline station and day. While there has been a number of papers that study interday price fluctuations, virtually no study on intraday price fluctuations exists, typically due to a lack of data.

In this paper, we investigate how a temporary, recurring variance in market structure affects gasoline prices across our period of observation of 2014. We choose gas stations of companies whose core business differs from selling gasoline as our main objects of investigation. While such stations selling gasoline as a "by-product", for instance next to supermarkets, play a minor role in Germany in terms of their overall nationwide market share (see, e.g., EID 2014), they often have a favorable feature we will exploit in the course of this paper. Namely, their opening hours are typically restricted and exogenously determined by their primary business activity (e.g., selling groceries). We argue that the opening hours of a station selling gasoline as a sideline business can be seen as an exogenous variation of the local market structure and temporarily increase the degree of price competition for nearby competitors. To isolate and quantify these effects in light of decreasing prices throughout the day in many market areas, we include counterfactual scenarios in our analysis and use a difference-in-difference framework. Our analysis uses a novel data set including a census of price quotes from virtually all German gasoline stations. With this data set, we are able to report intraday price changes and connect them with data on weekday-specific opening hours.

We find that stations selling gasoline as a "by-product" have a statistically significant negative price effect on nearby major-brand competitors during their hours of operation. With a gasoline station associated to a supermarket or car wash facility in the surrounding area, particularly major brands show a temporary price reaction beyond their usual daytime price reductions. The effect is largely consistent across rural and urban areas as well as different supermarket and car wash chains, and it is more pronounced during working days.

The remainder of this paper is structured as follows: Section 4.3 provides an overview of relevant empirical literature. In section 3.3, we briefly describe the German retail gasoline market (section 3.3.1) and specifically focus on stations selling gasoline as a "by-product" (section 3.3.2). Section 4.4 explains our data set before section 4.5 presents the empirical analysis. The latter includes both an introduction to observable intraday pricing patterns (section 3.5.1) as well as our identification strategy (section 3.5.2), and presents our findings in detail (section 3.5.3). Finally, section 4.6 concludes.

3.2 Related Literature

Numerous empirical studies investigate pricing on retail gasoline markets in different regional areas.[2] Most studies have focused on retail markets in North America (e.g., Borenstein and Shepard 1996; Doyle, Muehlegger, and Samphantharak 2010; Hosken, McMillan, and Taylor 2008; Lewis and Noel 2011; Shepard 1993 for markets in the U.S. or Atkinson 2009; Byrne, Leslie, and Ware 2015; Carranza, Clark, and Houde 2015; Noel 2007a, 2012, 2015; Slade 1987, 1992 for markets in Canada). While several studies use either cross-sectional price data or a single time series of prices, the majority relies on panel data with either daily, weekly, monthly or other (irregular, varying) frequencies of station-level or city-average prices. Regarding focus areas, Eckert (2013) suggests to distinguish between studies focusing on price dynamics, on the one hand, and studies analyzing determinants of price levels, on the other hand. Among the first-mentioned category are analyses of upstream (wholesale, crude oil) costs pass-through to retail prices, specifically with regards to response asymmetry (e.g., Kihm, Ritter, and Vance 2016; Noel 2009), as well as investigations exploring special aspects of Edgeworth cycles on gasoline markets (e.g., Doyle, Muehlegger, and Samphantharak 2010; Isakower and Wang 2014; Noel 2007b). Recurring, asymmetric price cycles, known as Edgeworth cycles, were theoretically explained by Maskin and Tirole (1988). They are characterized by a relenting phase with fast and large price increases (up to a level slightly above the monopoly price) and an undercutting phase consisting of a longer sequence of

[2] Eckert (2013) presents a comprehensive classification of existing empirical gasoline market studies along different criteria.

small price-cuts (down to the level of marginal cost).[3] The group of studies focusing on price level determinants, in turn, includes both studies examining the impact of mergers or regulatory changes (e.g., Dewenter, Heimeshoff, and Lüth 2017; Simpson and Taylor 2008; Wang 2009) and studies looking at price dispersion and price differentials among stations (e.g., Haucap, Heimeshoff, and Siekmann 2017; Lewis 2008; Pennerstorfer et al. 2015). Lach and Moraga-González (2009), for instance, investigate how the number of stations affects the daily distribution of prices with data from the Netherlands. They find an asymmetric effect of competition on prices and an increase in consumer welfare induced by an increase in the number of gasoline stations in the market.

In this paper, we will regionally focus on the German market. While in Germany, as in other countries, retail gasoline pricing is a topic of high public attention, empirical studies are rarely available. A noteworthy exception is a sector inquiry on fuel retailing conducted by the Bundeskartellamt (2009, 2011a,b). This investigation includes a price survey in four model regions, revealing evidence of recurring price cycles, a market-dominating oligopoly and implicit collusion.[4] Furthermore, in recent papers, Kihm, Ritter, and Vance (2016) and Frondel, Vance, and Kihm (2016) investigate the pass-through of crude oil price changes in Germany by using a large data set of prices.[5] Regarding retail price data, we will rely on a novel data set provided by the market transparency unit for fuels ("Markttransparenzstelle für Kraftstoffe", MTS-K), covering price changes of virtually all gasoline stations in Germany.[6] Haucap, Heimeshoff, and Siekmann (2017) use exactly this data set to analyze price drivers on a large-scale basis in Germany. Among other things, they find that the degree of local competition, measured by the number of different players in a given area, negatively affects average price levels.

Motivated by this finding, our goal is to investigate whether retailers selling gasoline as a sideline business have an impact on local prices during their opening hours or, generally speaking, whether a (recurring) exogenous variance of market structure affects market area price levels. For this purpose, we apply a difference-in-difference

[3]See Noel (2011) for a non-technical introduction to Edgeworth cycle theory. Moreover, Byrne (2012) includes an overview of literature on retail gasoline price cycles.

[4]Model regions were Cologne, Hamburg, Munich, and Leipzig; in total, price movements at 407 gasoline stations were analyzed with data from 1 January 2007 to 30 June 2010.

[5]Similarly, Asane-Otoo and Schneider (2015) analyze the adjustment of retail fuel prices in Germany to international crude oil prices over a longer time horizon. Their findings suggest symmetric price adjustments in recent years (i.e., 2009-2013). Their data set of weekly national or daily city-level data, however, does not allow a differentiation by brand.

[6]The emergence of the MTS-K was mainly motivated by findings described above in Bundeskartellamt (2011a,b). For descriptive statistics on MTS-K price data, please see Bundeskartellamt (2014, 2015, 2017).

framework and, thereby, explicitly account for counterfactual scenarios. Applying a difference-in-difference framework is an approach frequently used in contributions analyzing effects of mergers or regulatory changes on gasoline prices. As an example, Dewenter and Heimeshoff (2012) apply such a framework to estimate the impact of a one-off regulatory change on average prices (weekly, nationwide). The authors compare an asymmetric pricing rule in Austria and a symmetric pricing rule in Western Australia vis-à-vis unrestricted pricing regimes. While, for Austria, a decrease in price levels can be observed, there is no significant effect on Western Australian price levels. In a similar framework, comparing 27 European countries, Dewenter, Heimeshoff, and Lüth (2017), find evidence for increased gasoline and diesel prices as a result of the introduction of the so-called MTS-K in Germany. Moreover, Hastings (2004) and Taylor, Kreisle, and Zimmerman (2010) use a difference-in-difference-type model to study the effect of brand conversion (i.e., gasoline stations subject to a change of branding without impact on site location or station characteristics) on local prices. The two studies, however, yield ambiguous results regarding the price effect associated with a stronger presence of independent retailers.

Empirical literature specifically focusing on selling gasoline as a “by-product” is rare and largely related to stations associated to supermarkets. Zimmerman (2012) estimates the impact of hypermarket gasoline sales on annual average state-level gasoline prices in the U.S. from 1998 to 2002. He finds a significant competitive effect from hypermarkets, lower price levels with higher shares of hypermarkets, and increased consumer welfare. Ning and Haining (2003) focus on the Sheffield, UK, market with self-surveyed (bi-)weekly price data (from 1995 to 1997). Their regression results show that being attached to a supermarket location is a significant supply-side driver of prices. Finally, Wang (2015) investigates bundled discounts of supermarket and associated gasoline purchases, having access to daily price quotes from Western Australian stations before and after the introduction of bundled discount programs. Wang interprets the effect of introducing gasoline bundling programs by supermarkets as pro-competitive in the short-term while being neutral in the long-run.

Utilizing restricted opening hours of (supermarket or car wash) gasoline stations as an exogenous change in market structure is, to the best of our knowledge, a novel approach we will follow in this paper. This is enabled by having access to a granular price data set. After an introduction to the German retail gasoline market and the data set employed, we will present our empirical analysis in section 4.5.

3.3 The German Retail Gasoline Market

3.3.1 General Market Characteristics

Gasoline is reasonably homogeneous in terms of its chemical product characteristics. Typically, different gasoline products are sold at distributed retail stations. The most common product types sold in Germany are the two unleaded gasoline products "Super E5" (with a minimum research octane number, RON, of 95 and 5% of added ethanol) and "Super E10" (with an RON of 95 and 10% added ethanol) in addition to a standard diesel product. While most consumers can freely choose among different gasoline products, changing between gasoline and diesel is not an option due to different technical engine specifications. Given a lack of short-term substitutability for consumers, gasoline and diesel are typically regarded as different product markets.

Competition in gasoline markets (with fairly homogeneous products) is largely driven by price as well as other factors such as a station's brand recognition, its spatial location, or additional service offerings, for instance, in form of affiliated shops (see, e.g., OECD 2013, pp. 9-30). In Germany, pricing is not restricted by regulatory rules. Along with low menu costs, prices can be changed at virtually any time. At the same time, consumers can easily observe prices and switch suppliers at low costs. In practice, however, competition among stations is confined to reasonably small, local market areas.

The majority of stations is owned by vertically integrated oil companies. Five of these integrated players have both a broad, nationwide network of retail sites and substantial, direct access to refinery capacities in Germany (e.g., through joint ventures among some of these players). These five players are, thus, considered by the Bundeskartellamt (2011b) to form a market-dominating oligopoly. The players are Aral/ BP, Shell, Total, Esso/ ExxonMobil, and Jet/ ConocoPhilipps and they roughly serve two thirds of market demand. In this group of so-called oligopoly-type players, Jet has an ambiguous and legally disputed position (see, e.g., discussions in Bundeskartellamt 2011b, p. 13 or Haucap, Heimeshoff, and Siekmann 2017).[7] Therefore, we group stations operating under a brand of one of the remaining four players as "major brand" stations.[8] Apart from a few other integrated players (e.g.,

[7]While the Federal Cartel Office considers Jet as part of a jointly-dominant oligopoly, the Düsseldorf Higher Regional Court did not share this view in a recent merger case (see, e.g., Monopolkommission 2014).

[8]Brand affiliation and station ownership might not always coincide (see, e.g., Shepard 1993, pp. 60-66 or Bundeskartellamt 2011b, pp. 166-171). In this paper, we, strictly speaking, analyze brand affiliation, not station ownership.

Star/ Orlen or Agip/ ENI), numerous stations in Germany are run independently. Many of these independent players cooperate in associations (e.g., AVIA or bft). For all integrated players, but also for most independents, selling gasoline is considered the primary business activity while, among others, the sale of car-related products (e.g., oil, windscreen fluid), car wash services, or groceries might generate ancillary revenues. There are, however, a small number of independent stations, for which gasoline is not the core product. As these stations are, in our view, particularly interesting objects of investigation, we will introduce them in the following section.

3.3.2 Stations Selling Gasoline as a "By-Product"

In Germany, as in most other countries, the majority of retailers selling gasoline regards this as their primary business activity, independent of brand and other characteristics. However, a smaller number of retailers sell gasoline as a "by-product". Typically, such a retailer has an associated gasoline station on site, next to its primary business facilities. Gasoline might be sold at lower or even negative margins (i.e., priced as a "loss leader") to promote core sales (see Wang 2015; Zimmerman 2012). Most of these stations have the favorable feature that their opening hours – defining our "treatment effect" (see section 3.5.2) – are determined exogenously by the primary business activity. While opening hours are often limited by choice, they are also restricted by German law for many retailers (e.g., opening on Sundays is generally prohibited, restrictions on Saturdays, or even on other weekdays, are common).[9] Although gasoline stations and certain other businesses (e.g., airports, pharmacies) are generally exempted from these regulations, stations that sell gasoline as a "by-product" typically match the restricted opening hours of their primary retail business.[10] Hence, they usually do not determine their hours of operation strategically in response to gasoline-specific (local) competition or demand.

Among retailers selling gasoline as a "by-product" are, first of all, certain supermarket chains.[11] On the German market, there are more than 10,000 supermarkets

[9]Opening hours in Germany are regulated by state laws. In the most populated state North Rhine-Westphalia (NRW), for instance, the so-called "Ladenöffnungsgesetz – LÖG NRW" defines legal requirements. In NRW, retailers are allowed to open for up to 24 hours from Mondays to Fridays. State law requires retailers to close by 10:00 pm the latest on Saturdays and prohibits them from opening on Sundays (with up to four local exceptions per year; see `https://recht.nrw.de/lmi/owa/br_text_anzeigen?v_id=10000000000000000525`).

[10]Taking the example of car wash chain Mr. Wash (see discussion below and in Appendix 3.B), opening hours of the primary business and opening hours of gas stations either precisely match or deviate by no more than one hour.

[11]We will use the two terms supermarket and hypermarket synonymously for retail suppliers of groceries and other general merchandise.

plus an even higher number of grocery discounters.[12] Only a few of these supermarkets have associated gasoline stations, often with varying brand and ownership types: Some stations are owned and operated by the respective supermarket (chain), while others are typically located on supermarket premises but operated (and largely branded) by oil companies active in the gasoline retail segment. In its July 2014 gasoline station market survey, the independent German service provider "Energie Informationsdienst" (EID) identified approximately 560 supermarket stations in Germany, of which around 290 are located on supermarket premises but operated by oil companies with their respective brands.[13] This leaves around 270 "pure" supermarket stations owned and operated by the respective supermarket itself (EID 2014). Examples of supermarket chains in Germany with self-operated gasoline stations at selected sites include Famila (Nordost), Globus, and V-Markt. Among them, only Globus offers bundled discounts on gasoline prices (of up to 4 Eurocents/liter) based on the value of supermarket purchases.[14]

A second group of retailers selling gasoline as a "by-product" comprise car wash operators. Most car washes in Germany are themselves a "by-product" of gasoline stations. The German association "Bundesverband Tankstellen und Gewerbliche Autowäsche Deutschland e.V." (BTG) lists approximately 12,000 so-called in-bay automatic car washes (also called "roll-overs" as automatic machines typically clean the exterior of a stationary vehicle by rolling over it), most of which are located at gasoline stations' sites. On top, there are around 2,400 self-service car wash facilities, and around 1,500 conveyorized (automatic) car washes (also called "tunnel washes" where vehicles are moved through different cleaning components via a conveyor belt, which might include both exterior and interior cleaning).[15] The latter, most sophisticated category includes car wash chains with a primary focus on washing and cleaning services, some of which operate gasoline stations at selected sites, examples include Mr. Wash or CleanCar. In contrast to supermarkets, primary business

[12]See, e.g., www.bvlh.net/infothek_daten-fakten.html.

[13]In an international context, this represents a rather low market share of <5% (given a total of roughly 14,000 German gasoline stations). Wang (2015) presents indicative hypermarket station market shares for a few other countries. They range from around 6% in the U.S., 28% in the U.K., 44% in Australia, up to even 56% in France (also see Gauthier-Villars 2004). According to EID (2014), the 290 supermarket stations operated by oil companies include around 200 stations operated by Jet at Metro supermarkets, 30 stations operated by Shell at Edeka supermarkets, 30 Total-operated stations largely at Kaufland supermarkets, and 30 Orlen-operated (and star-branded) stations mostly at Famila supermarkets.

[14]Globus' discount program is called "Tankeschön". A discount between 1 and 4 Eurocents/liter for up to 250 liters per month is granted depending on prior-month supermarket purchase volume. To get the maximum discount, more than 300 Euro of supermarket purchases per month are required (see www.globus.de/de/services/tankeschoen/tankeschoen.jsp).

[15]See www.autowaschen.de/waschanlagen.html.

activities (i.e., providing car wash services) and sideline business activities (i.e., selling gasoline) are closely related to each other as both are car-related activities.

In the empirical analysis in section 4.5, we will utilize stations associated to either of the two groups, supermarkets and car wash operators, and analyze their impact on pricing by nearby stations selling gasoline as their core product.[16]

3.4 Price and Station Data

Several empirical studies on retail gasoline markets use either aggregated or self-collected price data or, more recently, rely on data from customer-collected price websites. The latter usually offers considerably higher frequency than the former, but these data sets typically not fully reflect intraday pricing patterns of individual stations, especially of small, independent players.[17] In Germany, the Federal Cartel Office has set up the creation of a so-called market transparency unit for fuel ("Markttransparenzstelle für Kraftstoffe", MTS-K), which started its regular operations on 1 December 2013.[18] Since then, the MTS-K collects all gasoline (i.e., Super E5, Super E10) and diesel prices from virtually all German gasoline stations.[19] Using this rich data set, inter alia, we are able to use exact station-level prices on an intraday level and to identify price spreads as well as the number and extent of price changes. Hence, the impact of individual players (here, supermarkets and car wash stations) on local prices can also be analyzed by this data set. As a number of stations – especially among the group of independents – failed to submit prices at the beginning of MTS-K's operation phase, we deliberately exclude the first month of data submission (i.e., December 2013) and rely on the first full year of price data, from January to December 2014.[20] We also exclude all stations located on highway service areas (i.e., Autobahn stations) for two reasons: First, these stations compete in a different competitive environment as they are (almost) exclusively leased out by Tank & Rast GmbH, a private company, which emerged from formerly state-owned

[16]There might be other groups of retailers selling gasoline as a "by-product" (e.g., some car dealerships). In this study, we focus on supermarkets and car washes only.

[17]Analyzing potential sample selection biases associated with publicly available gasoline price websites, Atkinson (2008) concludes that such prices are reliable to identify certain features of price competition, while "features that require data for certain types of independent stations or very high frequency data might not be well identified" (p. 174).

[18]For more information on the market transparency unit for fuel, please visit `www.bundeskartellamt.de/DE/Wirtschaftsbereiche/Mineral%C3%B6l/MTS-Kraftstoffe/mtskraftstoffe_node.html`.

[19]Gasoline station operators are obliged to report any price change to the MTS-K within five minutes time, which are then forwarded to authorized consumer information providers in real time. See Appendix 3.A for a description of price and station data included in the MTS-K data set.

[20]The data set was kindly provided by authorized consumer information provider "1-2-3 Tanken"

Autobahn gasoline station companies (see Bundeskartellamt 2011b, pp. 213-218). Secondly, consumers have limited accessibility to Autobahn stations as they can be reached solely via highways. Thereby, these stations are usually not a practicable alternative to road stations, even if they are nearby.[21] In its sector inquiry, the Federal Cartel Office also considered them to constitute a separate market. All retail prices are nominal end-customer prices in Euro(cents) per liter and include all taxes and duties (i.e., value-added tax, energy tax, and a fee for the Petroleum Stockholding Assocation "EBV"). For our empirical analysis in section 4.5, we compute hourly average prices for selected stations. For this purpose, we aggregate precise price quotes by weighting all prices charged throughout an hour with the specific length of their validity. When computing hourly prices, we see numerous hours, in which no price change is recorded. In these instances, we simple use the last valid price.

While wholesale prices are not registered on an intraday level, we account for regionally different, daily wholesale prices. Daily wholesale prices "ex-refinery" are taken from the Oil Market Report (O.M.R.), a widely used, independent information service provider. This price data suggests to differentiate between eight major refinery regions in Germany.[22] We assign each gasoline station to one of the refinery regions based on minimum linear distance to the region's market place (see the following paragraph for the calculation methodology). Ex-refinery wholesale prices are nominal and quoted in Euro(cents) per liter free on tank-lorry (fot) as of German refinery or storage including energy tax and "EBV" fees.[23]

To allow for a geographic delineation of market areas, we calculate linear distances ("as the crow flies") between each pair of stations on the basis of geographical coordinates (latitude, longitude) included in the MTS-K data set.[24] With information on distances between all stations, the number and type of competitors within specific areas can easily be determined.

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[21]To identify Autobahn stations within the MTS-K data set, we link information available on the Tank & Rast website (see `www.tank.rast.de`) with MTS-K station data. All Tank & Rast locations are found; additionally, further Autobahn stations (not operated by Tank & Rast) are identified on the basis of a keyword search (e.g., "A*" or "BAB*") of the MTS-K address field.

[22]Refinery regions are North (with market place Hamburg), East (Berlin), Seefeld, South-East (Leuna), West (Duisburg, Gelsenkirchen, Essen), Rhine-Main (Frankfurt), South-West (Karlsruhe), and South (Neustadt, Vohburg, Ingolstadt).

