Empirical Essays on Energy Economics

Inauguraldissertation
zur
Erlangung des Doktorgrades
der
Wirtschafts- und Sozialwissenschaftlichen Fakultät
der
Universität zu Köln

2012

vorgelegt
von

Diplom-Kaufmann Stefan Thoenes

aus

Siegburg

Referent:	Prof. Dr. Felix Höffler
Korreferent:	PD Dr. Christian Growitsch
Tag der Promotion:	13. Juni 2013

Acknowledgements

I am very thankful to my supervisor Felix Höffler for his great support and guidance since he joined the Institute of Energy Economics at the University of Cologne (EWI). He gave me the opportunity to pursue the topics I am interested in, encouraged me to think deeply about the underlying economics and helped me to improve my papers in a very constructive way.

I would also like to express my gratitude Christian Growitsch, who supported me especially during the beginning of my dissertation and offered valuable feedback on each of my chapters. I am also very grateful to him for stimulating my interest in natural gas markets and initiating the collaboration with Sebastian Nick.

I would also like to thank Johannes Münster for agreeing to be the chair of the examination committee for the defense of my thesis.

My two co-authors, Timo Gores and Sebastian Nick, deserve special thanks for the great teamwork on our successful research projects. These collaborations were always characterized by a highly productive working attitude and a very cordial personal relationship. The importance of both aspects cannot be overstated and I am therefore deeply indebted to Timo and Sebastian.

Additionally, I would like to thank Marc Oliver Bettzüge, Hendrik Wolff, Heike Wetzel, Oleg Badunenko, Broghan Helgeson, Johannes Viehmann, Sebastian Kranz, Jörg Breitung, Caroline Dieckhöner, Kristian Dicke, Benjamin Tischler, Jürgen Kruse, Jeffrey S. Racine, Christiane Baumeister and Tino Berger for their helpful comments and suggestions. I am also grateful to R. L. Polk & Co. for kindly providing data on vehicle registrations in the United States, which was used in the second chapter.

Finally, I would like to thank both the institutions of the Cologne Graduate School and the EWI for providing financial support and a collaborative research environment, which I have very much enjoyed during the last three years. As institutions are made of people, I am grateful to everyone who crossed my paths within both institutions as they all contributed to the great atmosphere and stimulating discussions. In this context, I would also like to thank Dagmar Weiler and Marc Oliver Bettzüge for giving me the permission to do an internship at Google in Zurich, which was a great experience and contributed to my inspiration for the second chapter of this thesis.

The second chapter benefited from comments by the participants of the 39$^{\text{th}}$ Annual Conference of the European Association for Research in Industrial Economics (EARIE) in Rome, the Behavioral Environmental Economics Conference 2012 at the Toulouse

School of Economics, the 12th European Conference of the International Association for Energy Economics (IAEE) in Venice and the 12th Student Chapter Workshop of the German section of the IAEE (GEE) in Düsseldorf. I am thankful to the Verein für Socialpolitik and the Deutsche Bundesbank for their grant for presentations at major international conferences. Regarding the third chapter, I am grateful for the comments of the participants of the 13th Young Energy Economists & Engineers Seminar (YEEES) at the European University Institute in Florence. Concerning the fourth chapter, I would also like to thank the participants of the Energy & Finance Conference 2011 at the Erasmus School of Economics in Rotterdam and the participants of the International Ruhr Energy Conference 2012 at the University of Duisburg-Essen for their valuable feedback. All chapters of this thesis benefited from the helpful suggestions of the participants of the research seminar of the Institute of Energy Economics at the University of Cologne.

Contents

Acknowledgements **ii**

List of Figures **vi**

List of Tables **vii**

1 Introduction **1**
1.1 Motivation 1
1.2 Outline of the Thesis 5

2 Attention, Media and Fuel Efficiency **17**
2.1 Introduction 17
2.2 Hybrid Vehicle Market and Consumer Attitudes 20
2.3 Data 22
2.4 What Drives the Attention Devoted to Hybrid Vehicles? 25
2.5 Attention and Hybrid Vehicle Purchases 36
2.6 Conclusion 41