[23]Ex-refinery prices can differ depending on whether they are sold "branded" or "unbranded", which, however, is not reflected in the data set. Price quotes are, moreover, not available on weekends and public holidays. We, therefore, assume prices to remain constant on previous-day levels in these cases.

[24]Linear distance is computed as the shortest distance between two geo-coded locations ("orthodromic distance"). Using $dist = arccos(sin(lat1) * sin(lat2) + cos(lat1) * cos(lat2) * cos(lon2 - lon1)) * earthradius$ to compute "arc length" distances in kilometers, with $(lat1, lon1)$ and $(lat2, lon2)$ as coordinates of start and end point given in radians (converted from degrees by multiplying with $2\pi/360$), and $earthradius = 6,378km$.

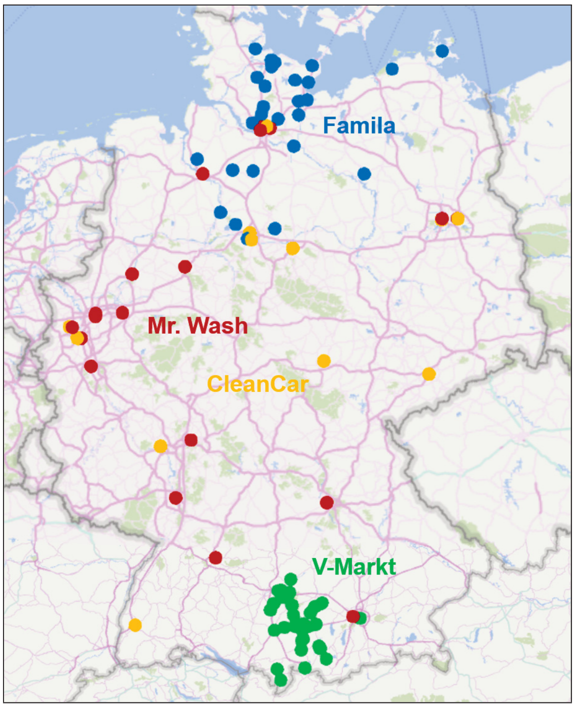


Figure 3.1: Gasoline Stations at Mr. Wash, V-Markt, Famila, and CleanCar

A crucial prerequisite for our empirical analysis is to identify gasoline stations located on premises of and operated by specific supermarket or car wash chains, where selling gasoline and diesel is considered a "by-product". We select Mr. Wash and CleanCar, two car wash chains, as well as V-Markt and Famila (Nordost), two supermarket chains for our analysis (see Appendix 3.B for details on stations' opening hours and local market structures).[25] Altogether, we have identified around 80 distinct locations with numerous other gasoline stations in the surrounding areas. With Famila being active in the North, V-Markt in the South, and Mr. Wash and CleanCar with several locations in the West, the selected chains also cover a broad geographic area within Germany (see Figure 3.1).

3.5 Empirical Analysis

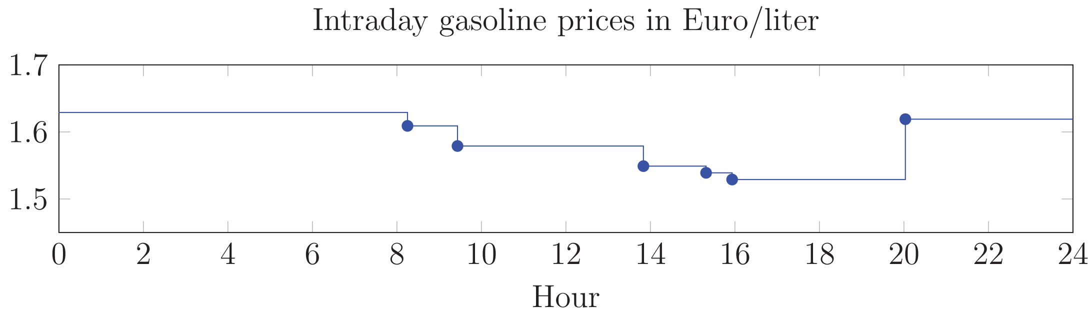
3.5.1 Pricing Patterns

In this first section of the empirical analysis, we will introduce typical pricing patterns of German gasoline stations. This facilitates a better understanding of the

[25]We do not include gasoline stations associated to Globus supermarkets in our analysis. First, retail prices at Globus-associated stations are influenced by bundled discounts (see section 3.3.2), which we cannot control for. Secondly, numerous gasoline stations at Globus markets offer 24-hour automatic fuel terminals beyond regular opening hours and are, hence, practically open 24/7.

price data used in our analysis and emphasizes the importance of including counterfactual scenarios in light of recurring (intraday) patterns, on which we will further elaborate in section 3.5.2.

Throughout the day, individual stations' prices are rarely constant. Instead, they vary, on average, by around nine Eurocents/liter resulting from, on average, between four and five price changes per day (also see Bundeskartellamt 2014 or Haucap, Heimeshoff, and Siekmann 2017, pp. 11-15). A typical intraday pattern comprises constant price levels during nighttime and rather volatile prices throughout the day. At numerous stations, prices are stepwise decreasing between morning and evening hours[26] until a single price increase takes place between about 8:00 pm and 10:00 pm. While price decreases throughout the day are often small and a result of local competitive dynamics (e.g., a station reacts to a price cut of a nearby competitor), price increases in the evening are usually significantly larger and offset intraday downward movements. Figure 3.2 shows such an exemplary intraday pricing pattern of a major station.



Note: Pricing of Aral station in Drolshagen on Monday, 4 August 2014.

Figure 3.2: Examplary Intraday Pricing Pattern

The pattern shown in Figure 3.2 is arguably similar to Edgeworth-type cycles (see Eckert 2003; Maskin and Tirole 1988; Noel 2008 for a formalization). In most of the empirical literature, Edgeworth cycles are usually associated with price movements across several days instead of within a single day.[27] In contrast to an Edgeworth-typical "war of attrition" with varying lengths at the cycle bottom, intraday cycles on the German market seem to be regularly restored following clear time patterns. Across the country, for example, Aral-branded stations typically lead price restorations with significant price jumps at around 8:00 pm (except for occasionally delayed

[26]There are a few exceptions to this rule. Noteworthy, numerous Shell-branded stations temporarily increase prices around noon, occasionally followed suit by selected nearby competitors.

[27]Most empirical studies investigating (elements of) Edgeworth cycles on gasoline markets use daily (average) prices observed across several months or years and find varying cycle lengths (e.g., biweekly, weekly, or even bimonthly, see Noel 2011, 2016). Atkinson, Eckert, and West (2014), analyzing daily price cycles by dividing the day into four periods, provide a noteworthy exception.

price jumps on Mondays). Shell-branded stations, in turn, increase prices at around 8:15 pm, often as a follower in markets with Aral-branded competitors. Variations of (average) prices across weekdays do not follow a universal pattern. In its analysis, the Bundeskartellamt (2011b, pp. 89-92), for instance, found the highest average prices on Friday and Saturday, while price levels on Mondays tended to be lowest. Shifts in wholesale prices (as key input costs) certainly are a driver of price level differences over time, so are varying demand characteristics across weekdays.

In our analysis, we will focus on station-specific price differences, acknowledging a potential, persistent gap in price levels among stations (e.g., due to brand recognition or station characteristics, see Eckert 2013). We will analyze differences in local pricing dynamics on an intraday level and across different weekdays. With lower daytime prices being common in most market areas, irrespective of market structure (as described above), it is essential to identify different magnitudes of price spreads. Our strategy for isolating the competitive effect of stations selling gasoline as a "by-product" on nearby competitors will be introduced in the next section.

3.5.2 Identification Strategy

Our aim is to isolate and quantify the effect of variations in local market structures on gasoline retail prices. We, therefore, identify players in our data set, whose primary business activity is not selling gasoline (i.e., Mr. Wash, V-Markt, CleanCar, and Famila). Haucap, Heimeshoff, and Siekmann (2017) find that players in this group tend to be among the lowest-priced gasoline providers.[28] Restricted opening hours of gas stations that are associated to supermarket or car wash operations act as an exogenous shock for other stations located in the same local area. We posit that such a market structure variance over time can be considered exogenous since opening hours of supermarkets or car wash facilities determine the opening hours of their associated stations. This is an intuitive assumption largely supported by our data set: Whenever the supermarket or car wash opens or close, they also open or close the gas station (also see Appendix 3.B).

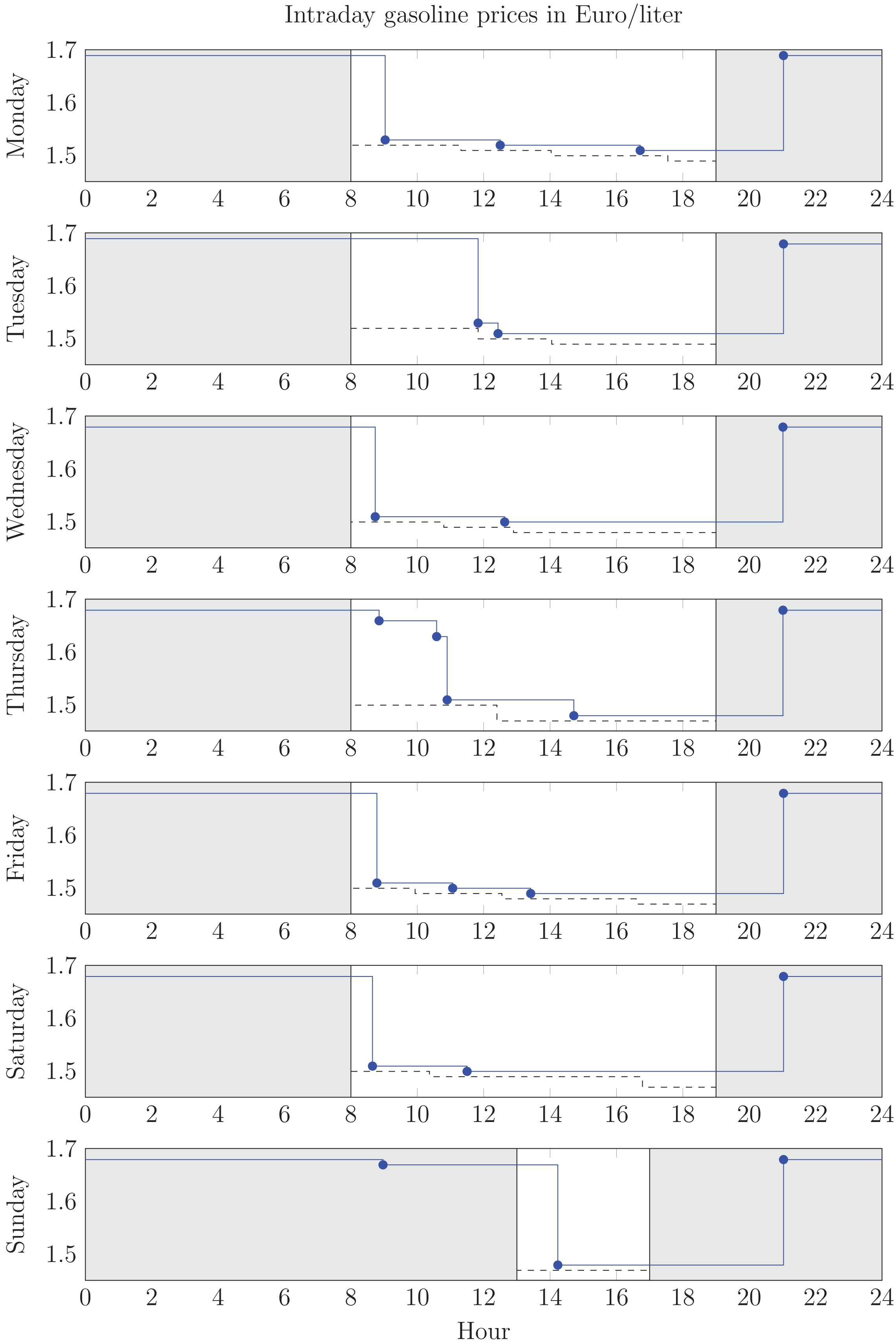
The hypothesis used in the course of the analysis is that a temporary presence of a station selling gasoline as a "by-product" increases the competitive pressure on nearby gasoline stations. We expect to see a price reaction, specifically visible at major-brand stations with sufficient leeway to lower prices if needed. In Figure 3.3, we present anecdotal evidence of this hypothesis. We choose a major station located near a station selling gasoline as a "by-product" (here, a car wash station), and plot

[28]In fact, the authors find that Mr. Wash and V-Markt are among the brands with lowest price levels.

actual price quotes of both players across a week. In this example, prices appear to stay on a higher level when the car wash station is closed, both during nighttime and during (parts of) daytime on Sunday. In contrast, sharp price-cuts begin as soon as the car wash station opens and competes in the market with lower-than-average price levels. While on some days during the exemplary week, reactions seem to follow almost immediately (i.e., within an hour), on other days (i.e., Tuesday, Thursday), it takes significantly longer until the price gap is diminished.

While this example is illustrative, its validity is limited: Price movements often follow similar patterns and have several reasons other than variations in market structure. A robust approach to isolate the price effect solely driven by the temporary market structure variance is to apply a difference-in-difference framework (see Wooldridge 2010, pp. 147-151; Angrist and Pischke 2009, pp. 227-243). By using such a framework, we specifically account for counterfactual scenarios, namely price developments in comparable local market areas without exogenously determined market structure variations. Therefore, we allocate all stations within a small range around a supermarket or car wash station in a so-called treatment group, and all stations in comparable local market settings in a so-called control group. Moreover, enabled by our rich panel data set, we use dummy variables reflecting whether a supermarket or car wash station is open during a specific hour of observation or not. Only by observing prices in both treatment and control groups as well as in hours with and without an additional (supermarket or car wash) player, we are able to identify the true "treatment effect". Using a difference-in-difference method is, thus, appropriate.

Selecting stations to be included in either treatment or control group is not trivial. We first define general selection criteria valid for both treatment and control group stations based on product type, opening hours, brand type, location, and local competition (see Table 3.1). As argued in section 3.3.1, we treat gasoline and diesel as distinct product markets. In our analysis, we will focus on Super E5 gasoline as the predominant fuel type in Germany. Furthermore, as we are interested in exploring the effect of restricted opening hours of supermarket or car wash players on other (non-restricted) local players, we include stations with 24/7 opening hours only. While we focus on major brands (i.e., Aral, Shell, Total, and Esso) with market power and leeway to adapt pricing to external shocks, we also check for the robustness of our results in specifications including all brands. We carefully select stations in comparable locations, reflecting a similar market setting and demand structure. Depending on the specification, this means we either look at stations in the same set of large cities or in the same rural areas (i.e., same set of first two-digit



Note: Pricing of Aral (solid) and Mr. Wash (dashed) stations at Stresemannstr., Hamburg in w/c 4 August 2014. Distance b/w stations: 0.18 km. Mr. Wash station is closed when shaded.

Figure 3.3: Exemplary Intraday Pricing in Local Market with Car Wash Station

ZIP code areas). Finally, we only include stations with a comparable number of local competitors across control and treatment groups.

Table 3.1: General Gasoline Station Selection Criteria

Criteria	Selection
Product type	Gasoline (i.e., Super E5) fuel
Opening hours	24/7 opening hours
Brand type	Major brands (robustness check: all brands)
Location	Urban areas ("same cities") or rural areas ("same ZIP code areas")
Competition	Comparable number of local competitors

With the general selection criteria as described above, delineating between treatment stations (i.e., stations affected by the presence of a nearby supermarket or car wash station) and control group stations is based on the local market area (see, e.g., Shepherd and Shepherd 2003, pp. 62-68). We apply linear distance measures to delineate markets, in line with Eckert and West (2005) and others, that means we choose a local market area definition of 2 km circular distance. Hence, gasoline stations in a 2 km surrounding around a supermarket or car wash station are considered to be part of the treatment group, while all other stations fall into the control group, given general selection criteria are met. Our treatment effect is determined by the opening hours of the respective stations (Table 3.2 summarizes selected treatment groups and effects). In section 3.5.3, we will estimate regressions for each supermarket or car wash chain separately as opening hours are largely homogeneous within a chain of stations selling gasoline as a "by-product", but they differ across chains (see Appendix 3.B). Moreover, as discussed above, we vary the composition of treatment and control group stations across specifications to account for player-specific local market conditions (i.e., location in either rural or urban areas and different ranges of local competitors).

Table 3.2: Treatment Group Stations and Treatment Effect

Criteria	Selection
Treatment group	Stations within 2 km linear distance of treatment stations
Treatment effect	Opening hours of treatment stations (retail chain-specific)

In the next section, we will introduce our generic regression model and present results for different specifications, taking selection criteria as described above into consideration.

3.5.3 Results

In this section, we document our empirical findings from regressing gasoline prices on dummies indicating treatment and control group as well as opening hours and relevant covariates. We estimate pooled difference-in-difference regressions described below in equation (3.1),

$$p_{it} = \alpha + \beta open_t + \gamma nearby_i + \delta(open_t * nearby_i) + \boldsymbol{x}_{it}\boldsymbol{\lambda} + u_{it} \tag{3.1}$$

with p_{it} as station i's hourly average gasoline (i.e., Super E5) retail price, $open_t$ as a dummy reflecting opening hours of stations selling gasoline as a "by-product" (equal to one when a supermarket or car wash station is open, and zero otherwise), and $nearby_i$ as a second dummy to distinguish between treatment area stations (i.e., equal to one) and control area stations (i.e., equal to zero). Furthermore, the expression $(open_t * nearby_i)$ interacts both dummies to measure the difference-in-difference between treatment and control areas as well as periods with and without an additional (supermarket, car wash) player in the local market area. Opening hours of stations selling gasoline as a "by-product" are, thus, only used as a shock to (major brand) stations' prices in local markets. Finally, $\boldsymbol{x}_{it}$ represents a vector of covariates, which includes a full set of weekday dummies as well as regional ex-refinery prices.[29] On top of using a standard difference-in-difference approach, we also utilize the panel structure of our data set by running fixed effects models. While being comparable to equation (3.1), our fixed effects specifications additionally include gasoline station-fixed effects to account for unobserved heterogeneity.

Mr. Wash car washes (and associated gasoline stations) are usually located at the periphery of large cities, facing a high competitor station density. Nearby competitors are mostly affiliated to major brands and have a high share of 24/7 opening. In contrast, all 19 Mr. Wash locations are characterized by restricted and highly homogeneous opening hours (i.e., 8:00 am to 7:00 pm from Mondays to Saturdays; see Appendix 3.B and, specifically, Table 3.6 for details). Table 3.3 presents results of a number of gasoline price specifications.[30] All specifications include stations surrounding Mr. Wash with unrestricted opening hours in the treatment group. As explained in section 3.5.2, the control group, in turn, comprises similarly-specified stations (i.e., between 5 and 14 direct competitors with 24/7 opening), located in the same set of large cities. Specifications differ in that either solely major brands

[29] As selected stations' input cost movements might not be in sync, we control for regionally-different (daily) ex-refinery prices on a station-level.

[30] All coefficients are denoted in Eurocents/liter of fuel. Instead of using clustered standard errors as in Table 3.6, we also estimated regressions with bootstrapped standard errors, leading to largely comparable results.

or all brands are present, and hourly prices from Mondays to Saturdays (for all 19 Mr. Wash locations) or all weekdays (for 13 locations closed on Sundays) are included.[31] Most importantly for our research question, we see a significant negative difference-in-difference coefficient $open * nearby$ of around -1 Eurocent/liter across all specifications with major brands. Thus, we find evidence of a price-decreasing effect of the temporary entry of Mr. Wash on major-brand stations in the surrounding area. Specifications including all brands also show negative coefficients, which, however, fall short of statistical significance (at least, if all days are included). Moreover, the importance of including counterfactual market scenarios is obvious: With around -6 Eurocents/liter, the *open* dummy coefficients indicate a significant price difference between daytime and nighttime hours, irrespective of treatment or control group.[32] Only by interacting *open* and *nearby* dummies, we see the true treatment effect, which reflects deeper price-cuts in treatment areas. With the *nearby* coefficients not being significantly different from zero, we do not observe a disparity between stations in either group. Finally, in line with expectations, ex-refinery price changes are highly significant predictors of day-to-day retail price movements. In addition to results in Table 3.3, Figure 3.4 shows coefficients of hour dummies from separate regressions of treatment and control group stations included in Mr. Wash specifications. We see both the typical downward trend during daytime, but also a deeper price-cut for treatment group stations during Mr. Wash's operating hours.

In contrast to urban locations of car washes, *V-Markt* supermarkets are mostly situated in rural areas in Bavaria. Gasoline stations associated to V-Markt stores typically have just a few competitors, only part of which are open 24/7 (see Table 3.7 in Appendix 3.B). V-Markt stations themselves largely open between 8:00 am and 8:00 pm from Monday to Friday, while often starting half an hour earlier on Saturday and remaining fully closed on Sunday.[33] Gasoline specifications for V-Markt can be found in Table 3.4. Similarly to above, we define treatment and control group stations to have a comparable number of competitors (here, zero

[31]Please note that using a different subset of stations leads to a much smaller number of total observations in specifications with Monday to Sunday prices versus specifications with Monday to Saturday prices (in Table 3.3), even though an additional weekday is included. Adjusting the number of stations is required to robustly specify treatment effects associated with hourly prices as, in this example, opening hours on Sundays are non-homogeneous across Mr. Wash gas stations (see Appendix 3.B for an overview of opening hours).

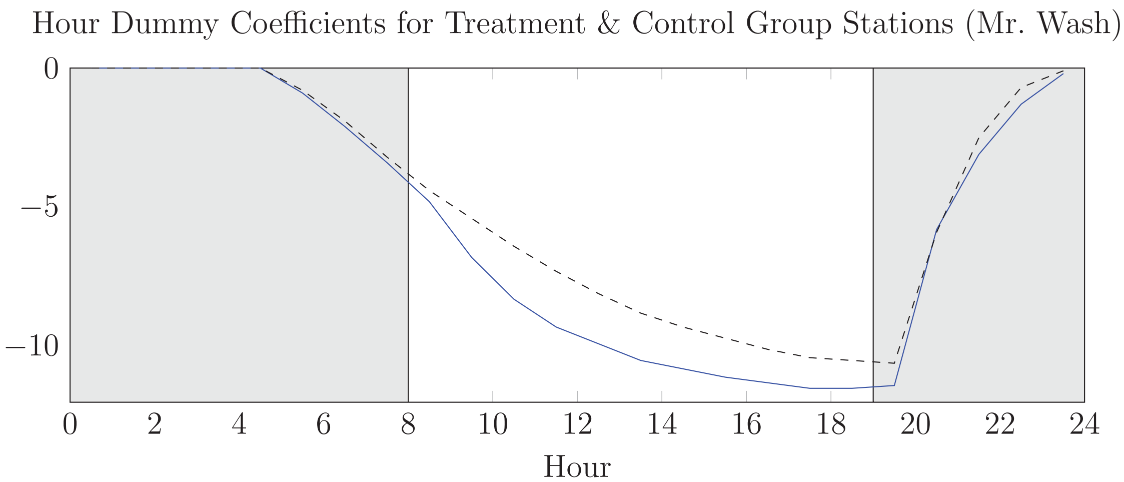
[32]We also estimate the same specifications with a full set of hour dummies. This leads to a large difference in magnitude of *open* dummy coefficients between specifications with prices from Monday to Saturday (of about -10 to -9 Eurocents/liter) and specifications with prices from Monday to Sunday (of about -1 Eurocent/liter). Hence, even without a Mr. Wash station in the market on Sundays, a certain spread between day- and nighttime prices is observable.

[33]We exclude six V-Markt locations (and surrounding area stations) from our analysis, which offer 24-hour automatic fuel terminals and are, thus, practically open 24/7.

Table 3.3: Regression of Gasoline Retail Prices (Mr. Wash)

Dependent variable:	Difference-in-difference				Fixed effects	
Hourly price	Major brands		All brands		Major	All
	(1)	(2)	(3)	(4)	(5)	(6)
open ∗ nearby	-1.240***	-0.858**	-1.018***	-0.652*	-0.858**	-0.651*
	(0.00)	(0.01)	(0.00)	(0.08)	(0.01)	(0.08)
open	-6.214***	-6.586***	-5.357***	-5.913***	-6.586***	-5.914***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
nearby	0.362	-0.200	0.054	-0.430	–	–
	(0.33)	(0.63)	(0.91)	(0.39)		
Ex-refinery price	1.116***	1.117***	1.107***	1.108***	1.120***	1.112***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	23.078***	23.790***	22.812***	23.809***	23.356***	23.212***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weekday dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,523,402	1,374,250	3,549,617	1,770,816	1,374,250	1,770,816
Groups	–	–	–	–	158	205
R^2	0.744	0.732	0.699	0.694	0.731	0.694

Note: Heteroskedasticity- and cluster-robust p-values in parentheses (clustered by ZIP code region).
Asterisks: Statistical significance at 1% (***), 5% (**), or 10% (*) level.
Specifications: (1), (3) include Mon-Sat; (2), (4), (5), (6) include Mon-Sun.



Note: Coefficients of hour dummies (in Eurocents/liter) from separate regressions on treatment group (solid line) and control group (dashed line) gasoline stations (omitted variable: 12 am dummy). Mr. Wash stations in treatment areas are closed when shaded.

Figure 3.4: Relative Hourly Prices for Mr. Wash Specification

Table 3.4: Regression of Gasoline Retail Prices (V-Markt)

Dependent variable:	Difference-in-difference				Fixed effects	
Hourly price	Major brands		All brands		Major	All
	(1)	(2)	(3)	(4)	(5)	(6)
open ∗ nearby	-0.732*	-0.700*	0.074	0.113	-0.700*	0.114
	(0.10)	(0.09)	(0.92)	(0.87)	(0.09)	(0.87)
open	-5.264***	-5.266***	-2.712***	-2.715***	-5.266***	-2.716***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
nearby	-0.286	-0.319	-0.440	-0.480	–	–
	(0.37)	(0.32)	(0.60)	(0.56)		
Ex-refinery price	1.139***	1.143***	1.075***	1.079***	1.148***	1.086***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	21.856***	21.389***	25.705***	25.240***	20.805***	24.328***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weekday dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	417,118	486,886	1,411,625	1,647,888	486,886	1,647,888
Groups	–	–	–	–	56	198
R^2	0.762	0.748	0.675	0.671	0.748	0.671

Note: Heteroskedasticity- and cluster-robust p-values in parentheses (clustered by ZIP code region).
Asterisks: Statistical significance at 1% (***), 5% (**), or 10% (*) level.
Specifications: (1), (3) include Mon-Sat; (2), (4), (5), (6) include Mon-Sun.

Table 3.5: Regression of Gasoline Retail Prices (CleanCar, Famila)

Dependent variable:	Difference-in-difference			
Hourly price	CleanCar		Famila	
	Major	All	Major	All
	(1)	(2)	(3)	(4)
open ∗ nearby	-1.099***	-0.889**	-0.632	-0.847**
	(0.00)	(0.01)	(0.20)	(0.03)
open	-5.903***	-5.093***	-3.356***	-3.036***
	(0.00)	(0.00)	(0.00)	(0.00)
nearby	0.577**	0.384	1.597*	1.861***
	(0.04)	(0.39)	(0.05)	(0.00)
Ex-refinery price	1.119***	1.113***	1.106***	1.088***
	(0.00)	(0.00)	(0.00)	(0.00)
Constant	22.279***	21.770***	21.405***	23.164***
	(0.00)	(0.00)	(0.00)	(0.00)
Weekday dummies	Yes	Yes	Yes	Yes
Observations	1,122,368	1,540,246	2,857,599	4,592,057
Groups	–	–	–	–
R^2	0.747	0.711	0.635	0.643

Note: Heteroskedasticity- and cluster-robust p-values in parentheses
(clustered by ZIP code region).
Asterisks: Statistical significance at 1% (***), 5% (**), or 10% (*) level.
Specifications: (1)–(4) include Mon-Sat.

to six), 24/7 opening, and a rural market setting. For the latter, we focus on areas with a first two-digits ZIP code[34] range between 86 and 89, which include all (valid) V-Markt station surroundings and mirrors South German rural areas for stations to be included in our control group. We find key similarities among V-Markt and Mr. Wash specifications. First and foremost, difference-in-difference coefficients are, again, significant for major brands (albeit the number of major-brand stations included in the treatment group is small). Indeed, the effect for V-Markt in major brand specifications is slightly smaller but less volatile to including Sundays, possibly related to a rural market setting with lower competition intensity and less interferences. For specifications including all brands, in turn, we see *open* dummy coefficients with only half the size (indicating overall less dynamic pricing) and non-significant treatment effects. Common to all estimations, and particularly obvious for V-Markt, is a smaller coefficient of determination in specifications with all brands. Adding further but more heterogeneous players, hence, does not increase the explanatory power of the model.[35] Comparing findings in Tables 3.3 and 3.4, we see significant negative treatment effects in both car wash and supermarket settings with locations in urban and rural areas, respectively.

To check for robustness of results against using other players selling gasoline as a "by-product" in different geographic areas, we briefly discuss both a further car wash chain (i.e., *CleanCar*) and a second supermarket chain (i.e., *Famila*) in the following. CleanCar, as a player in the conveyorized car wash segment, has locations in larger cities with a slightly different regional footprint than Mr. Wash, while Famila, with locations in Northern Germany, usually operates associated gasoline stations in smaller cities (see Tables 3.8 and 3.9 in Appendix 3.B for details). Both players are characterized by more heterogeneous opening hours across stations, also with regard to opening on Sundays (i.e., partly outside of usual business hours). Table 3.5 shows results for two specifications per brand (with major or all brands, respectively).[36] We, again, include stations in comparable ZIP code areas (for Famila) or the same set of cities (for CleanCar) in our control groups, in addition to further selection

[34]In Germany, the first two digits of the five-digit ZIP code indicate regions.

[35]Again, including hour dummies in the model leads to a large difference in *open* dummy coefficients among specifications with and without Sunday prices (about -5 Eurocents/liter and 0 Eurocents/liter, respectively) with the remaining intraday price fluctuation being absorbed by hour dummies.

[36]We only use specifications with prices from Mondays to Saturdays (and, consequently, do not estimate fixed effects models) given heterogeneous hours of operation on Sundays. Furthermore, due to slight variations in working day opening hours, we use the median opening and closing times across stations to set respective dummy variables (i.e., for CleanCar from 6:00am–9:00pm from Monday to Friday and from 7:00am–8:00pm on Saturday; for Famila from 7:00am–9:00pm from Monday to Friday and from 7:00am–8:00pm on Saturday).

criteria as described above. Results in Table 3.5 are largely consistent with previous findings, especially with regards to negative difference-in-difference coefficients. Only for Famila's major brand specification, the coefficient is non-significant in light of a small number of rather scattered major brand stations with 24/7 opening in the surrounding of Famila markets.

3.6 Conclusion

In light of highly fluctuating prices, competition dynamics on retail gasoline markets are of major interest for consumers, policymakers, and competition authorities alike. Nonetheless, characteristics of local markets favoring a more competitive pricing behavior of individual stations during the day have not been fully understood, partly due to a lack of granular data sets for empirical investigations. In this paper, we have specifically examined the impact of stations selling gasoline as a "by-product" on local intraday prices in Germany. Analyzing this aspect of pricing dynamics is enabled by a rich data set including price quotes from all gasoline stations across the country.

Stations selling gasoline as a "by-product" are typically characterized by limited opening hours, which are exogenously determined by the primary business activities, in our example, either supermarket or car wash operations. We use this external shock to local market structures to explore the potential price effect a temporary low-priced alternative has on nearby competitors. Identifying this price effect requires to take typical intraday pricing patterns, as found on numerous local markets in Germany, into consideration. Such patterns are similar to Edgeworth-type cycles in several respects: During daytime, prices often gradually decrease until a single large price increase in the evening offsets downward movements. In view of this pattern, including counterfactual market scenarios is crucial to isolate the sought-after effect from other price movements present in comparable market settings. Therefore, we have estimated models using hourly average price data in a difference-in-difference framework.

We find a significant negative price effect of stations selling gasoline as a "by-product" on nearby competitors. Our results indicate that, when a supermarket or car wash player is open, particularly major brands show a price reaction beyond usual daytime price reductions. These brands seem to have both the leeway and the willingness to temporarily reduce their otherwise above-average price positions in response to outside competitive pressure. The limited magnitude of price reactions compared with individual observations (e.g., as shown in Figure 3.3) may be explained by interferences contained in control group areas (i.e., other players with restricted opening hours). Still, the negative price effects identified in this study are statistically significant and robust against using different supermarket or car wash players. The effect tends to be more pronounced during working days with a higher competition intensity. From a policy perspective, a relevant contribution of this paper is empirical evidence that specific independent players can exert competitive pressure on local price levels, also with regard to market-dominating competitors.

Our findings are conditional on a few assumptions including the selection of stations for both control and treatment groups as well as our method of calculating average prices. Further research in the area of gasoline retail pricing is needed to fully comprehend intraday pricing mechanisms and could, among others, explore the presences and causes of intraday price cycling and establish a relation between such cycles and Edgeworth theory.

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Appendix

3.A MTS-K Data Set

In this appendix, we provide the reader with additional information on the main data source used in this paper and explain any modifications of the data set prior to using it for the empirical analysis.

With the creation of the market transparency unit for fuel ("Markttransparenzstelle für Kraftstoffe", MTS-K), a novel panel data set including price quotes from virtually all German gasoline stations emerged. Since 1 December 2013, gasoline station owners are obliged to report any price alteration of Super E5, Super E10 and Diesel fuel to the MTS-K. In addition to price quotes, the MTS-K data set contains basic information on each station's location (including address and geographical coordinates), its brand affiliation, and opening hours (per weekday). The emergence of the MTS-K was mainly motivated by a sector inquiry conducted by the German Federal Cartel Office with findings described in Bundeskartellamt (2009, 2011a,b). Descriptive statistics on prices during the first months of MTS-K operation can be found in Bundeskartellamt (2014).

In our empirical analysis, we rely on the first full calendar year of data, from January to December 2014. Although MTS-K's standard operation phase ("Regelbetrieb") started on 1 December 2013, we deliberately exclude the first month as several stations failed to submit prices from the very beginning. As we do not impose (further) restrictions on the number of price quotes per station, we allow the data set to be unbalanced. Moreover, we slightly amend raw data as submitted by individual gasoline stations to the MTS-K: First of all, following validation rules proposed by the Bundeskartellamt (2011b, Appendix p. 3), we correct price data for incorrect input (e.g., empty price cells, zero price change, or price change greater than 20 Eurocents/liter). Secondly, we exclude both inactive stations as well as stations listed in the data set, which do not submit any price quotes. Finally, we conduct several quality checks of opening hour data (especially for selected stations selling gasoline as a "by-product") and revise obvious misentries.

In total, the MTS-K data set comprises approximately 14,000 gasoline stations with roughly 25 million price quotes per fuel type within the twelve months considered in our analysis. Necessary data adjustments account for about 1% of all submitted prices.[37]

[37] Also see Appendix A in Haucap, Heimeshoff, and Siekmann 2017.

3.B Locations and Market Structure

In this appendix, we present a detailed overview regarding locations, opening hours, and market structure variables of stations selling gasoline as a "by-product" used in our analysis. Specifically, we discuss gasoline stations associated to Mr. Wash (see Table 3.6), V-Markt (see Table 3.7), Famila (see Table 3.8), and CleanCar (see Table 3.9) locations, which are included in the MTS-K data set.[38] Opening hours are presented by weekday (i.e., Monday to Friday, Saturday, and Sunday). Market structure variables comprise details on the number and type of nearby competitors in a surrounding area of 2 km as well as information on whether competitors have unrestricted (i.e., 24/7) or restricted (e.g., closed on Sundays) opening hours.

Mr. Wash currently operates at 30 locations in total, 19 of which have associated gasoline stations (see Table 3.6). Gasoline stations' opening hours are closely aligned to those of car wash operations: They either precisely match car washes' opening hours or deviate by no more than one hour on all weekdays (i.e., gasoline stations might open up to one hour in advance of and close up to one hour later than car washes). Opening hours across Mr. Wash gasoline stations are highly homogeneous during all weekdays except Sundays. From Mondays till Saturdays, all 19 stations open for exactly eleven hours, from 8:00 am to 7:00 pm. On Sundays, car washes' and, consequently, gasoline stations' opening hours are more diverse: While 13 locations are closed, six other locations are open, between four and nine hours. Mr. Wash car washes are typically situated in the periphery of large cities (e.g., in commercial areas). As a result, the number of competitors, also with unrestricted opening hours, are above average. Competitors in 2 km distance range from 6 to 14, around two thirds of them with 24/7 opening hours. More than half of all competitors can be classified as major brands.

V-Markt, the brand name of Georg Jos. Kaes GmbH, operates at 54 locations (i.e., 42 V-Markt and twelve V-Baumarkt), 35 of which have associated gasoline stations (some also with car washes). Of these 35 locations, 30 submitted price data to MTS-K during 2014 and are, thus, included in Table 3.7. Gasoline stations' opening hours are largely in line with opening hours of corresponding supermarkets and are quite homogeneous across locations: 20 locations open from 8:00 am to 8:00 pm from Mondays to Fridays and from 7:30 am to 8:00 pm on Saturdays.[39] While a few gasoline stations' hours of operation slightly vary, six stations notably deviate

[38]Next to data included in the MTS-K data set, this appendix relies on further information from corresponding corporate websites (see `www.mrwash.de`, `www.v-markt.de`, `www.famila-nordost.de`, and `www.cleancar.de`).

[39]In the empirical analysis with hourly prices, we treat opening and closing between two (full) hours (e.g., at 7:30 am) as if they would occur at the next full hour (e.g., at 8:00 am).

with 24/7 opening. These six stations are equipped with self-service terminals, which may be used after regular opening hours. To avoid misinterpretation, we disregard these stations from our analysis. V-Markt supermarkets (and, similarly, construction markets) are mostly located in rural areas in Bavaria, often with just a few (i.e., between zero and six) competitors in a surrounding area of 2 km.[40] Similar to V-Markt stations themselves, nearby competitors hardly open 24/7: Only a third of all stations are always open.

Under the umbrella of the **Famila** group, there are two independent supermarket chains: Famila Nordwest (with about 20 locations) and Famila Nordost (with about 80 locations). Famila Nordost (hereafter: Famila) operates 26 own gasoline stations, of which 23 submitted price data to MTS-K from January to August 2014 and are, thus, included in Table 3.8. Opening hours differ slightly across gasoline station locations, but are largely in line with opening hours of corresponding supermarkets, at least from Mondays to Saturdays.[41] At eleven locations, Famila gasoline stations also open on Sundays – independent of supermarket operations. Famila supermarkets, based in Northern Germany, are mostly located in rural areas or smaller cities. Except for locations in Hanover and Neumünster, local competition is limited to between zero and four other stations. While only about a third of all competitors open 24/7, within the subgroup of major brands, this share rises to above 50%.

Similar to Mr. Wash, **CleanCar** car washes are located in larger cities, although the regional footprint of the two players varies. CleanCar operates at 24 locations in Germany (plus three locations in Vienna), of which 13 have associated gasoline stations and twelve submitted prices to the MTS-K (see Table 3.9). Opening hours slightly vary across locations, on working days between 6:00 and 8:00 am in the morning and 6:00 and 10:00 pm in the evening. The majority of gasoline stations also opens on Sundays, not necessarily in line with car washes' hours of operation. CleanCar's local competitive environment (between three and 15 competitors) is characterized by a large share of major-brand stations and an above-average level of unrestricted opening hours.

With insights gained in this appendix, we affirm our focus on Mr. Wash and V-Markt locations with homogeneous opening hours and a clear match between primary operations and gasoline stations. Famila and CleanCar locations, with more diverse opening hours and partly autonomous Sunday opening, are instead used for robustness checks.

[40] The V-Markt station in Munich with 14 nearby competitors is an exception. We will exclude this station in our specifications in section 3.5.3.

[41] The Famila market in Kiel with 24/7 opening is an obvious exception, which we, consequently, exclude from the analysis.

Table 3.6: Opening Hours and Market Structure of Mr. Wash Gasoline Stations

#	Mr. Wash stations	Opening hours			Competitors					
		Mon-Fri	Sat	Sun	All brands			Major brands		
					All	Sun	24/7	All	Sun	24/7
1	Hammer Str. 169, Münster	8:00-19:00	8:00-19:00	closed	11	10	6	3	3	2
2	Stresemannstr. 13a, Bremen	8:00-19:00	8:00-19:00	closed	14	12	5	8	8	4
3	Raderthalgürtel 1, Köln	8:00-19:00	8:00-19:00	closed	7	7	4	5	5	4
4	Heiliger Weg 68, Dortmund	8:00-19:00	8:00-19:00	closed	12	12	10	8	8	7
5	Gladbecker Str. 415, Essen	8:00-19:00	8:00-19:00	closed	9	9	6	6	5	4
6	Ziegelstr. 71-75, Bielefeld	8:00-19:00	8:00-19:00	closed	9	9	3	2	2	2
7	Hanauer Landstr. 419, Frankfurt	8:00-19:00	8:00-19:00	closed	5	4	3	4	4	3
8	Dießemer Bruch 91, Krefeld	8:00-19:00	8:00-19:00	closed	11	10	6	5	5	4
9	Völklinger Str. 48, Düsseldorf	8:00-19:00	8:00-19:00	closed	8	7	5	7	7	5
10	Heilbronner Str. 309, Stuttgart	8:00-19:00	8:00-19:00	closed	10	9	6	6	6	5
11	Hans-Böckler-Str. 23, Essen	8:00-19:00	8:00-19:00	closed	9	9	6	5	5	4
12	Möhlstraße 7-17, Mannheim	8:00-19:00	8:00-19:00	closed	9	8	6	6	6	6
13	Nopitschstr. 80, Nürnberg	8:00-19:00	8:00-19:00	closed	7	7	4	4	4	3
14	Kollaustraße 71, Hamburg	8:00-19:00	8:00-19:00	13:00-17:00	11	11	9	4	4	4
15	Stresemannstr. 349-351, Hamburg	8:00-19:00	8:00-19:00	13:00-17:00	10	10	9	6	6	6
16	Landsberger Str. 420+426, München	8:00-19:00	8:00-19:00	12:00-18:00	5	5	2	3	3	2
17	Friedrich-Ebert-Damm 170, Hamburg	8:00-19:00	8:00-19:00	12:00-19:00	7	7	6	5	5	4
18	Nonnendammallee 27, Berlin	8:00-19:00	8:00-19:00	9:00-18:00	5	5	3	2	2	2
19	Rhinstr. 136, Berlin	8:00-19:00	8:00-19:00	9:00-18:00	10	9	7	4	4	1

Note: Sorted by increasing opening hours; competitors within 2 km distance around Mr. Wash, either all, with Sunday ("Sun") or unrestricted ("24/7") opening.