3 What Drives Natural Gas Prices? - A Structural VAR Approach **42**
3.1 Introduction 42
3.2 Data 45
3.3 A Structural VAR for the German Natural Gas Market 48
3.4 Results 52
3.5 Event Studies of Supply Interruptions: Historical Decomposition of Structural Shocks 56
3.5.1 The Russian-Ukrainian Gas Conflict of 2009 57
3.5.2 The “Arab Spring” and the Civil War in Libya 2011 59
3.5.3 Supply Interruptions of Russian Natural Gas Deliveries in February 2012 61
3.6 Conclusion 62

4 Understanding the Determinants of Electricity Prices and the Impact of the German Nuclear Moratorium in 2011 **64**
4.1 Introduction 64
4.2 Data 67
4.3 Semiparametric Varying Coefficient Model 69

4.4 Analysis of the German Nuclear Moratorium in 2011 74
4.5 Conclusion 79

A Supplementary Material for Chapter 2 **81**

B Supplementary Material for Chapter 3 **84**

C Supplementary Material for Chapter 4 **88**

Bibliography **91**

Curriculum Vitae **100**

List of Figures

2.1 Gasoline Price, Media Coverage and Attention Devoted to Hybrid Vehicles 34
2.2 Gasoline Price, Media Coverage and Attention Devoted to Fuel Economy 35
2.3 Gasoline Price, Attention and Registrations of Hybrid Vehicles 40

3.1 Responses of the Natural Gas Price 53
3.2 Historical Decomposition of Structural Influences During the Russian-Ukrainian Gas Dispute of January 2009 58
3.3 Historical Decomposition of Structural Influences During the Financial Crisis Following the Bankruptcy of Lehman Brothers on September 15$^{\text{th}}$, 2008 59
3.4 Historical Decomposition of Structural Influences During the Supply Shortfall After the Libyan Civil War in the Spring of 2011 60
3.5 Historical Decomposition of Structural Influences During the Russian Supply Shortfall in February 2012 61

4.1 Semiparametric Cointegration Parameter Estimates of Fuel Prices 71
4.2 QQ-plot of the Fit of the Semiparametric Model 72
4.3 Simulated Merit Order for Different Natural Gas and Carbon Price Scenarios 73
4.4 Base Electricity Futures Prices at the Time of the Announcement of the Nuclear Moratorium 74
4.5 Derivation of the Capacity Effect of the Nuclear Moratorium 76
4.6 Implied Capacity Effect of the Nuclear Moratorium 78

B.1 Plots of the Time Series Used for the Analysis 85
B.2 Responses of LNG, Storage and the Natural Gas Price 86

List of Tables

2.1 Average Monthly US Google Search Volume for Fuel Efficiency Related Terms . . . 23
2.2 List of Newspapers Used in the Analysis . . . 24
2.3 Panel Regression Results of the Impact of Local Media Coverage on the Interest in Hybrid Vehicles . . . 32
2.4 Panel Regression Results of the Impact of Local Media Coverage on the Interest in Fuel Economy . . . 33
2.5 Panel Regression Results of the Impact of Attention on the Registrations of Hybrid Vehicles . . . 38
2.6 Panel Regression Results of the Impact of Attention on the Market Share of Hybrid Vehicles . . . 39

3.1 Variable Definitions . . . 45
3.2 Identification of the Contemporaneous Matrix . . . 50
3.3 Lag Restrictions in the VAR Model . . . 51
3.4 Forecast Error Variance Decomposition for the Natural Gas Price . . . 55

4.1 The German Electricity Generation Portfolio by Technology . . . 68
4.2 Summary Statistics . . . 68

A.1 LexisNexis Database Search Queries for all Newspapers . . . 82
A.2 Summary Statistics . . . 83

B.1 Summary of Sources, Russian Supply Shortfall of February 2012 . . . 87

C.1 Augmented Dickey Fuller Unit Root Tests . . . 89
C.2 Johansen Cointegration Analysis of Electricity, Gas and Carbon Prices . . . 90

Chapter 1

Introduction

1.1 Motivation

In a globalized world, all sources of energy and their respective prices are interdependent. Hence, it is necessary to consider different types of energy commodities in a specific context in order to make a contribution to an overall view of the field of energy economics. This thesis deals with the dynamics of energy prices in different markets. In Chapters 2 to 4, three distinct essays each focus on one aspect regarding the price development of the energy commodities crude oil, natural gas and electricity.