Source: MTS-K data set, Mr. Wash website.

Table 3.7: Opening Hours and Market Structure of V-Markt Gasoline Stations

#	V-Markt/ V-Baumarkt stations	Opening hours			Competitors					
		Mon-Fri	Sat	Sun	All brands			Major brands		
					All	Sun	24/7	All	Sun	24/7
1	Hauptstraße 41, Kirchheim	8:00-20:00	7:30-14:00	closed	1	1	1	0	0	0
2	Am Mühlbach 1, Saulgrub	8:00-19:00	7:30-18:00	closed	0	0	0	0	0	0
3	Justus-von-Liebig-Straße 1, Buchloe	8:00-20:00	8:00-20:00	closed	2	2	1	1	1	0
4	Sudetenstr. 50, Neugablonz	8:00-20:00	7:30-20:00	closed	5	5	3	2	2	1
5	Gutenbergstraße 4, Bobingen	8:00-20:00	7:30-20:00	closed	2	2	0	1	1	0
6	G.-Daimler-Straße 15, Bad Wörishofen	8:00-20:00	7:30-20:00	closed	1	1	0	0	0	0
7	Industriestraße 1, Burgau	8:00-20:00	7:30-20:00	closed	4	4	1	2	2	0
8	Saumweg 19, Illertissen	8:00-20:00	7:30-20:00	closed	2	2	0	2	2	0
9	Im Engelfeld 5, Immenstadt	8:00-20:00	7:30-20:00	closed	3	3	0	1	1	0
10	Josef-Landes-Straße 40, Kaufbeuren	8:00-20:00	7:30-20:00	closed	3	3	0	1	1	0
11	Weiler Weg 1, Ichenhausen	8:00-20:00	7:30-20:00	closed	2	2	0	1	1	0
12	Max-von-Eyth-Straße 4, Landsberg	8:00-20:00	7:30-20:00	closed	4	4	3	2	2	2
13	Dillingerstraße 25, Lauingen	8:00-20:00	7:30-20:00	closed	3	3	2	0	0	0
14	J.-G.-Fendt-Straße 33, Marktoberdorf	8:00-20:00	7:30-20:00	closed	4	4	1	2	2	0
15	Augsburger Straße 50, Günzburg	8:00-20:00	7:30-20:00	closed	3	3	0	1	1	0
16	Werner-Von-Braun-Straße 16, Memmingen	8:00-20:00	7:30-20:00	closed	6	5	3	1	1	0
17	Ammergauer Straße 60, Peiting	8:00-20:00	7:30-20:00	closed	2	2	1	1	1	0
18	Wiesenweg 15, Schongau	8:00-20:00	7:30-20:00	closed	1	1	0	1	1	0
19	G.-Daimler-Straße 6, Schwabmünchen	8:00-20:00	7:30-20:00	closed	1	1	0	1	1	0
20	Allgäuer Straße 19, Mindelheim	8:00-20:00	7:30-20:00	closed	5	4	1	3	3	0
21	Bürgerm.-Raab Straße 31, Thannhausen	8:00-20:00	7:30-20:00	closed	3	3	0	0	0	0
22	Herzog-Georg-Straße 1, Weißenhorn	8:00-20:00	7:30-20:00	closed	2	2	1	2	2	1
23	Danziger Straße 1, Türkheim	8:00-20:00	7:30-20:00	closed	1	1	0	0	0	0
24	Balanstr. 50, München	6:00-21:00	6:00-21:00	closed	14	13	8	7	7	5
25	Augsburger Straße 38, Leipheim	0:00-0:00	0:00-0:00	0:00-0:00	3	3	1	1	1	0
26	Kemptener Str. 107, Füssen	0:00-0:00	0:00-0:00	0:00-0:00	1	1	0	0	0	0
27	Sudetenstraße 5, Kaufbeuren	0:00-0:00	0:00-0:00	0:00-0:00	6	5	2	3	3	1
28	Frühmahd 1, Erkheim	0:00-0:00	0:00-0:00	0:00-0:00	1	1	1	1	1	1
29	Bundesstraße 16, Fischen/Langenwang	0:00-0:00	0:00-0:00	0:00-0:00	1	1	0	1	1	0
30	Grünzweigstraße 1, Kissing	0:00-0:00	0:00-0:00	0:00-0:00	1	1	1	0	0	0

Note: Sorted by increasing opening hours; competitors within 2 km distance around V-Markt, either all, with Sunday ("Sun") or unrestricted ("24/7") opening.
Source: MTS-K data set, V-Markt website.

Table 3.8: Opening Hours and Market Structure of Famila Gasoline Stations

#	Famila stations	Opening hours			Competitors					
		Mon-Fri	Sat	Sun	All brands			Major brands		
					All	Sun	24/7	All	Sun	24/7
1	Möllerung 11, Lübeck	8:00-20:00	8:00-20:00	closed	2	2	1	2	2	1
2	Bornumer Straße 141, Hannover	8:00-20:00	8:00-20:00	closed	11	9	4	5	5	3
3	Haart 224, Neumünster	8:00-21:00	8:00-21:00	closed	7	6	1	2	2	1
4	Ravensbusch 12, Stockelsdorf	8:00-21:00	8:00-21:00	closed	4	4	1	2	2	1
5	Kisdorfer Weg 13, Kaltenkirchen	7:45-20:15	7:45-20:15	closed	0	0	0	0	0	0
6	Kornkamp 50, Ahrensburg	7:45-21:30	7:45-21:30	closed	1	1	0	0	0	0
7	Lemker Straße 20, Nienburg	7:30-20:30	7:30-20:30	closed	4	3	1	1	1	1
8	Rudolf-Diesel-Ring 32, Neustadt a.R.	7:30-20:30	7:30-20:30	closed	2	2	0	1	1	0
9	Pascalstrasse 9, Quickborn	7:00-20:00	7:00-20:00	closed	1	1	1	1	1	1
10	Mecklenburger Straße 1-3, Lauenburg	7:00-21:00	7:00-20:00	closed	2	2	1	2	2	1
11	Am Vogelsang 12, Schneverdingen	7:00-21:00	7:00-21:00	closed	3	3	1	0	0	0
12	Westring 2, Pinneberg	7:00-21:30	7:00-21:30	closed	1	1	1	0	0	0
13	Plöner Landstraße 41861, Eutin	8:00-20:00	8:00-20:00	11:00-19:00	1	1	1	1	1	1
14	Rettiner Weg 77, Neustadt / Holstein	7:30-20:15	7:30-20:25	11:00-19:00	2	2	0	0	0	0
15	Am Vossberg 1, Oldenburg / Holstein	7:00-21:00	7:00-21:00	11:00-19:00	1	1	0	0	0	0
16	Schönkirchener Straße 80, Kiel	7:00-21:00	7:00-21:00	8:00-21:00	2	2	1	1	1	1
17	Schwarzer Weg 11, Perleberg	6:00-20:00	8:00-20:00	8:00-20:00	1	1	0	1	1	0
18	Sanitzer Str. 3, Ribnitz-Damgarten	6:00-21:00	7:00-21:00	9:00-21:00	2	2	1	2	2	1
19	Hördorfer Weg 52, Osterholz-Scharmb.	6:00-22:00	6:00-22:00	8:00-20:00	1	1	0	1	1	0
20	Auf dem Rusch 1, Rotenburg	6:00-21:30	6:00-21:30	7:00-21:30	4	4	2	2	2	2
21	Prinz-Heinrich-Str. 20, Kiel	6:00-22:00	7:00-22:00	8:00-22:00	3	3	1	2	2	1
22	Timmasper Weg 1, Nortorf	6:00-22:00	7:00-22:00	8:00-22:00	1	1	0	1	1	0
23	Grot Steenbusch 35, Kiel	0:00-0:00	0:00-0:00	0:00-0:00	1	1	1	0	0	0

Note: Sorted by increasing opening hours; competitors within 2 km distance around Famila, either all, with Sunday (“Sun”) or unrestricted (“24/7”) opening.

Source: MTS-K data set, Famila website/ customer service.

Table 3.9: Opening Hours and Market Structure of CleanCar Gasoline Stations

#	CleanCar stations	Opening hours			Competitors					
		Mon-Fri	Sat	Sun	All brands			Major brands		
					All	Sun	24/7	All	Sun	24/7
1	Marzahner Chaussee 232, Berlin	7:00-19:00	8:00-18:00	closed	6	6	2	4	4	1
2	Hildesheimer Str. 214, Hannover	7:00-19:00	7:00-18:00	closed	5	5	3	4	4	2
3	Vahrenwalder Str. 285, Hannover	7:00-19:00	7:00-18:00	closed	9	9	4	3	3	3
4	St. Töniser Str. 71, Krefeld	6:00-20:00	7:00-20:00	closed	7	6	3	2	2	2
5	Düsseldorfer Str. 26, Neuss	6:00-20:00	6:00-20:00	closed	3	3	2	3	3	2
6	Lembergallee 1, Freiburg	6:00-22:00	7:00-20:00	9:00-17:00	3	3	1	1	1	0
7	Kieler Str. 195, Hamburg	6:00-22:00	7:00-20:00	9:00-20:00	15	15	14	8	8	8
8	Zwickauer Str. 200, Chemnitz	6:00-21:00	7:00-21:00	8:00-20:00	6	6	1	4	4	1
9	Paul-Stieglitz-Str. 1, Erfurt	6:00-21:00	6:00-21:00	8:00-17:00	4	4	3	3	3	2
10	Charlottenburger Chaussee 53a, Berlin	6:00-21:00	6:00-21:00	8:00-20:00	6	6	4	3	3	3
11	Steilshooper Allee 5, Hamburg	6:00-21:00	7:00-21:00	7:00-21:00	7	7	4	5	5	3
12	Äppelallee 112, Wiesbaden	6:00-22:00	7:00-22:00	8:00-20:00	5	5	0	3	3	0

Note: Sorted by increasing opening hours; competitors within 2 km distance around CleanCar, either all, with Sunday ("Sun") or unrestricted ("24/7") opening.
Source: MTS-K data set, CleanCar website.

Declaration of Contribution

Hereby I, Manuel Siekmann, declare that the chapter *"Selling Gasoline as a 'By-Product': The Impact of Market Structure on Local Prices"* is co-authored by Justus Haucap and Ulrich Heimeshoff. It is based on DICE Discussion Paper No. 240 (Haucap, Heimeshoff, and Siekmann 2016).

My contributions to this chapter are as follows:

- I was responsible for data gathering, preparation and analysis
- I wrote major parts of the introduction, the literature review, the section on market and data, the empirical analysis, and the conclusion

Signature of co-author 1 (Justus Haucap): ________________________

Signature of co-author 2 (Ulrich Heimeshoff): ________________________

Chapter 4

Characteristics, Causes, and Price Effects: Empirical Evidence of Intraday Edgeworth Cycles[1]

Edgeworth cycles represent the leading concept to explain observed pricing patterns on retail gasoline markets and have been subject to numerous empirical investigations on an interday level. In this paper, I present unique evidence of the presence, causes, and price effects of intraday Edgeworth-type cycles for an entire OECD country, using high-frequency price data from German gasoline stations. I find vast evidence of intraday cycles across municipalities in Germany. Cycle asymmetry and intensity is stronger in more concentrated markets and decreases with a higher share of non-major brands. My analysis suggests that intraday cycles are a sign of competition with a price decreasing effect during evening hours, where consumers conscious of their purchase timing can benefit most.

[1]This chapter is based on a working paper (Siekmann 2017).

4.1 Introduction

On retail gasoline markets around the world, price volatility is typically far greater than changes in oil or refinery prices would suggest. Often, retail pricing follows a distinctive pattern with asymmetric cycles, albeit length and amplitude vary. Alternating periods of fast and large price increases and a longer sequence of stepwise price decreases are characteristic features of these recurring cycles. Edgeworth cycles, formalized by Maskin and Tirole (1988), represent the leading theory to explain such pricing patterns. Numerous empirical studies have investigated the presence and characteristics of Edgeworth cycles on retail gasoline markets, primarily for markets in the U.S. (e.g., Doyle, Muehlegger, and Samphantharak 2010; Zimmerman, Yun, and Taylor 2013), Canada (e.g., Atkinson, Eckert, and West 2014; Noel 2007a,b), Australia (e.g., Wang 2008; Wills-Johnson and Bloch 2010c), and a few European countries (e.g., Foros and Steen 2013).

Analyzing price competition on retail gasoline markets is a highly relevant topic as consumers often spend a significant portion of their disposable income at gasoline stations, which are to a large extent operated by just a few integrated players. For this and other reasons, the sector is frequently subject to inquiries from competition authorities (see, e.g., OECD 2013) and direct policy interventions, ranging from price transparency initiatives (e.g., in Germany), price increase notifications or limitations (e.g., in Austria or Australia) to the strict regulation of prices or margins (e.g., in some provinces in Canada). While, from a policy perspective, understanding the welfare effects of price cycles is fundamental, this aspect has received limited attention from authorities and researchers so far (e.g., Noel 2012, 2015; Zimmerman, Yun, and Taylor 2013).

On the German market, motorists frequently observe sharp price fluctuations during the course of a single day, which the competition authority has confirmed for four major cities as part of a fuel sector inquiry (see Bundeskartellamt 2011a,b) and for eight major cities in subsequent analyses (see Bundeskartellamt 2015, 2017). To derive reliable, empirical findings on the characteristics, causes, and price effects of such intraday cycles, it is essential to have access to data of adequate granularity and frequency, which rarely is the case (see discussions in Atkinson, Eckert, and West 2014; Eckert and West 2004). Consequently, price cycles on an intraday level as found on the German market, which are more pronounced than cycles over several days, have not been extensively studied so far. Only recently, enabled by a census of price data, a number of authors have started looking into salient features of intraday pricing (e.g., Eibelshäuser and Wilhelm 2016; Haucap, Heimeshoff, and Siekmann 2016; Neukirch and Wein 2016).

In this paper, I present unique evidence of price competition on an intraday level, investigating the presence, causes, and price effects of intraday Edgeworth cycles, using a novel high-frequency price data set covering virtually all gasoline stations in Germany. With this data, I am able to investigate precise pricing patterns and explore recurring cycles without relying on aggregated observations across time or markets. While, similar to investigations by the German Federal Cartel Office, most existing studies focus on larger metropolitan areas (e.g., Lewis 2012; Noel 2012), I am first to explicitly analyze cycles across an entire country without price regulations, covering numerous municipalities, from urban to rural areas.

I find broad evidence of intraday cycling across municipalities in Germany. Both the asymmetry and the intensity of cycles is driven by a higher density of stations, a higher density of population per station, as well as a lower share of non-major brands. My analysis suggests that intraday cycles are a sign of competition with a price decreasing effect, most pronounced during evening hours. Thereby, consumers can gain from the presence of price cycles and benefit most if they behave less myopic but optimize their intraday purchase timing strategies.

The remainder of this paper is structured as follows: Section 4.2 discusses the concept of Edgeworth cycles before section 4.3 presents an overview of relevant empirical literature. In section 4.4, I explain the data set used before section 4.5 presents the empirical analysis. The latter includes the identification of price cycles (section 4.5.1), an analysis of cycle causes (section 4.5.2), as well as a perspective on price effects (section 4.5.3) and consumer purchase strategies (section 4.5.4). Finally, section 4.6 concludes and provides ideas for further research.

4.2 Edgeworth Cycles

In light of fast-changing retail gasoline prices, numerous studies focusing on dynamic pricing behavior have been published. Recurring, asymmetric cyclical patterns are often referred to Edgeworth price cycles, which arguably represents the leading theory behind price cycles found on many gasoline retail markets (Noel 2011).[2]

[2]Some authors doubt the common association of price cycles with Edgeworth theory and propose alternative explanations for pricing dynamics. Hosken, McMillan, and Taylor (2008), for example, discuss both static and dynamic models (including Edgeworth cycles) to explain observed prices in suburban Washington, D.C. The authors state that, using Edgeworth models, it is difficult to determine if stations are in a cycling equilibrium, and conclude that, similar to other discussed models, Edgeworth theory only explains some aspects of gasoline pricing. Noel (2007b, pp. 87-90) investigates – and argues against – a range of competing hypotheses, including fluctuating demand, differences in menu or monitoring costs, the depletion of the inventories in the underground tanks at retail stations, discounts off the posted rack price, and covert collusion. On the Norwegian market, Foros and Steen (2013) find evidence of weekly price cycles but do not associate them

The theoretical foundations of such asymmetric price cycles date back to Francis Ysidro Edgeworth (1925). Formalizing Edgeworth's ideas, Maskin and Tirole (1988) introduce a Bertrand duopoly model, where two symmetric firms produce homogeneous goods at constant costs and are restricted to using Markov strategies (i.e., a firm's pricing decision is only dependent on the other firm's price). The authors show that asymmetric price cycles (called "Edgeworth cycles") might result as a Markov Perfect Equilibrium (MPE), while an equilibrium with constant "focal prices" over time represents a second possible outcome (for the latter, also see Noel 2007a). In the Edgeworth cycle equilibrium, firms pursue symmetric strategies (Maskin and Tirole 1988, p. 587) with best response functions of the form

$$R(p) = \begin{cases} \overline{p} & \text{for } p > \overline{p} \\ p-k & \text{for } \overline{p} \geq p > \underline{p} \\ c & \text{for } \underline{p} \geq p > c \\ c & \text{with probability } \mu(\delta) \text{ for } p = c \\ \overline{p}+k & \text{with probability } 1-\mu(\delta) \text{ for } p = c \\ c & \text{for } p < c \end{cases} \tag{4.1}$$

where $\underline{p}$ and $\overline{p}$ are two prices for which $\underline{p} < \overline{p}$, c represents (constant) marginal costs and k is a single step on a discrete price grid. Edgeworth cycles, with their distinctive "sawtooth" pattern, are, hence, characterized by a longer sequence of small price decreases, down to the level of marginal cost (called "undercutting phase", with stepwise price reductions $p-k$, eventually, until $p = c$) and a single, large price increase, up to a level slightly above the monopoly price (called "relenting phase", with a price increase to $\overline{p}+k$). Typically, at the lowest point, a "war of attrition" among competitors starts, where firms play a mixed strategy of maintaining prices at marginal costs c (with probability $\mu(\delta)$) until one of them initiates a cycle restoration (with probability $1-\mu(\delta)$). This essentially restarts the price cycle with a new series of tit-for-tat price undercuttings. It is important to note that Edgeworth cycles are both independent of input cost movements as well as demand levels but rather a result of firms' pricing strategies.[3]

While visual observations indicate strong similarities between the sawtooth pattern of Edgeworth cycles and empirically observed pricing patterns on many retail gasoline markets, formal verifications prove to be challenging given a lack of testable predictions. Over the years, however, the basic model of Maskin and Tirole

with Edgeworth-type cycles. Instead, the authors argue that price controls cause observed patterns (inducing a day-of-the-week effect, with prices regularly jumping up on Mondays).

[3]For a more detailed, non-technical introduction to Edgeworth cycles, see Noel (2011).

(1988) has been refined, most notably by Eckert (2003), Noel (2008), Wills-Johnson and Bloch (2010a), and – more recently – by Eibelshäuser and Wilhelm (2016), all of them addressing issues with relevance for gasoline markets. First of all, Eckert (2003) introduces supplier heterogeneity (e.g., major and independent brands) and allows for an uneven split of market shares between duopolists even with equal prices. In this setup, the author concludes that, in the presence of asymmetric firms, cycles are more likely to arise. Secondly, Noel (2008) includes fluctuating marginal costs, capacity constraints, and a third player into the model. In his analysis, Noel (2008) shows, among other things, that a triopoly setup might result in anomalies such as delayed price adjustments or "false start" (i.e., reversed) price increases. Third, Wills-Johnson and Bloch (2010a) extend the model by exploring a spatial framework for Edgeworth cycles, showing how cycles might occur in a market characterized by spatial competition. Finally, Eibelshäuser and Wilhelm (2016) take a modified approach, inspired by higher frequency, intraday price cycles documented on German gasoline markets. Given the finite time horizon of these intraday cycles, the authors generalize the two-firm setup presented in Wallner (1999) and test its predictions on the equilibrium price path.

4.3 Empirical Literature

Castanias and Johnson (1993) are among the first to find similarities between empirical price cycles on U.S. gasoline markets and the Maskin and Tirole (1988) model. Since then, numerous empirical publications have investigated elements of Edgeworth cycles on retail gasoline markets, explored reasons why and where they exist, and described their main features (see Eckert 2013; Noel 2011, 2016 for overviews of empirical studies).[4] A typical Edgeworth-type cycle found on many gasoline markets lasts for about a week with a range of eight to ten percent of the price. Cycle length (e.g., from daily to monthly) and amplitudes, however, might vary significantly (Noel 2016). Once they have started, cycles tend to be persistent, with the exception that large shocks such as an unexpected refinery fire (see Atkinson, Eckert, and West 2014 for an example) or substantial regulatory interventions (see Wang 2009 for an example) might temporarily or even permanently stop price cy-

[4]Edgeworth cycles have also been studied on a few other markets. Closely related to gasoline markets, Isakower and Wang (2014) explore price cycles for a non-gasoline product, namely liquified petroleum gas (LPG), and find that LPG cycles in Western Australia are both longer and more asymmetric than comparable gasoline price cycles. The authors associate their finding to a potentially more elastic aggregate demand for LPG compared with gasoline. In a different context, Zhang (2005), moreover, presents an empirical investigation of Edgeworth cycles in online advertising auctions.

cles. While most studies are able to confirm elements of Edgeworth cycle theory, findings are often limited by data availability and frequency.

Several studies, largely relying on city-level data, are able to document price cycles primarily on markets in the Midwestern U.S. (e.g., Zimmerman, Yun, and Taylor 2013), Canada (e.g., Noel 2007a), and Australia (e.g., Wang 2008). To identify cycling markets, Doyle, Muehlegger, and Samphantharak (2010), Lewis (2009, 2012), and Noel (2015), among others, suggest to use the median value of price changes in a market area to separate cycling from non-cycling markets, assuming to find a negative value in cycling markets with considerably more price decreases than increases, while average price changes should be closer to zero.[5] Typically, authors also define a cut-off value for the median of price changes to separate cities with low cycle intensity from cities with high cycle intensity.[6]

Next to the identification of cycles, several authors have explored causes of Edgeworth cycles. Among other things, they found that with a higher share of independent retail stations, more markets tend to exhibit cycling behavior (see, e.g., Noel 2007a for Canadian and Lewis 2009 for U.S. cities). Using gasoline station-level data, often gathered from a sample of retail sites, several authors show that large firms tend to initiate the relenting phase, while small firms are more likely to undercut (see, e.g., Atkinson 2009; Noel 2007b for stations in Canada). Lewis (2012), more specifically, associates price cycling (and price restorations) to the presence of two specific independent retail chains, Speedway and QuickTrip, on U.S. markets. With U.S. station-level data, Doyle, Muehlegger, and Samphantharak (2010), moreover, provide evidence that the most and least concentrated markets are less likely to cycle. In their study, the authors also dissent from previous findings that markets are generally more likely to cycle with a higher share of independents. Instead, Doyle, Muehlegger, and Samphantharak (2010) find that markets tend to cycle if independent stations with a large market share have significant convenience store operations. Finally, some studies in this context test for a potential interdependency of Edgeworth cycles with "rockets and feathers" pricing on retail gasoline markets.[7]

[5]More precisely, Lewis (2009) introduces the "median daily change in the city average price" (p. 589) as a proxy metric for the extent of price cycles. This metric has been widely applied by other authors.

[6]For Midwestern U.S. markets, authors suggest to define cities as cycling with a median price change below -0.2 (Lewis 2012, p. 345), -0.3 (Lewis 2009, p. 591), or -0.5 (Doyle, Muehlegger, and Samphantharak 2010, p. 654) US-cents per gallon. As a second approach prevalent in empirical literature to identify Edgeworth cycles, Eckert (2002) and Noel (2007a,b, 2008), for example, apply a Markov-switching regression model (see Hamilton 1989). This approach specifically allows the authors to estimate the length of cycling phases, which, however, is less relevant in a finite time horizon setting.

[7]Empirical studies on rockets and feathers pricing explore the dynamic relationship between input (i.e., oil or wholesale) prices and retail prices. The main hypothesis in this area is that there

While both rockets and feathers pricing and Edgeworth cycles describe asymmetric pricing phenomena, they differ as price changes are either caused by cost shocks or happen independent of costs. Studies combining the two concepts argue that input cost increases might trigger an Edgeworth cycle restoration, while cost decreases allow for additional leeway for price undercuttings (see, e.g., Eckert 2002; Noel 2009). Lewis (2009) and Lewis and Noel (2011), for instance, investigate the speed of response to cost shocks in cities with and without price cycles and find prices in Edgeworth-type markets to fall more quickly after wholesale price spikes (e.g., following Hurricane Rita), so that the presence of Edgeworth cycles might partially mitigate the rockets and feathers phenomenon.

From a competition policy perspective, it is fundamental to understand the welfare consequences of Edgeworth cycles, in addition to its characteristics and potential causes. Nevertheless, this is a largely untapped field of empirical investigations. While some authors have associated price cycles with explicit or implicit collusion (e.g., Erutku and Hildebrand 2010; Wang 2008), recent empirical evidence suggests that cycling markets coincide with lower average price levels (e.g., Doyle, Muehlegger, and Samphantharak 2010; Noel 2011; Zimmerman, Yun, and Taylor 2013). Noel (2015), for instance, finds that the cessation of cycles in three Canadian cities as a result of a refinery fire has led to a price increase and concludes that Edgeworth cycles may be beneficial to consumers. On top, in cycling markets with a higher price spread, informed consumers can benefit from adapting their purchase timing and, therefore, further reduce actual prices vis-à-vis (unweighted) average prices.[8] Accurately forecasting gasoline price cycles, however, might not be trivial from a consumer's perspective as, for instance, illustrated in Noel (2012), presenting a purchase timing study assuming perfect foresight of consumers, or Noel and Chu (2015), with a discussion on consumer strategies relying on prior and known price data only.[9]

Empirical studies investigating Edgeworth cycles on an intraday level are rare, probably due to a lack of appropriate data sets. On the German market, enabled by

is an asymmetric response, with a quick (rocket-like) increase of retail prices as a reaction to input price increases and a slow (feather-like) decrease as a reaction to input price decreases (see, e.g., Bachmeier and Griffin 2003; Bacon 1991; Borenstein, Cameron, and Gilbert 1997; Verlinda 2008).

[8]This essentially requires consumers to be aware of price cycles and to take advantage of cycles by shifting demand into low-price periods. Based on survey data, the ACCC (2007, p. 178) states that 83% of motorists in Australia are aware of regular price cycles and 74% nominated Tuesday as the cheapest weekday. Survey data for Norway, reported in Foros and Steen (2008, pp. 22-23), shows that a third of surveyed consumers are aware of weekly price patterns. For the German market, Dewenter, Haucap, and Heimeshoff (2012, p. 26) present survey results stating that 54% of respondents refuel either on specific days or as a result of noticed price decreases.

[9]Also see Woods (2014) for a discussion on consumer welfare gains from Edgeworth cycles.

full price transparency (compare section 4.4), a number of papers recently emerged, which focus on aspects of inter- or intraday price competition (e.g., Frondel, Vance, and Kihm 2016; Haucap, Heimeshoff, and Siekmann 2017; Kihm, Ritter, and Vance 2016). To the best of my knowledge, three of these papers specifically investigate features of intraday price cycles and are, thus, of relevance for my analysis: First, Haucap, Heimeshoff, and Siekmann (2016) present a plausibly causal investigation of the impact of market structure on local prices. The authors use a temporary, intraday variance in market structure – given by exogenously determined opening hours of stations selling gasoline as a by-product – and find a negative price effect of this subset of independent stations on nearby major-brand competitors. Secondly, Neukirch and Wein (2016) focus their analysis on medium-sized German cities (with between 60,000 and 100,000 citizens) and provide evidence of collusive behavior of major brands with regard to upward price movements in evening hours. Third, Eibelshäuser and Wilhelm (2016), who specifically look at Edgeworth-type behavior on an intraday level, test a number of predictions of a finite time horizon model and conclude that intraday cycles are an outcome of intense price competition.[10] In contrast to the studies described above, I comprehensively investigate intraday price cycle characteristics, potential causes, and price effects. While most empirical studies focus on single cities or a sample of typically larger metropolitan areas (e.g., Wills-Johnson and Bloch 2010b,c analyze cycles in Perth, Noel 2012 looks at stations in Toronto),[11] I contribute an empirical analysis including nationwide municipalities in a major OECD country.

4.4 Data

Several authors have stressed the importance of data granularity and frequency related to empirical studies on Edgeworth-type cycles on gasoline markets. Atkinson, Eckert, and West (2014) and Eckert and West (2004) highlight issues associated with using data of insufficient frequency or covering only a sample of stations. According to the authors, several studies might not capture cycles well and derive misleading findings subject to the exact time of observation.[12] Even in light of recent data sets

[10]Moreover, Boehnke (2014) presents a study on intraday pricing using self-collected data, arguing that price patterns in Germany might be a result of temporary price discrimination.

[11]Noteworthy, in this context, are also empirical studies investigating Metropolitan Statistical Areas (MSAs) in the United States. These include Lewis (2009) looking at 85 MSAs, Doyle, Muehlegger, and Samphantharak (2010) with 115 MSAs, Lewis (2012) with 280 MSAs, and Zimmerman, Yun, and Taylor (2013) with 350 MSAs.

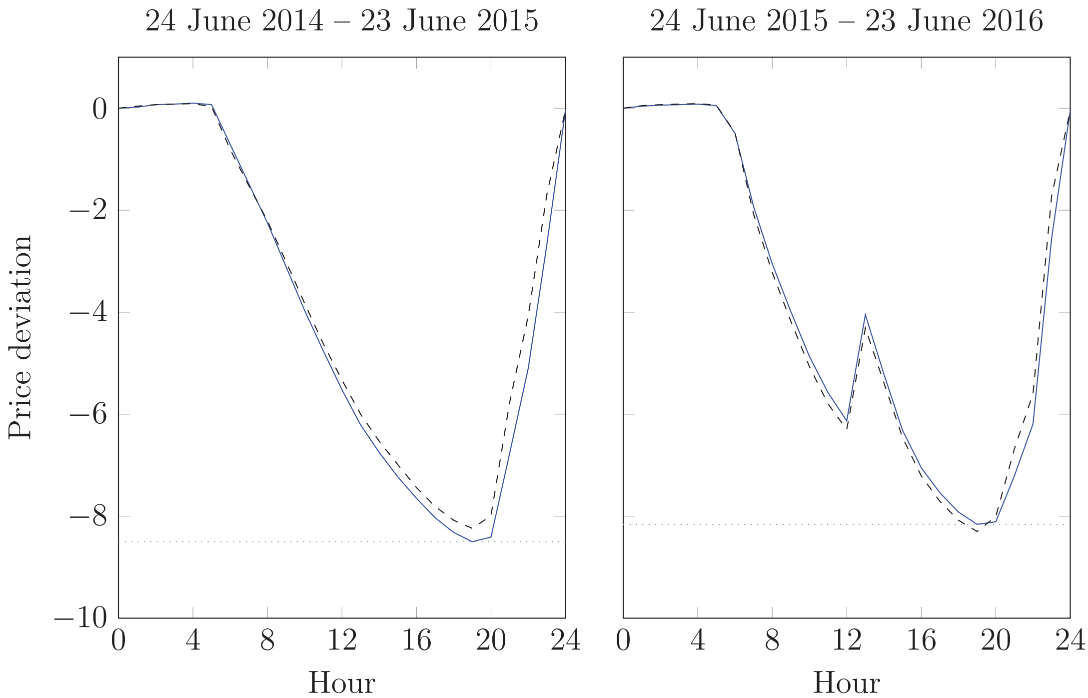
[12]Similarly, Bettendorf, van der Geest, and Varkevisser (2003) find ambiguous results in a rockets-and-feathers type analysis for the Dutch market. Depending on the weekday on which prices are observed, the authors' estimations suggest either price symmetry or asymmetry.

collected from pricing website, Atkinson (2008) points to sample selection bias issues, for instance, regarding the role of individual brands. Reliable analysis on granular price cycles, thus, requires high-frequency data of a comprehensive set of gasoline stations. In this study, I use a novel data set covering virtually all gasoline stations in Germany with exact time stamps of all price quotes. This data is arguably of higher precision than data used in most other studies on Edgeworth cycles.[13] Established by the German Federal Cartel Office, the so-called market transparency unit for fuel ("Markttransparenzstelle für Kraftstoffe", MTS-K) centrally collects all fuel prices since the end of 2013 (see Bundeskartellamt 2013, 2014, 2015, 2017).[14] Retail prices are nominal end-customer prices in Euro(cents) per liter of Super E5 fuel and include all taxes and duties (i.e., value-added tax, energy tax, and a fee for the Petroleum Stockholding Assocation "EBV"). I investigate a period of observation including two years, from mid-2014 to mid-2016. With this, I reflect a change in the equilibrium pricing pattern first observed on 24$^{\text{th}}$ June 2015. Starting from this date, a minor price increase around noon can be found at the majority of gas stations (see Bundeskartellamt 2015, pp. 20-23). I include a full year of data before and after this change (i.e., the period of observation covers 24$^{\text{th}}$ June 2014 to 23$^{\text{rd}}$ June 2015 and 24$^{\text{th}}$ June 2015 to 23$^{\text{rd}}$ June 2016, in total 731 days). Figure 4.1 shows stylized hourly price deviations from daily starting prices, split by respective one-year periods and averaged over all 13,448 stations included in my analysis, with a total of 57.4 million price quotes.[15] Note that, to eliminate cross-sectional variance, I only include gas stations with *(i)* price quotes for Super E5 in each calendar year, *(ii)* an initial price quote recorded before the 24$^{\text{th}}$ June 2014, and *(iii)* at least one price quote after the 23$^{\text{rd}}$ June 2016. Moreover, to find accurate results, I identify and exclude gas stations with "abnormal" time periods in which no price alteration has been recorded. Specifically, I disregard stations with *(i)* no price quote for more than a quarter of a year or *(ii)* no price quote for more than a week if this is atypical for the specific gas station; that is, if the single-longest (or, second-longest) time period between two consecutive price quotes is more than ten times longer than the second-longest (or, third-longest) time period between two price quotes. Thereby, I effectively correct for gas stations subject to a temporary close-down of operations, a change of the service provider responsible for price submissions or similar reasons,

[13]In addition to recent studies on the German market, Atkinson (2009) presents one of the studies using more granular data so far with bi-hourly observations.

[14]Gasoline station operators are obliged to report any price change to the MTS-K within five minutes time, which are then forwarded to authorized consumer information providers in real time. The data set used in this study was kindly provided by consumer information provider "1-2-3 Tanken" (on 2 January 2017).

[15]Cycles are comparable across weekdays (see Figure 4.11 in the Appendix).



Note: Hourly deviation of individual gas station's price (in Eurocents/liter) from the same station's daily starting price (at midnight), averaged across all gas stations in Germany (using point-in-time prices at full hours). Dashed line shows hourly deviations only including stations open 24/7.

Figure 4.1: Average Hourly Price Deviation

causing a erroneously recorded period without new price quotes (see section 4.A in the Appendix for a description of raw data preparation steps and Figure 4.6 in the Appendix for a distribution of average daily price quotes across stations).

In addition to retail prices, I control for refinery region-specific, daily wholesale prices provided by data provider Oil Market Report (O.M.R.). Wholesale prices "ex-refinery" differ by eight major refinery regions in Germany, I assign each municipality or gasoline station to one of those regions based on minimum linear distance to the region's market place.[16]

Basic MTS-K data on individual gasoline stations includes the geographical position (longitude, latitude), brand affiliation, and details on business hours.[17] I complement these basic station characteristics by including conventional brand clusters

[16]Refinery regions are North (with market place Hamburg), East (Berlin), Seefeld, South-East (Leuna), West (Duisburg, Gelsenkirchen, Essen), Rhine-Main (Frankfurt), South-West (Karlsruhe), and South (Neustadt, Vohburg, Ingolstadt). Ex-refinery prices can differ depending on whether they are sold "branded" or "unbranded", which is not reflected in the data set. Price quotes are, moreover, not available on weekends and public holidays. I assume prices to remain constant on previous-day levels in these cases.

[17]Figure 4.7 in the Appendix provides summary statistics on weekday-specific business hours of gas stations included in this study. Note that $<1\%$ of stations have more than one pair of opening and closing times per weekday (e.g., due to closing after midnight for a short period of time); in these instances, stations are treated as if closing at midnight.

(i.e., separating major brands Aral, Shell, Total, and Esso from other, non-major brands) and by including station characteristics such as the presence and size of an associated shop with data collected by data provider "Petrolview". Moreover, with specific relevance for this study, I conduct reverse geocoding with MTS-K's geo coordinates to identify the unique municipality identification number ("amtlicher Gemeindeschlüssel") of each station based on OpenStreetMap data.[18] With the municipality identifier for each gas station, I can analyze price cycles on a municipality level and make use of the categorization of city types applied by the German Federal Office for Building and Regional Planning ("Bundesamt für Bauwesen und Raumordnung", BBR).[19] Finally, I include official statistics from the so-called Regional Data Base Germany.[20] This includes data on population, area, and the share of commuters on a granular municipality level, as well as disposable household income, GDP per capita, and the number of cars per capita, which are available for cities and administrative districts.

In the following section, I will present empirical evidence on four areas, namely, identifying Edgeworth-type cycles, characterizing cycles' causes, determining price effects, and consumer purchase strategies. Figure 4.8 in the Appendix summarizes the development of station-level metrics central to this study (i.e., daily average retail and wholesale price levels, price spreads, size and count of price changes), based on the data sets described above, over the course of the two-year period under observation.

4.5 Empirical Analysis

4.5.1 Cycle Identification and Characteristics

Sharp price fluctuations during the day are frequently observed by many motorists. Similar to what Edgeworth theory suggests, intraday price cycles, as depicted in Figure 4.1, are characterized by a comparably long period of decreasing prices and abrupt price restorations. While price restorations are highly synchronous, price

[18]The official municipality identification number ("amtlicher Gemeindeschlüssel") uniquely identifies each municipality (cities, towns, and rural communities). As an example, the identifier for Berlin is 11000000, for Drolshagen it is 5966008.

[19]The BBR classifies municipalities into major cities (with a population of >100k), mid-sized cities (20–100k), larger towns (10–20k), small towns (5–10k), and rural communities (<5k). In addition to population, the BBR classification also considers the degree of available city functions. This may lead to deviations from the pure population-based threshold levels described above (see `www.bbsr.bund.de/BBSR/DE/Raumbeobachtung/Raumabgrenzungen/StadtGemeindetyp/StadtGemeindetyp_node.html`). Figure 4.10 in the Appendix gives an overview of municipality types across Germany.

[20]"Regionaldatenbank Deutschland", see `www.regionalstatistik.de`.

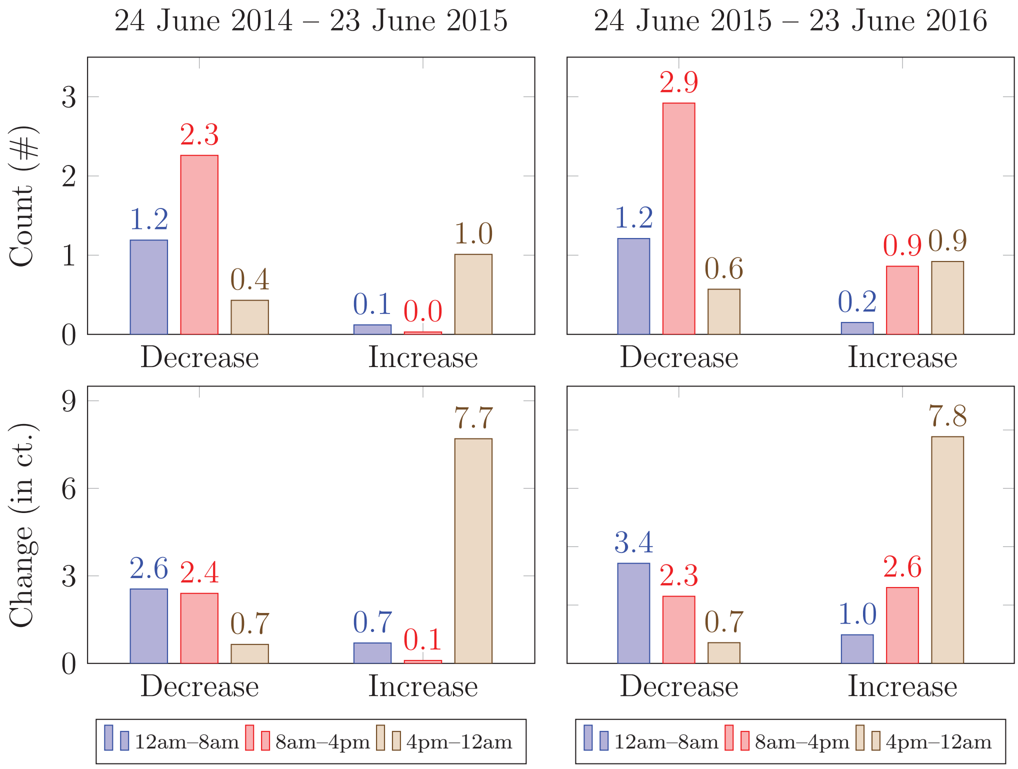
decreases typically happen autonomously on a local level and reflect prevalent competitive dynamics (Eibelshäuser and Wilhelm 2016). Price restorations of intraday cycles in Germany are clearly driven by players with a significant market share, albeit not by independents, in contrast to what Lewis (2012) observed for U.S. cities. Instead, as a common pattern, major-brand Aral (or Shell) initiates daily price restoration rounds with Shell (or Aral) reacting in a short period of time, before other players follow suit (Neukirch and Wein 2016). In this first section of the empirical analysis, I will present descriptive evidence of intraday price cycles along specific metrics to identify and measure price cycles, which I will use in cross-sectional and panel regressions on cycle causes and price effects in the following sections.