Crude oil is the most relevant primary energy carrier, accounting for 33.1% of the total global energy consumption in the year 2011 (BP, 2012b). Therefore, the oil price and its development are very important for many stakeholders and it is not surprising that there exists a large literature on oil prices. Most studies, such as Kilian (2009) and Lippi and Nobili (2012), argue that the oil price development is caused by the interaction of different shocks, which may be aggregate macroeconomic shocks or oil market specific influences. For instance, Kilian and Hicks (2012) argue that the oil price increase of 2008, with crude oil prices exceeding 145 US Dollars per barrel, was mainly caused by an aggregate demand shock due to an unexpected strong economic growth in the emerging markets.

Similarly, the effect of oil prices on the gross domestic product and inflation has attracted a lot of interest. Since Hamilton (1983), it has often been argued that oil price shocks were at least a contributing factor for recessions. There is a myriad of studies investigating this relationship, but the general view on the topic is not conclusive. As discussed by Barsky and Kilian (2004), the timing of oil price shocks is consistent with the hypothesis that they coincide with recessions, but there is also evidence that oil prices are not the major factor influencing the macroeconomic development. Kilian and Vigfusson (2011) provide an overview about recent developments in the literature and argue that oil price shocks may have asymmetric effects on real output.

Especially the oil consumption within the transportation sector plays a predominant role in the oil market. Considering the United States, 71% of the crude oil consumption was used for transportation, while 23% of the oil consumption in the year 2011 was accounted for by industry (EIA, 2012).[1] Looking at the future of oil, the size and composition of the global vehicle stock will therefore have a large influence on the market outcomes. According to the Energy Outlook 2030 by BP (2012a), the development in the transportation sector, and especially the success in increasing fuel efficiency, is one of the three key determinants shaping future global energy demand. Better fuel efficiency of vehicles will be necessary, as vehicles sales are forecasted to increase by 60%. Hybrid vehicles are expected to be the major factor for improving efficiency, with a projected share of 56% of total global vehicles sales by the year 2030 (BP, 2012a). Mainly driven by the higher penetration of hybrid vehicles, the energy consumption in the transport sector is expected to increase by only 26% until 2030 (BP, 2012a).

However, in order to realize these ambitious forecasts, consumers need to adapt their purchasing behavior and switch from conventional combustion engines to hybrid vehicles. In Chapter 2, we therefore study the role of gasoline prices as a signal to induce consumers to switch to efficient technologies. The consumers' reaction to the signal of gasoline prices is a crucial determinant for the diffusion of fuel efficient vehicles. Taking a behavioral perspective, we focus on the information processing of how consumers perceive gasoline prices. In particular, we explore two channels which potentially affect consumers: They may either be directly affected by the observed development of the gasoline price or may rather respond to media coverage on the gasoline price and efficient technologies. Drawing upon the economics of limited attention, we argue that attention to new efficient technologies is a necessary condition for considering hybrid vehicles in a purchasing decision.

In the empirical analysis, we focus on the consumer behavior in the United States for two reasons. First, the regulation of automotive energy efficiency in the United States is not as strict as in the European Union or Japan (Anderson et al., 2011b). Second, consistent with the different regulation and the comparatively low gasoline prices, the United States are the largest consumer of crude oil, having one of the highest per capita consumption levels and accounting for 20.5% of the total world oil consumption in the year 2011 (BP, 2012b).

[1] Oil had a share of 93% of the total energy consumption in the transportation sector in the United States in the year 2011 (EIA, 2012).

The question of which determinants help to increase fuel efficiency is highly relevant for several reasons. First, the EIA (2012) estimates consumer expenditures for motor gasoline to be 377 billion US Dollars in the United States in the year 2010. Second, the transportation sector, with oil as the predominant primary energy carrier, constitutes 34% of the total carbon dioxide emissions of the United States.[2] Increasing the fuel efficiency of the vehicle fleet would therefore both decrease the fuel costs and have a positive environmental impact.

Next to oil, natural gas is the second most important primary energy carrier both in the OECD countries and in the European Union (BP, 2012b). While crude oil is a globally integrated market (see Bentzen, 2007), the natural gas market is often considered to be organized more regionally due to transportation restrictions and costs. However, the natural gas trade has gradually become more globally integrated as the importance of liquefied natural gas (LNG) increases. In the year 2011, about one third of the global international gas trade flows were LNG, while two thirds were transported via pipelines (BP, 2012b). There is also evidence that global gas prices reflect the increasing market integration (see Neumann, 2009).

Given the increasing similarities between oil and gas markets, we argue that it is meaningful to employ modeling techniques similar to the standard for modeling oil prices. In the third chapter, we therefore develop a structural vector autoregression model for the natural gas market, which allows us to disentangle the different fundamental influences affecting natural gas prices.

We focus on the continental European market, which is an interesting setting to analyze the impact of politically induced supply interruptions. The production of crude oil and natural gas is strongly dependent on politically vulnerable regions. The Middle East accounted for 32.6% of the global oil production in the year 2011 (BP, 2012b). For natural gas, Russia accounted for 18.5% of the total global production, while the Middle East constituted 16.0% and Africa 6.2% (BP, 2012b). The political issues related to countries supplying natural gas to the European market had a significant influence on energy prices and the security of supply. In this context, gas transit issues with Ukraine and political risks associated with Russia and Northern Africa played a major role. Our approach regarding supply shortfalls is similar to Kilian (2008), who analyzes the oil price effect of exogenous political events in the Middle East.

In particular, we consider the price formation during three recent supply interruptions, namely the Russian-Ukrainian gas dispute of January 2009, the Libyan civil war in 2011 and the shortfall of Russian gas deliveries in February 2012. For example in February

[2]Source: United States Department of Energy, "Emissions of Greenhouse Gases in the United States 2009", DOE/EIA-0573(2009), Figure 3, U.S. energy-related carbon dioxide emissions by sector, 2009.

2012, the natural gas price increased sharply, but it remained unclear to which extent this price spike was driven by extraordinarily low temperatures, supply disruptions from Russia or uncertainty about future natural gas supplies. By decomposing the historical structural shocks during this situation, we are able to show that the observed price spike was mainly caused by the cold weather, while the supply interruption was only a contributing factor. In addition to the discussion about the security of supply, our approach reveals new insights into the formation of gas prices at the liberalized continental European gas hubs.

Understanding the determinants of the natural gas price is important because natural gas is used for many purposes. The main applications are in the residential and commercial heating sector, in industrial production processes and in electricity generation. Therefore, the natural gas price also directly affects the electricity price.

However, the relationship between the commodities used for electricity generation and the price of electricity is complex and highly nonlinear. The relationship depends on the technology used for generating electricity, which may be different depending on the level of demand that has to be satisfied by thermal power plants. Due to the fact that electricity cannot be stored at reasonable costs, the supply and demand have to be matched at any moment of time. Therefore, the power plant portfolio consists of several technologies, such as coal fired power plants or combined cycle gas turbines, which have different characteristics regarding their cost structure.

It is difficult to properly account for the composition of the power plant portfolio when modeling the relationship between the prices of inputs, such as natural gas, and the price of electricity. Following the idea that the relationship between fuel prices and the electricity price depends on the current level of demand, Chapter 4 suggests a semiparametric econometric approach to allow for this kind of flexibility. The model is used for an empirical analysis of the price determinants in the German electricity market.

However, when looking at the price formation in this electricity market, especially the unexpected change of the German nuclear policy was a pivotal event affecting the market. On Friday, March 11^{th}, 2011 a disastrous earthquake and tsunami damaged the nuclear power plant in Fukushima, Japan. This nuclear accident triggered a new global discussion about the benefits and risks of nuclear power generation. Following the events in Japan, the German government decided to put the so-called nuclear moratorium in place, which immediately led to the temporary closure of eight nuclear power plants.

After the announcement of this unprecedented policy intervention, the German electricity futures prices rose sharply. This exogenous political intervention makes it possible to perform an event study to test the hypothesis of information efficiency in the electricity market. Following the definition of Malkiel and Fama (1970), the analysis focuses on the semi-strong form of market efficiency, i.e. that prices reflect all publicly available information.

It is the aim of Chapter 4 to determine whether the increase in the electricity price reflects the underlying change of the power plant portfolio, implying that the market reacts efficiently to new information. Furthermore, futures prices are used to measure the market's expectations for the time after the official end of the moratorium, which was initially imposed for a three-month period.