To understand timing, quantity, and magnitude of price changes, let me start with dividing the day into three time periods of equal length: from midnight to 8 am, from 8 am to 4 pm, and from 4 pm to midnight. Figure 4.2 separates price increases from price decreases and illustrates the pure number of price changes next to the average magnitude of changes across all gas stations. I find that price decreases usually happen in the first part (with a count of 1.2) and, predominantly, in the second part of the day (count of 2.3 or 2.9), that is before 4 pm. Afterwards, only occasional price decreases are observable. On average, price decreases have a comparably limited magnitude, in the first two periods of between 2.3 and 3.4 Eurocents/liter. Now, looking at price increases, I again find a pattern resembling Edgeworth-type behavior, with a single, large price increase in the evening hours of a magnitude of 7.7 to 7.8 Eurocents/liter. As discussed before, in June 2015, the equilibrium pattern of intraday pricing changed from one daily cycle to two cycles, with a major increase in the evening and an additional, minor price restoration around noon. Figure 4.2 confirms this, showing close to a single increase also in the second part of the day, during the second year of observation, with a smaller magnitude of 2.6 Eurocents/liter.[21]

Let me now turn to statistical indicators to identify price cycles. Similar to Lewis (2009) and other studies, first of all, I use the median of price changes as the key metric to recognize the presence of asymmetric price cycles. However, while Lewis (2009), using daily observations, suggests the "median daily change in the city average price" (p. 589), I take advantage of the census of price quotes at hand and compute the median of all intraday price changes on a station-level, averaged across municipalities.[22] Indeed, I find distinctly negative median values across the

[21] Note that this also explains the increase in the number of price changes in the second year of observation, found in Figure 4.8 in the Appendix. According to Eibelshäuser and Wilhelm (2016), occasional price increases observed in the morning are to be associated to stations with restricted opening hours, adjusting their prices shortly after opening.

[22] Thereby, all price changes are considered for computing the median value, albeit the number



Note: Number and magnitude (in Eurocents/liter) of price changes for the time period shown, averaged across all days and stations.

Figure 4.2: Average Number and Magnitude of Price Changes by Time Period

country of, on average, -1.2 Eurocents/liter, while the mean of all price changes is marginally positive (with 0.004 Eurocents/liter) and the difference between both metrics is highly significant (t test shows significant difference on the 1% level). This finding suggests a comparable magnitude of the sum of price increases and the sum of price decreases per day in absolute terms, whereas the count of price decreases is higher than the count of price increases. While this underpins the fundamental *asymmetry* of price cycles, I argue that the intraday price spread, which is at a level of 10.0 Eurocents/liter averaged across gas stations, reveals further valuable insights into the *intensity* of price cycles.[23]

Next, I will look at cycling patterns through the lens of municipalities. Figure 4.3 and 4.4 show hourly price deviations in exemplary municipalities with high

of changes and the length of validity of individual prices may vary. This arguably gives smaller values compared with computing the median across fixed time interval (i.e., daily) price changes.

[23]Note that intraday price spreads are considerably higher than day-on-day price changes, which are typically not more than 2.0 Eurocents/liter (averaged across gas stations). As intraday price spreads, I report averages across gas station-specific spreads in a municipality, in contrast to municipality-wide price spreads. Naturally, municipality-level price spreads are more pronounced than averages of within-city station-level price spreads. For eight major cities (with numerous gas stations each), the Bundeskartellamt (2015) finds city spreads of at least between 15 and 20 Eurocents/liter or even beyond 20 Eurocents/liter in the cities Berlin, Hamburg, and Cologne.

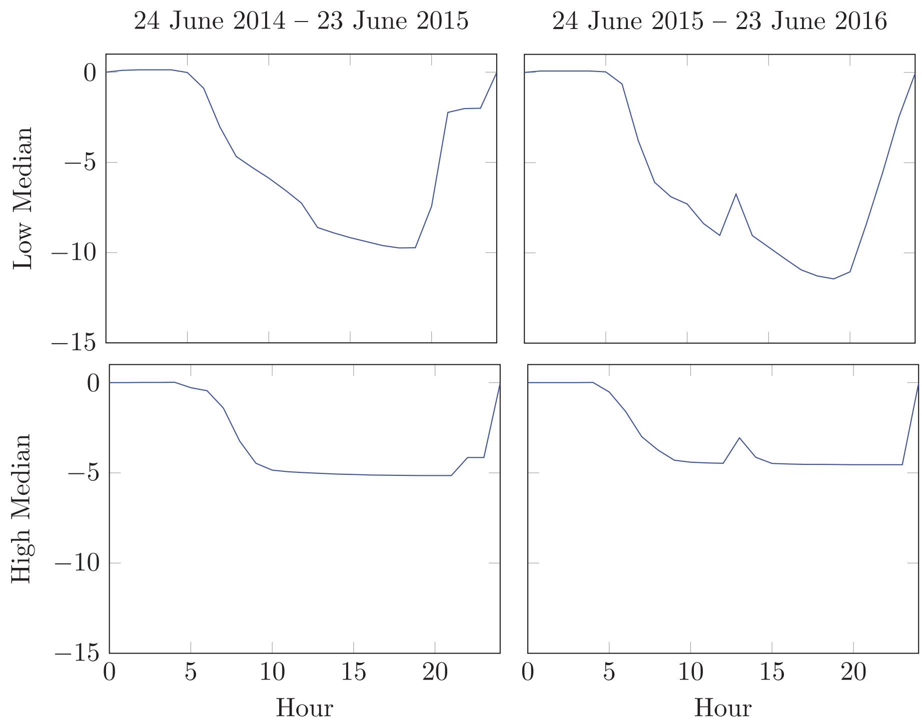
Table 4.1: Interpretation of Statistical Indicators

Object of investigation		Statistical indicator	
Cycle asymmetry	+	Median of price changes	−
	−		+
Cycle intensity	+	Daily price spread	+
	−		−

and low values across the metrics median of price changes and daily price spreads defined above. Note that the two statistical indicators used to approximate cycles asymmetry and cycle intensity need to be interpreted differently: While a higher price spread is associated with more intense cycling, a lower median of price changes suggests to find more asymmetric cycles (see Table 4.1). First, looking at Figure 4.3, the anecdotal evidence shows that a city with a highly negative median price change (at the top) correlates with an asymmetric, "sawtooth" price pattern. In a city with a median of price changes around zero (at the bottom), in turn, price decreases and increases appear more symmetric, albeit a cycle might still be present. Secondly, while a high price spread per se (as in the top part of Figure 4.4) is not a sufficient condition for Edgeworth-type cycling, it does gives an indication of the intensity of cycles if compared with a city having a lower level of price spreads (at the bottom). In a more systematic way, Figure 4.9 in the Appendix shows Kernel densities for the two cycle metrics across 4,301 German municipalities.[24] Overall, I find vast evidence of Edgeworth-type cycles across municipalities in Germany. In line with previous studies, I suggest a cut-off value to separate cycling from non-cycling cities. Assuming a value for the median of price changes of -0.3 Eurocents/liter, close to 300 municipalities (or 7%) show rather "sticky" prices, while the majority is considered as cycling. Most of the less cycling municipalities are rural communities or smaller towns, among them, however, are also eight mid-sized cities and one major city (i.e., Trier). While the intensity of cycling, measured by average station-level price spreads, is more distributed, with up to 18 Eurocents/liter at the maximum, a small fraction of close to 200 municipalities show an average daily price spread of less than 2.0 Eurocents/liter.[25]

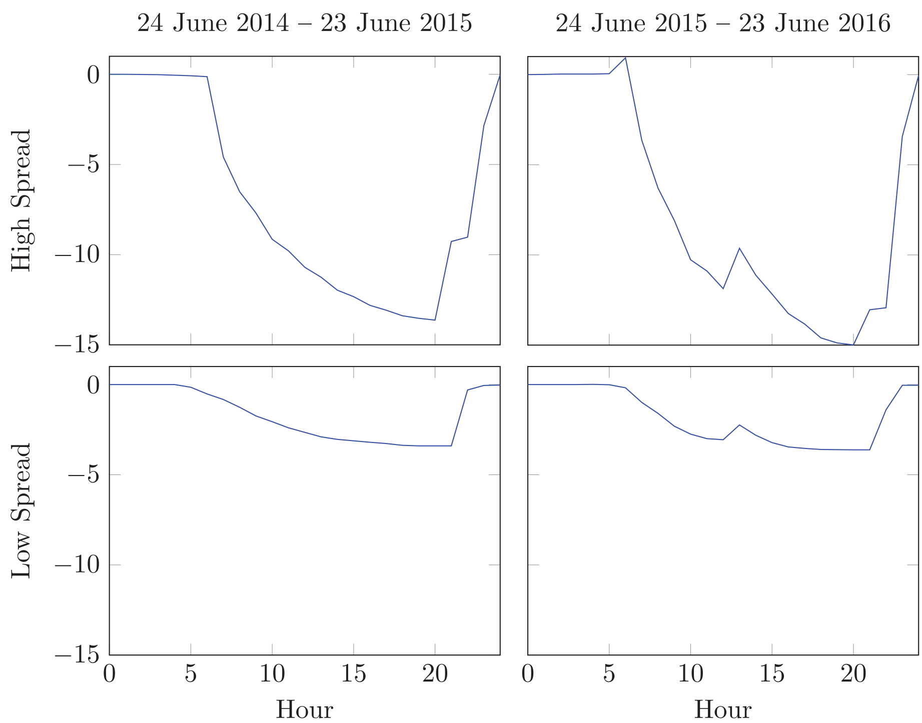
[24]See Table 4.4 in the Appendix for a clustered overview of municipalities in the data set. Comparing municipalities included in my analysis with the last full census of data from BBR (as of Dec 2014), I cover 77 out of 77 (100%) major cities, 682 of 771 (88%) mid-sized cities, 943 of 1,183 (80%) larger towns, 1,376 of 3,430 (40%) small towns, and 1,202 of 5,729 (21%) rural communities. Lower percentages in rural communities are a result of the fact that not every town or rural area has a gas station in its territory.

[25]Rather "sticky" pricing at individual gas stations was anecdotally validated in random phone calls with gas station operators, conducted in January 2017.



Note: Hourly price deviation for the city of Allersberg at the top (with -2.0 Eurocents/liter median of price changes across three stations) and the city of Ochtrup at the bottom (0.0 Eurocents/liter across four stations).

Figure 4.3: Exemplary Municipalities with Low and High Median of Price Changes



Note: Hourly price deviation for the city of Schlüchtern at the top (with 16.2 Eurocents/liter average price spread across four stations) and the city of Moosburg at the bottom (4.0 Eurocents/liter across four stations).

Figure 4.4: Exemplary Municipalities with High and Low Station-level Price Spread

4.5.2 Cycle Causes

In this part of the empirical analysis, I will focus on identifying reasons for a higher cycle asymmetry and intensity in some municipalities versus lower cycling in others. To explore causes for cycling cities, Lewis (2009), Noel (2007a), and Wills-Johnson and Bloch (2010c), for instance, estimate cross-sectional regressions of their median of price change metric on several supply- and demand-side variables. I will closely resemble their approach to identify municipality-specific characteristics associated with cycling behavior and estimate descriptive regressions of the two metrics determining price cycle asymmetry and intensity introduced in the previous section on local market characteristics. Table 4.2 shows a number of specifications with either the median of price changes (i.e., in specifications (1) to (3)) or the daily average price spread (i.e., in specifications (4) to (6)) as the dependent variable. In light of regionally observed price differences (see Bundeskartellamt 2015, p. 6), standard errors are clustered by close to 100 ZIP code regions and results are provided with and without federal state fixed effects. As covariates, I include regressors found by Noel (2007a) to be significant, such as the penetration of independent gas stations in a market as well as the density of stations and the population density per station, all of which positively impact on price cycling in Noel's study. Furthermore, I include similar variables as suggested by Lewis (2009) to be potentially associated with search, travel, or switching costs of consumers (i.e., household income and cars per capita), and complement them with further demographic variables, namely the local GDP per capita and the local share of commuters.[26] Finally, I include two regressions (i.e., specifications (3) and (6)) with station-level cycle metrics as dependent variables, to explicitly test for the potential impact of gas station characteristics on price cycles.

Estimation results in Table 4.2 suggest both a stronger cycle asymmetry and cycle intensity associated with a higher density of stations and a higher population density per station. In contrast to studies on interday cycles in other markets, however, I find indicative evidence that with an increasing share of independent stations, the asymmetry and intensity of cycles is lower.[27] With regard to comparable municipalities, the presence of non-major brands can, thereby, imply a price spread reduction of around 4 Eurocents/liter, albeit this finding alone may not be used to draw conclusions on price levels. In their study, Doyle, Muehlegger, and Samphantharak (2010) find that the presence of gas stations with convenience stores impact

[26] Due to a lack of granular demographic variables for some municipalities, specifications include 3,552 municipalities.

[27] To eliminate a potential bias caused by restricted business hours, I conduct robustness checks with regressions including gas stations opening 24/7 only, leading to comparable findings.

Table 4.2: Regression of Retail Price Cycle Metrics

Dependent variable:	Median of price changes			Price spread		
	Municipality		Station	Municipality		Station
	(1)	(2)	(3)	(4)	(5)	(6)
Non-major market share	0.387***	0.379***	0.307***	-4.504***	-4.511***	-3.852***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Stations per km^2	-0.460***	-0.363***	-0.297***	3.670***	3.008***	1.667**
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)
Population per station ('000)	-0.014***	-0.013***	-0.009**	0.064**	0.073**	0.017
	(0.00)	(0.00)	(0.02)	(0.03)	(0.01)	(0.47)
Commuter share	-0.091	-0.079	-0.138***	0.482	0.603	0.834**
	(0.13)	(0.15)	(0.00)	(0.31)	(0.10)	(0.01)
Income per capita ('000 EUR)	0.009	-0.001	-0.004	-0.033	-0.018	0.024
	(0.16)	(0.85)	(0.41)	(0.57)	(0.73)	(0.46)
GDP per capita ('000 EUR)	0.002**	0.001	-0.001	-0.016*	-0.005	0.003
	(0.04)	(0.50)	(0.20)	(0.06)	(0.50)	(0.39)
Cars per capita	-0.212	-0.712**	-0.102	0.285	7.310***	0.344
	(0.50)	(0.01)	(0.39)	(0.92)	(0.00)	(0.72)
Convenience store			-0.084***			0.944***
			(0.00)			(0.00)
Car wash			-0.159***			1.416***
			(0.00)			(0.00)
Constant	-1.390***	-1.056***	-1.084***	12.481***	8.203***	8.644***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
State-fixed effects	–	Yes	Yes	–	Yes	Yes
Station-specific characteristics	–	–	Yes	–	–	Yes
Number of observations	3,552	3,552	12,036	3,552	3,552	12,036
R^2	0.140	0.162	0.126	0.287	0.321	0.197

Note: Dependent variable in Eurocents/ liter; robust p-values in parentheses (clustered by ZIP code areas).
Asterisks: Statistical significance at 1% (***), 5% (**), or 10% (*) level.

on cycling. In specifications (3) and (6), using station-level data, I indeed find evidence of a positive impact of, in general, more sophisticated station operations (e.g., the presence of a convenience store or a car wash facility) on cycle asymmetry and intensity. On top, only in station-level specifications, an increasing commuter share significantly influences cycling behavior. Findings from descriptive regressions presented in this section may, thus, give guidance on where to find differences in intraday price cycling across municipalities. In the following section, I will comment on the impact that price cycles have on price levels.

4.5.3 Price Effects

Retail price levels averaged across stations have been fluctuating between 1.15 and 1.48 Euro/liter (daily minimum prices) or 1.27 and 1.67 Euro/liter (daily maximum prices) across the two-year period of observation, with local minima in January 2015 and February 2016 (see Figure 4.8 in the Appendix). In fact, prices are dispersed across individual stations and across regions. Haucap, Heimeshoff, and Siekmann (2017) show that station heterogeneity determines prices to a considerable extent. On a regional level, the Federal Cartel Office in Germany has recently explained that price levels vary across ZIP code regions in a "non-uniform way" (Bundeskartellamt 2015, p. 6). While both price dispersion and price cycling are frequently discussed topics, the impact of cycles on price levels and consumer welfare has hardly been explored. In this section, I will test whether price levels in markets with a higher cycle intensity are indeed lower, as suggested by recent literature (e.g., Noel 2015; Zimmerman, Yun, and Taylor 2013). This question is not trivial to answer as, in the absence of volume data, comparing prices relies on the researcher's choice of the "average price" metric.[28] To avoid biases on the selected, non-weighted average price, I will compare the impact of cycling metrics on the minimum and maximum price per day as well as two point-in-time prices (i.e., at 8 am and 6 pm). Therefore, I specify a random-effects model of municipality-level prices on cycling metrics and a set of control variables as shown in equation 4.2 below

$$p_{it} = \alpha + \beta c_{it} + \gamma * cycle_{it} + \boldsymbol{x}_i \boldsymbol{\delta} + \boldsymbol{d}_{it} \boldsymbol{\epsilon} + u_{it} \tag{4.2}$$

with p_{it} as the point-in-time, minimum, or maximum daily price of municipality i at day t, c_{it} as region-specific input costs "ex-refinery", $cycle_{it}$ as a (continuous or boolean) price cycle asymmetry or intensity metric, $\boldsymbol{x}_i$ as a vector of municipality-specific control variables (see section 4.5.2), and $\boldsymbol{d}_{it}$ as a vector of dummy variables to control for weekdays and federal states. Table 4.3 presents results for a number of specifications of the model introduced in equation 4.2, estimating the impact of the median of price changes and the daily price spread, as well as a dummy variable separating cycling from non-cycling markets defined by a cut-off value applied to the median of price changes (as defined in section 4.5.1) on retail prices.

Results in Table 4.3 suggest that neither a higher cycling asymmetry nor a higher intensity lead to lower price levels at all times. However, I find consistent evidence for a stronger price-lowering than price-increasing effect of cycle metrics, both comparing specifications with minimum versus maximum prices and with morning versus evening prices. I interpret this as supporting evidence of the pro-competitive nature of price cycles. While I incorporate both supply- and demand-side effects in my random effects regression, I may still be faced with omitted variable bias. This is true for most empirical studies investigating price cycles as true causal relationships are difficult to obtain in light of typically persisting cycling behavior (Noel 2015). To further validate my findings, I make use of a change in pricing patterns observed in some of the municipalities as a result of the change in the equilibrium price path in the middle of my period of observation: Using the cut-off value of

[28] Also see the discussion in Bundeskartellamt (2017, pp. 24-25) on the influence of the choice of the "average price" on results.

Table 4.3: Regression of Retail Price Levels on Price Cycle Metrics

Dependent variable:	Daily minimum price				Daily maximum price				Point-in-time price at 8 am				Point-in-time price at 6 pm			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Median of price change	0.253				-0.224				-0.393				0.402			
	(0.00)				(0.00)				(0.00)				(0.00)			
(Med. change <-0.3 ct.)		-0.896		-0.686		0.673		*0.317*		1.076		*-0.029*		-1.155		-0.776
		(0.00)		(0.00)		(0.00)		*(0.25)*		(0.00)		*(0.91)*		(0.00)		(0.00)
Price spread			-0.359				0.641				0.083				-0.323	
			(0.00)				(0.00)				(0.00)				(0.00)	
Ex-refinery price	1.209	1.206	1.207	0.990	1.206	1.209	1.207	1.052	1.249	1.254	1.254	1.037	1.204	1.199	1.200	0.994
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	8.846	9.594	11.165	28.013	15.184	14.603	11.166	27.626	7.037	6.089	6.315	26.713	9.944	10.951	12.127	28.218
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weekday dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month dummies	–	–	–	Yes	–	–	–	Yes	–	–	–	Yes	–	–	–	Yes
Year dummies	–	–	–	Yes	–	–	–	Yes	–	–	–	Yes	–	–	–	Yes
Federal state dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality characteristics	Yes	Yes	Yes	–	Yes	Yes	Yes	–	Yes	Yes	Yes	–	Yes	Yes	Yes	–
Municipality fixed effects	–	–	–	Yes	–	–	–	Yes	–	–	–	Yes	–	–	–	Yes
Number of days	731	731	731	731	731	731	731	731	731	731	731	731	731	731	731	731
Number of municipalities	3,552	3,552	3,552	128	3,552	3,552	3,552	128	3,552	3,552	3,552	128	3,552	3,552	3,552	128
Number of observations	2,596,512	2,596,512	2,596,512	93,568	2,596,512	2,596,512	2,596,512	93,568	2,596,512	2,596,512	2,596,512	93,568	2,596,512	2,596,512	2,596,512	93,568
R^2	0.940	0.940	0.946	0.866	0.897	0.897	0.950	0.774	0.913	0.912	0.913	0.786	0.936	0.936	0.940	0.860

Note: Dependent variable in Eurocents/liter; robust p-values in parentheses (clustered by ZIP code areas).
Asterisks: Statistical non-significance denoted in italics.

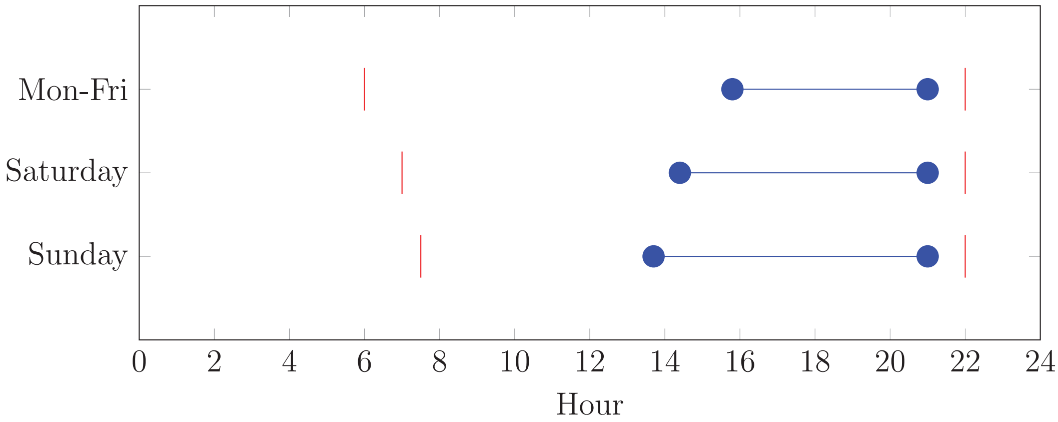
-0.3 Eurocents/liter for the median of price changes identified in section 4.5.1, I can extract 100 municipalities which change from cycling to non-cycling, while further 28 municipalities change from non-cycling to cycling from the first to the second year of observation. Closely following the model specified in Zimmerman, Yun, and Taylor (2013, p. 312), I estimate a municipality fixed effects regression for the subset of municipalities that have changed from cycling to non-cycling, or vice versa, and further include a full set of month and year dummies. Results for the subset of stations included in this arguably more rigid fixed effects estimation are depicted in specifications (4), (8), (12), and (16) of Table 4.3. Interestingly, I cannot identify a significant positive impact of cycle metrics on maximum or morning price levels. Price cycles, thus, seem to have an ambiguous influence during higher priced times of the day. However, results confirm the previous evidence of a highly significant, negative impact on minimum or evening price levels.

4.5.4 Purchase Strategies

Cycling markets offer consumers a menu of prices from which they can choose. In a market with full price transparency and intense price cycles, consumers that have the flexibility to shift consumption can potentially increase their welfare by applying individual purchase timing strategies. Noel (2012) rightly argues that, as a prerequisite, any purchase timing rule needs to not only be effective, but also simple to follow. Thereby, consumers may be encouraged to behave less myopic and, instead, refuel in anticipation of price developments. In a finite time horizon setting, finding a simple rule on an intraday level is much easier to achieve as it is in comparable studies with unpredictably long price cycles (see Noel 2012; Noel and Chu 2015). I will, thus, conclude my empirical analysis with a comment on intraday purchase timing strategies.

Providing advice on purchase timing on a given weekday and in a given municipality essentially relies on investigating *when* and *for how long* prices are on their minimum level. In the extreme, I find that the duration of daily minimum price periods varies from virtually the entire day (in the case of "sticky" prices) to just a few minutes. Figure 4.5 illustrates start and end times of minimum prices, averaged across municipalities and split by weekday. On a nationwide level, Figure 4.5 shows that the window of opportunity for consumers to purchase at the lowest price lasts from around 4 pm (on weekdays) or approximately 2 pm (on weekends) until 9 pm.[29] Moreover, Table 4.5 in the Appendix presents descriptive regression

[29]This is largely in line with findings from the Federal Cartel Office, which says that prices in the eight major cities in scope of their analysis are lowest between approximately 6 pm up to 9



Note: Weekday-specific median of start and end of minimum price per municipality (blue circle) as well as opening and closing times of 8,263 gas stations (61% of total) with restricted business hours (red lines), all other stations with 24/7 opening hours.

Figure 4.5: Duration of Average Minimum Price Periods by Weekday

results of start and end time of the minimum daily price on certain characteristics an informed consumer might be aware of or could, at least, approximate (such as the population density of the municipality, the non-major market share, or the day of the week). Most notably, estimation results suggest that, in a given market with a higher share of non-major gas stations, consumers have more time flexibility to purchase at the lowest price, which is reached up to two hours earlier. The share of non-major brands, in turn, has a non-significant influence on the end time of the minimum price, as price restorations are less impacted by the market area but largely determined by a predetermined rule set. Moreover, during weekdays and in municipalities with a higher density of stations or population, the length of validity of the minimum price tends to be shorter.

Making a conscious decision on purchase timing assumes flexibility and negligible transaction costs from time and effort to pursue purchase timing strategies (e.g., rearranging consumption patterns in cases where refueling is part of a regular routine). Nonetheless, potential benefits from adhering to simple rules might be substantial in light of station-level price spreads of averagely 10 Eurocents/liter or beyond 20 Eurocents/liter for a given municipality at a given day (see Bundeskartellamt 2015).

4.6 Conclusion

In this paper, I have presented comprehensive evidence of intraday Edgeworth-type price cycles on retail gasoline markets, a rarely studied field in empirical litera-

pm latest (Bundeskartellamt 2017, p. 2). Note that, by including rural areas, the average length of validity of minimum prices is, thus, widened.

ture. Specifically, I have investigated the characteristics, causes, and price effects of high-frequency cycles – described by statistical indicators for cycle asymmetry (i.e., median of price changes) and cycle intensity (i.e., daily price spreads) – across municipalities in Germany, enabled by a census of price data covering the entire country.

In line with what motorists frequently observe, I find vast evidence of intraday cycling across German municipalities, with only a small fraction of typically rural areas being characterized by less intense cycling. This is a noteworthy difference to several studies on interday cycles, which typically find only occasional evidence of cycling cities (e.g., in a smaller number of contiguous upper Midwestern states in the U.S. as found by Zimmerman, Yun, and Taylor 2013).

With regard to causes of price cycles, my empirical findings suggest to see both more asymmetric and more intense cycles in the presence of a higher density of stations and a higher population density per station. I also find that more sophisticated gas station operations (e.g., stations with a convenience store or a car wash facility) positively impact cycling behavior. In contrast to other studies (e.g, Lewis 2009), however, cycle intensity is found to be lower in markets with a higher share of non-major brands. Especially in market areas with a prevalence of independents and non-existing or limited competition from major brands, the tendency to witness excessive cycling seems to diminish.

From a policy perspective, the impact of cycles on price levels and consumer welfare is a highly relevant topic. In this study, I am first to provide an empirical link between intraday cycling markets and price levels across the day. I find evidence for the pro-competitive nature of price cycles, with a distinct, price-lowering effect, which is most pronounced during evening hours. While the latter is supported by random and fixed effects estimations, the influence of price cycles during higher priced times of the day is ambiguous. Hence, consumers can gain from the presence of price cycles and benefit most if they behave less myopic but optimize their intraday purchase timing strategies, albeit transaction costs might increase (especially if refueling is an integral part of a regular consumption pattern).

This study has certain limitations, most notably with regard to the process of data validation and aggregation (also see section 4.A in the Appendix) and the (indirect) reflection of market structures (e.g., via brand shares). Further research in the area of intraday price cycles on gasoline markets may focus on investigating the impact of cycles on realized prices with the help of volume data (see, e.g., Hashimi and Jeffreys 2016). This could add valuable insights to the discussion whether consumers benefit from a higher cycle intensity or a higher market transparency in general. In light of full price transparency for consumers and suppliers alike, another interesting aspect could be to examine the effect of emerging price matching schemes, as recently introduced by players like Shell and HEM on the German market, on price cycles and competitive dynamics (see, e.g., Dewenter and Schwalbe 2016).

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Appendix

4.A Preparation of MTS-K Raw Data

In this appendix, I provide additional information on the main data source used in this paper, the market transparency unit for fuel ("Markttransparenzstelle für Kraftstoffe", MTS-K) and explain any modifications of the data set prior to using it for my empirical analysis. With the creation of the MTS-K, a novel panel data set including price quotes from virtually all German gasoline stations emerged. Since December 2013, gasoline station owners are obliged to report any price alteration to the MTS-K.

First of all, I correct MTS-K raw price data for obvious errors, closely following validation rules suggested by the Federal Cartel Office (Bundeskartellamt 2011b, Appendix p. 3).[30] Secondly, to eliminate cross-sectional variance across the period of observation from mid-2014 to mid-2016, I only consider gas stations actually quoting prices for fuel type Super E5 during each calendar year of my period of observation. Furthermore, each station's initial price quote needs to be recorded before the 24$^{\text{th}}$ June 2014, while I require at least one price quote after 23$^{\text{rd}}$ June 2016 to ensure stations are active throughout the entire period.[31] Based on these modifications, I have a total of 13,877 gas stations.

Despite the cautious approach chosen to select gas stations, data accuracy might still be a potential concern, especially when conducting analysis on a granular, intraday level. I, therefore, check individual station price data for outliers with regard to longer time periods, in which no Super E5 price quotes have been recorded. From discussions with practitioners, such periods may occur due to

[30]Also see the online Appendix section 1 of Haucap, Heimeshoff, and Siekmann (2017) for a detailed description of the data set and the method used for raw data preparation.

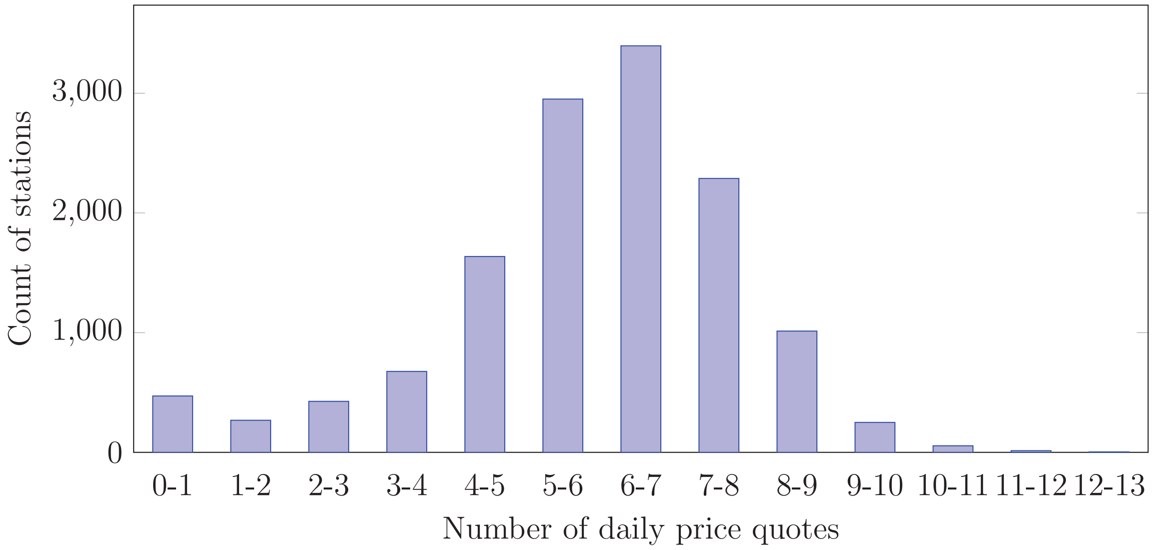
[31]Some stations do not quote prices before 24$^{\text{th}}$ June 2014 as they either belong to the limited number of smaller stations not required to submit prices to MTS-K from the beginning on or as they have started operations only during my period of observation. Moreover, some stations have stopped quoting prices during my period of observation as they have either closed or changed their branding and, consequently, their entry in the data set.

- a temporary close-down of operations (e.g., due to construction work at the gas station),
- technical problems with regard to (own) price submissions, or
- a change of the service provider responsible for price submissions (typically, the provider of the cash register system).

For the reasons stated above, individual gas stations may be subject to one or more "abnormally" long periods without new price quotations, leading to erroneous results if not corrected for. To identify stations with such a pattern, I calculate the exact time period between each pair of consecutive price quotes for all stations and sort them by descending order. I find that 12,093 (87%) gas stations change prices at least once a week throughout the entire period of observation, without any exception.[32] From the remaining 1,784 (13%) stations, I exclude stations with abnormalities by comparing the relative difference between the single longest time period between two consecutive price quotes to the second longest time period, then the relative difference between the second longest time period to the third longest time period, and so on. I find a number of stations with one or, to a lesser extent, two abnormal periods without price quotes. In total, I exclude 353 stations, where the second longest time period between two price quotes is less than 10% of the single longest time period. Similarly, I exclude 16 further stations, where the third longest time period between two price quotes is less than 10% of the second longest time period (i.e., assuming two outliers). In other words, if the longest (or, second longest) period a station doesn't change its price is more than 10 times higher than the second longest (or, third longest) period, I consider this to be abnormal and invalid. Finally, I exclude 60 stations not quoting prices for more than a quarter of a year (assumed with 90 days). With these adjustments to raw data, I have 13,448 valid stations, which I use for my empirical analysis.

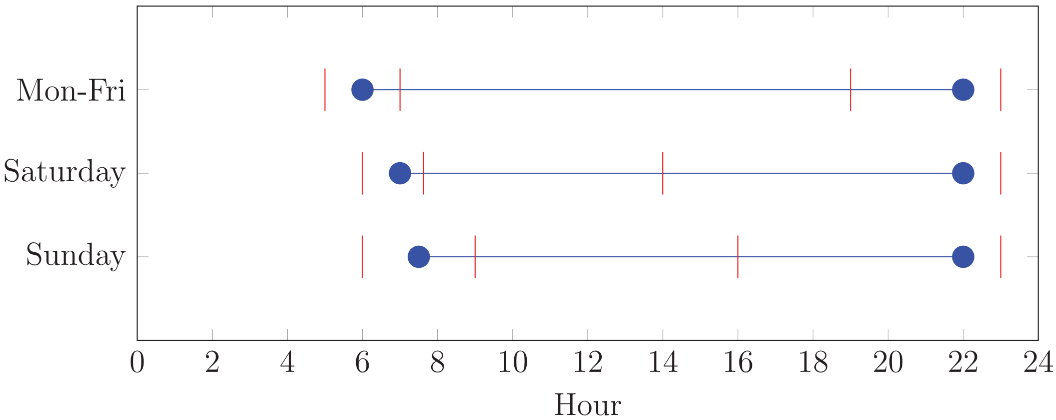
[32] 13,179 (95%) stations change prices at least every month (assumed with 30 days).

4.B Figures and Tables



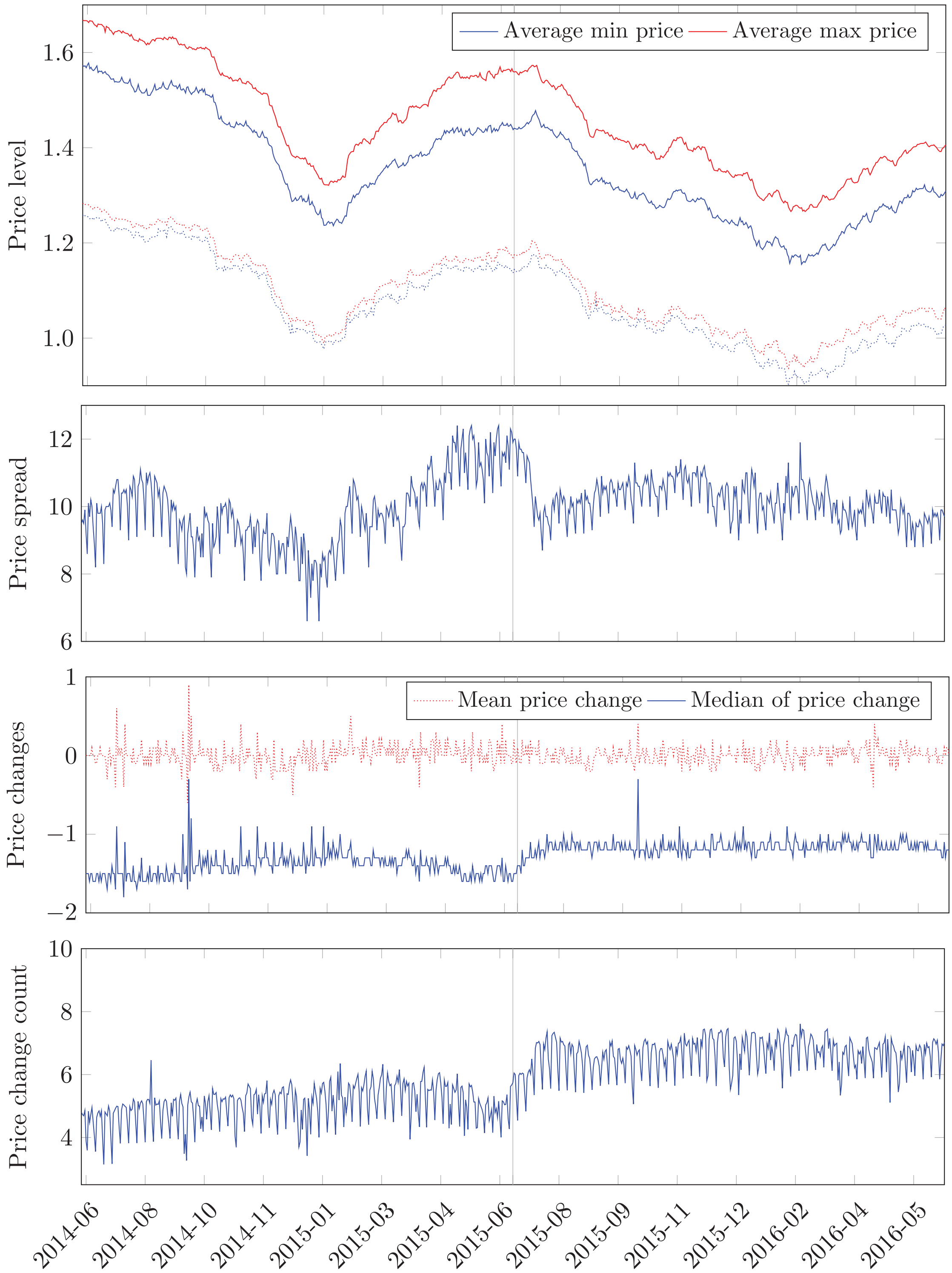
Note: Distribution of number of daily price quotes over two-year period of observation.

Figure 4.6: Daily Average Price Quote across Gas Stations



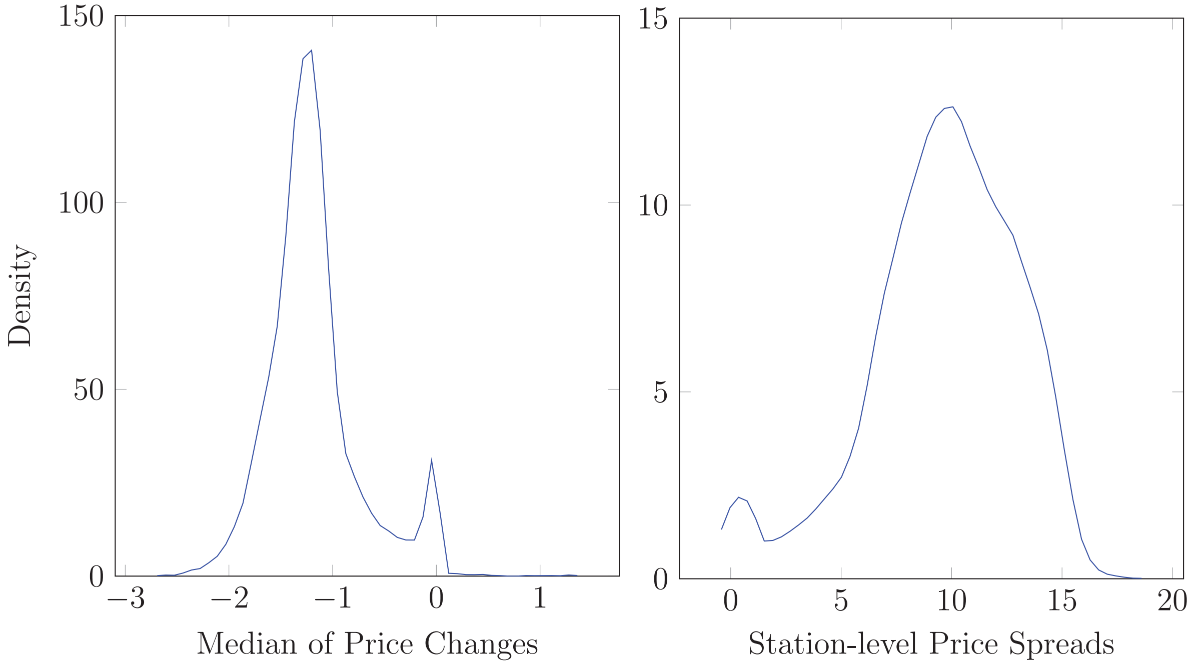
Note: Weekday-specific median (blue circles) as well as 10^{th} and 90^{th} percentiles (red vertical lines) of opening and closing times of all 8,263 gas stations (61% of total) with restricted business hours.

Figure 4.7: Overview of Business Hours



Note: Average across station-specific daily Super E5 retail min and max price levels (solid) as well as min and max refinery region's prices (dotted, in Euro/liter); daily average price spread (in Eurocents/liter); average of mean and median price changes (in Eurocents/liter); count of daily price changes averaged across all gas stations; vertical line indicates change of equilibrium price pattern (see Bundeskartellamt 2015, pp. 20-23).

Figure 4.8: Average Daily Station Statistics



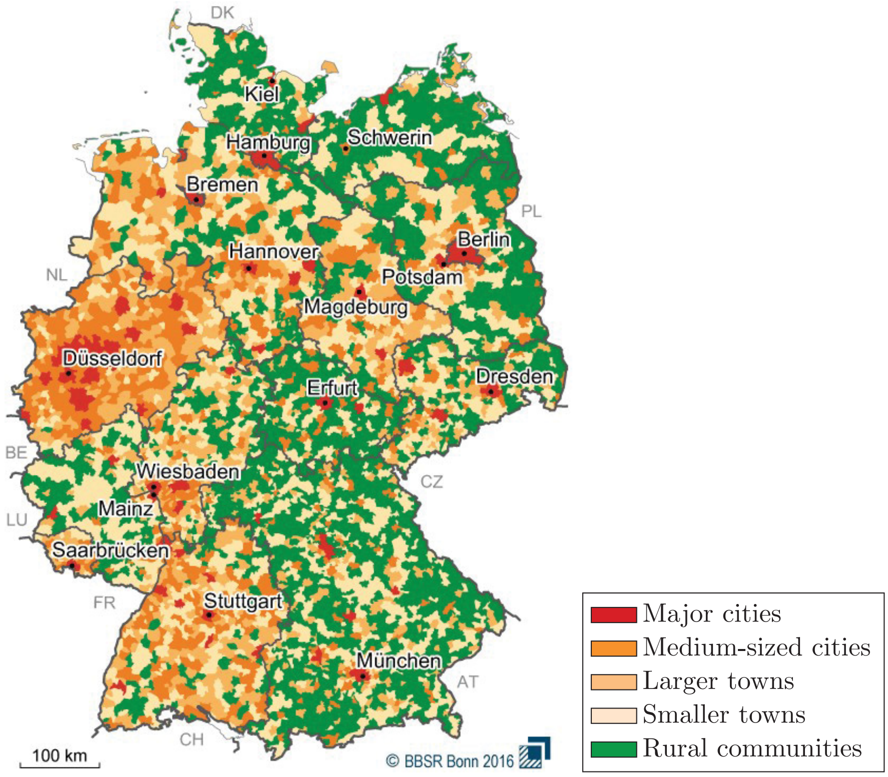
Note: Median of daily price changes and station-level price spreads in Eurocents/liter.

Figure 4.9: Kernel Densities of Price Cycle Metrics by Municipality

Table 4.4: Classification of Municipalities

Type	Classification min	Classification max	City count	Stations total	Stations avg.	Price spread	Price count	Median change
Major cities	100k		77	3,072	39.9	10.6	6.3	-1.29
Mid-sized cities	20k	100k	682	4,160	6.1	10.2	5.9	-1.25
Larger towns	10k	20k	943	2,551	2.7	10.1	5.7	-1.23
Small towns	5k	10k	1,376	2,224	1.6	9.3	5.3	-1.15
Rural areas		5k	1,202	1,441	1.2	9.1	5.3	-1.15

Note: Deviation from purely population-based classification possible based on city functions.
Source: BBR classification with MTS-K price and station data.



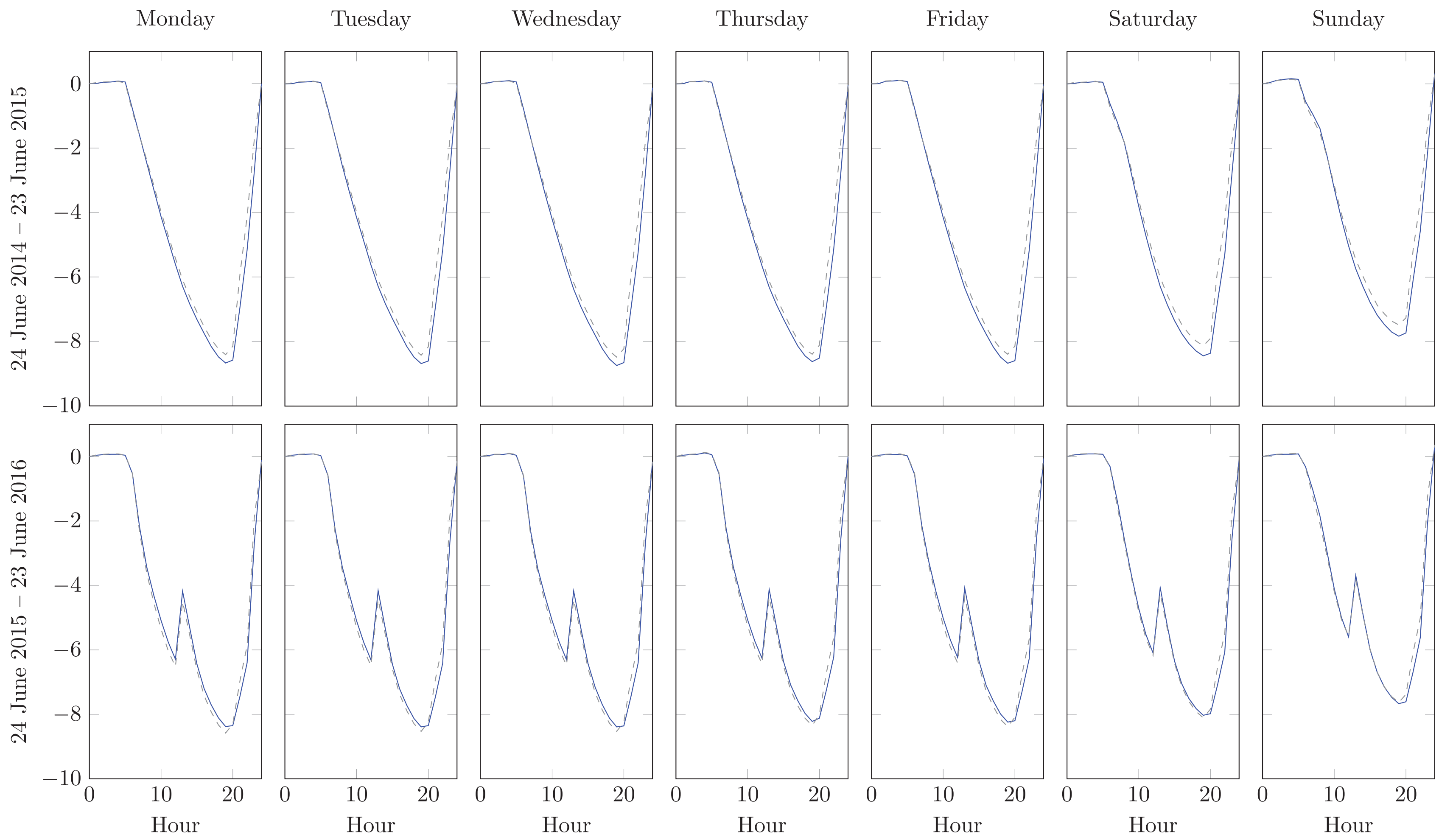
Source: Bundesamt für Bauwesen und Raumordnung (BBR)

Figure 4.10: Map of Municipality Types in Germany

Table 4.5: Regression of Minimum Price Start and End Time

Dependent variable:	Start time (1)	End time (2)
Non-major market share	-1.841*** (0.00)	0.071 (0.51)
Stations per km^2	4.367*** (0.00)	1.354*** (0.00)
Population per station ('000)	0.143*** (0.00)	0.087*** (0.00)
Weekday	0.833*** (0.00)	0.188*** (0.00)
Sunday	-0.439*** (0.00)	0.248*** (0.00)
Constant	13.812*** (0.00)	18.439*** (0.00)
State fixed effects	Yes	Yes
Number of observations	2,975,253	2,975,253
R^2	0.081	0.031

Note: Dependent variable in time of day;
robust p-values in parentheses (clustered by ZIP code areas).
Asterisks: Statistical significance at 1% (***), 5% (**), or 10% (*) level.



Note: Average deviation of individual gas station's price from the same station's daily starting price (at midnight) across all valid gas stations in Germany (point-in-time prices at full hour in Eurocents/liter shown). Sunday prices without stations closed on Sundays; deviations from stations open 24/7 dashed.

Figure 4.11: Average Weekday-specific Hourly Price Deviation

Chapter 5

Conclusion and Policy Implications

Competition and pricing on retail gasoline markets are highly debated topics in many countries around the globe, often associated with suspicions with regard to collusive behavior of market participants. With the introduction of the market transparency unit for fuel in 2013, prices of virtually all gasoline stations in Germany are fully transparent and can be compared in real time. In this dissertation, I have presented three empirical papers on salient features of retail gasoline markets, analyzing price data gathered by the MTS-K for a total of around 14,500 gas stations between January 2014 and June 2016. In addition to high-frequency retail prices, my analyses rely on a range of additional data points such as wholesale prices, specific characteristics of gas stations (e.g., opening hours, distances to other stations and refineries, availability of car washes and shops), and local market characteristics (e.g., commuter shares, local GPD).

In Chapter 2, *Fuel Prices and Station Heterogeneity on Retail Gasoline Markets* (co-authored by Justus Haucap and Ulrich Heimeshoff), we have investigated how and why average or point-in-time price levels as well as the number of price changes differ across stations in Germany. We showed that 80-90% of the price distribution can be associated to statistically observable station characteristics and wholesale price shocks, with ex-refinery prices being a good predictor of input cost changes (with a cost pass-through from gas station operators to consumers of around 90-100%). Stations located at highway service areas or associated to premium brands charge significantly higher prices (on average, +5.7 Eurocents/ liter or +2.5 Eurocents/ liter, respectively), albeit the exact price difference of individual brands varies (e.g., from +4 Eurocents/ liter surcharge at Aral and Shell stations to a non-significant difference observed at Jet stations vis-à-vis independent brands). In addition, certain brands seem to have distinct day- and nighttime pricing strategies as a reaction to local competition intensity. Moreover, additional service offerings positively affect price levels (by up to 3 Eurocents/ liter), while heterogeneity among local competitors appears to imply lower prices. Finally, stations offering gasoline as a "by-product" (e.g., supermarket-owned stations) have considerably lower prices, albeit opening hours are structurally different.

Chapter 3, *Selling Gasoline as a "By-Product": The Impact of Market Structure on Local Prices* (co-authored by Justus Haucap and Ulrich Heimeshoff), takes up a key finding of the previous chapter by focusing on typically low-priced station operators, for which gasoline is considered a secondary product to other retail operations (e.g., supermarkets, car washes). In a plausibly causal analysis on intraday pricing patterns, we used varying opening hours of stations selling gasoline as a "by-product" as an exogenous shock to local market structures. In light of typically step-wise decreasing prices during the day in the majority of markets, our analysis explicitly accounts for counterfactual market scenarios by applying a difference-in-difference framework. Our results show a statistically significant, negative price effect of gas stations selling gasoline as a "by-product" on nearby competitors. We specifically examined two supermarket players (i.e., Famila and V-Markt) as well as two car wash chains (i.e., Mr. Wash, CleanCar), covering a broad geographic area across Germany. Whenever a gas station associated to one of the supermarket or car wash chains is open, particularly major brand competitors show a downward price reaction beyond the typical pricing pattern.

In Chapter 4, *Characteristics, Causes, and Price Effects: Empirical Evidence of Intraday Edgeworth Cycles*, eventually, I have focused on analyzing high-frequency price cycles, which is rarely addressed in empirical literature. By introducing statistical indicators for cycle asymmetry (i.e., median of price changes) and cycle intensity (i.e., daily price spreads), I determined characteristics, causes, and price effects of intraday price cycles across municipalities in Germany. My empirical analysis proves the existence of intense price cycling during the day in most cities across the country, with only a few exceptions – predominantly in rural areas. Moreover, I provide a link between cycling and price levels during the day that illustrates the pro-competitive nature of price cycles. While the influence of cycling on price levels is ambiguous during high-priced times of the day (e.g., in the morning), I find a statistically significant price-lowering effect during low-priced times of the day (e.g., in the evening) across both random and fixed effects specifications.

Findings of this dissertation are highly relevant for the policy debate. First and foremost, the proven high level of pass-through from ex-refinery to retail prices is a sign of intense competition on the level of gas stations. My analysis has also shown that the distance to the closest refinery has an impact on prices; the additional distance to the second closest refinery, however, seems irrelevant. Secondly, parts of price differences among stations can be explained by factors determining product differentiation (such as additional service offerings like a larger shop or the presence of a car wash facility). Third, the intensity of local competition significantly impacts price levels. As my analysis revealed, the sheer number of gas stations in the vicinity is, however, less relevant than the heterogeneity of stations: A mix of independents and large brands in a local market seems most beneficial for competition. Fourth, gas station with a strong brand are able to impose higher prices, albeit brand-specific price premia vary.[1] For Jet, presumably one of the jointly-dominating oligopoly players, however, I could not identify a statistically significant price premium, even in contrast to smaller brands like OMV or AVIA. This finding speaks against the Federal Cartel Office's hypothesis of a five-player oligopoly (including Aral, Shell, Esso, Total, and Jet) but rather confirms the Düsseldorf Higher Regional Court's position against this assumption in a recent merger case (see, e.g., Monopolkommission 2014).

Fifth, the observed price premium at gas stations located on highway service areas of 5.7 Eurocents/liter, on average, or more than 9.0 Eurocents/liter in the evening hours, is a strong argument in favor of the Federal Cartel Office's definition of highway gas station as a separate market (Bundeskartellamt 2011, p. 13). Further, comparing gas stations at highway service areas with gas stations on regular roads showed that prices among the two groups converge during nighttime, when several regular gas stations are closed and competition, as a result, declines. The fact that stations located on highway service areas change their prices only half as often as all other gas stations provides supporting evidence on the competitive nature of frequent price changes. Sixth, I confirmed the pro-competitive nature of a higher cycle asymmetry and intensity including a price-lowering effect, which is most pronounced during evening hours. Finally, I showed that gas stations associated to supermarkets or cash washes are not only among the lowest-priced gas stations but also have a price-lowering effect on other gas stations in the surrounding during their opening hours. With this analysis, I provide evidence that independent players can exert competitive pressure on local price levels, also on market-dominating competitors.

In sum, I have drawn a comprehensive picture of the factors influencing retail gasoline prices and competition. Most important from a policy perspective is the

[1] While Aral's and Shell's prices are, ceteris paribus, around 4 Eurocents/liter higher than prices at independent stations, premia at Esso and Total are below 3 Eurocents/liter.

finding that competitive forces are, at least to a measurable degree, working, in contrast to suspicions sometimes voiced in policy circles. Consumer-oriented findings from this dissertation have been published in high-circulation newspapers BILD,[2] Frankfurter Allgemeine Zeitung,[3] and Focus Online.[4] Thereby, my dissertation has also contributed to reducing information asymmetries for end consumers with regards to factors influencing pricing patterns at gas stations in Germany.

Further research in the area of gasoline retailing could focus on one of the following areas. First, extending the observations to pre-MTS-K time periods on a comparably granular level (subject to data availability) would enable an assessment of the effect of price transparency on competitive economics, price levels, and price cycles (see, e.g., Dewenter, Heimeshoff, and Lüth 2017). Secondly, analyzing volume data in addition to prices would establish a link between supply and demand, and helps to explore realized prices in the presence of cycling markets (see, e.g., Hashimi and Jeffreys 2016; Haucap et al. 2017). Thirdly, refining theoretical foundations on Edgeworth cycles on an intraday level is possible (see, e.g., Eibelshäuser and Wilhelm 2016), similar to investigating other salient features of competition, such as the strategic role of opening hours (see, e.g., Kügler and Weiss 2016) and the specifics of border regions (see, e.g., Banfi, Filippini, and Hunt 2005). Fourth, while Frondel, Vance, and Kihm (2016) contributed a first analysis on price pass-through from crude oil to retail on the German market, further investigating this aspect, for instance focusing on the often quoted "rockets and feathers" phenomenon (from oil to refinery to retail) could be another interesting field to study. Moreover, a largely untapped area of empirical research includes questions around "margin squeeze" on gasoline markets (see, e.g., Anderson and Johnson 1999; Noel 2016).[5] Margin squeeze represents a situation where there is a narrow or even negative margin between a vertically integrated supplier's wholesale price (for a rival) and its own downstream price, making it impossible for a rival to compete. As large integrated oil companies (in Germany as in many other other countries) own relevant refinery

[2] "Tank-Report: Ist der Sprit an Feiertagen viel teurer?", BILD (10 April 2017), URL: `www.bild.de/bild-plus/geld/wirtschaft/politik-inland/ist-der-sprit-an-feiertagen-teurer-51241128.html`.

[3] "Preise für Benzin und Diesel schwanken immer stärker", Frankfurter Allgemeine Zeitung (11 August 2015), URL: `www.faz.net/aktuell/finanzen/devisen-rohstoffe/an-tankstellen-schwanken-benzinpreise-immer-staerker-13743603.html`.

[4] "Autobahn, große Ketten, freie Anbieter: Benzinpreis-Forscher zeigt, wann und wo man am günstigsten tankt", Focus Online (13 April 2017), URL: `www.focus.de/auto/videos/autobahn-grosse-ketten-freie-anbieter-benzinpreis-forscher-gibt-spar-tipps-so-nutzen-sie-den-wettbewerb-fuer-sich_id_6954292.html`.

[5] Beyond retail gasoline, margin squeeze has attracted researchers' interest on other markets, in particular on deregulated telecommunications markets (see, e.g., Gaudin and Saavedra 2014; Haucap and Heimeshoff 2009).

capacities and supply both their own as well as other (small chains, independent) gas stations, vertically integrated players might be in a position to suppress small chains or single independent stations.[6] Finally, economic effects of the price matching schemes newly introduced by Shell and HEM in 2015 could be subject to further analysis, as they may harm – or possibly spur – competition (see, e.g., Dewenter and Schwalbe 2016).[7] Under these pricing schemes, customers are offered a price guarantee, thus they face either a price equal to the cheapest competitor in the surrounding area (at HEM, in a 5 km vicinity) or a price of not more than +2 Eurocents/liter (at Shell, including the ten closest competitors).[8]

[6]See, e.g., Bräuninger, Leschus, and Matthies 2010; Bundeskartellamt 2009; Europia 2013 for discussions on the German refinery sector.

[7]Price matching schemes are already under scrutiny by the German Federal Cartel Office in other markets (see, e.g., Hamelmann, Haucap, and Wey 2015 for a study on the online hotel booking market).

[8]Shell offers registered users of their "Clubsmart" program an automated price reduction at the point of sale to a price of not more than +2 Eurocents/liter compared with the lowest price of the ten closest branded gas stations (by linear distance), irrespective of the price "at the pump" (see `www.shellsmart.com/smart/promotion?pId=1&site=de-de`). Similarly, HEM (in cooperation with price data provider "clever-tanken.de") offers so-called "clever-deals" at participating gas stations, comparing prices to all stations in a 5 km vicinity and matching the lowest price at the point of sale (see `www.clever-tanken.de/news/Start_HEM_Tiefpreisgarantie_2015`).

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Eidesstattliche Versicherung

Ich, Manuel Siekmann, versichere an Eides statt, dass die vorliegende Dissertation von mir selbstständig und ohne unzulässige fremde Hilfe unter Beachtung der "Grundsätze zur Sicherung guter wissenschaftlicher Praxis an der Heinrich-Heine-Universität Düsseldorf" erstellt worden ist.

Düsseldorf, der 31. Mai 2017: ________________________

Unterschrift