1.2 Outline of the Thesis

This thesis consists of three distinct essays, which each discuss different aspects of energy prices. In Chapter 2, we begin with the implications of changes in the price of crude oil. We focus on the demand side and in particular on the diffusion of energy efficient technologies. In our empirical analysis, we show how changes in the gasoline price affect the consumers' attention and search behavior in the hybrid vehicle market. This chapter is based on the working paper by Thoenes and Gores (2012). Both authors contributed equally to all aspects of the essay.

While Chapter 2 discusses the effect of gasoline prices on consumer behavior, the following two chapters focus on the determinants and formation of energy prices. Chapter 3 discusses the price formation at the liberalized continental European natural gas hubs and puts a particular focus on the effect of three recent interruptions of gas imports from Russia and Libya. This chapter is based on the working paper "What Drives Natural Gas Prices? - A Structural VAR Approach", which is a joint work with Sebastian Nick, who co-authored the study and contributed to all aspects of the essay in equal parts.

Considering the European energy markets, especially the political influence on the electricity market was an important factor in the recent years. Chapter 4 therefore analyzes the German Nuclear Moratorium in March 2011, which had a distinct impact on the electricity market and can be seen as a turning point of the national energy policy. This chapter is based on the working paper by Thoenes (2011), which is single-authored.

To summarize, three different aspects of energy prices are analyzed. Chapter 2 treats how consumers as end-users react to energy prices. In the third chapter, the price determinants and dynamics of a primary energy carrier are modeled. Finally, Chapter 4 discusses the pricing mechanism of a secondary energy carrier with a special focus on an event study of a political intervention affecting the market.

In the following part of the introduction, the research question and methodology of each of the three chapters are outlined. Furthermore, the results and possible caveats of the chosen approaches are discussed.

In Chapter 2, we analyze the drivers of the consumers' attention devoted to fuel efficiency and environmental friendliness when purchasing a vehicle.

The relevance of attention in an economic decision is based on the capacity model of attention by Kahneman (1973), assuming that the total amount of mental effort a person can exert is limited. Therefore, a person's attention has to be divided between competing activities requiring a certain amount of attention. The theory suggests that the processing of information is a limiting factor in a consumer's purchasing decision. The relative importance of these cognitive limitations is assumed to rise with the complexity of the decision, which depends on the number of possible choices or products, the number of relevant product characteristics and the difficulty to assess each option. In this context, Gabaix et al. (2006) show in a laboratory experiment that a model of costly information acquisition, consistent with scarce cognitive resources, performs well in predicting the observed behavior. Also other studies, such as Da et al. (2011) and Masatlioglu et al. (2012), highlight that attention plays an important role in a purchasing or investment decision process.

The fuel efficiency of cars is an interesting setting for the analysis of attention effects as consumers often do not consider a vehicle's fuel consumption as one of the relevant product characteristics in their purchasing decision (see Allcott, 2011) or are unable to correctly evaluate the costs and benefits of better fuel efficiency (see Turrentine and Kurani, 2007). These results in the literature highlight that the decision is highly complex and consumers may be limited by their cognitive abilities.

If the consumers' attention is considered to be a relevant factor in economic decisions, it becomes a crucial question how attention can be measured consistently and which factors cause the attention to fluctuate. In this context, we employ the observable online search behavior as a reasonable proxy of revealed attention. We argue that the search behavior mainly depends on two different channels. First, the gasoline price determines the profitability of an investment in fuel efficiency and is therefore obviously a relevant factor. Second, we argue that media coverage has a distinct influence in drawing attention to a certain topic, in line with the agenda-setting theory of McCombs and Shaw (1972).

In order to empirically analyze whether media has an effect on the consumers' attention to fuel efficient vehicles, we create quantitative measures of a wide range of newspaper and television news coverage. In total, our media coverage variables capture about 40,000 relevant articles in the largest newspapers in the United States as well as approximately 1,000 evening news segments of the four major US television broadcasting networks. However, if only the current level of media coverage and attention are observed, there is an identification problem: Does media coverage itself increase the consumers' attention or do consumers merely react to the underlying event that was reported? The ideal procedure would be to control for the underlying event and then vary only the media exposure for a randomly assigned treatment and control group. In this case, the difference in the subsequent reactions of both groups is consequently the treatment effect of media coverage. In order to estimate the effect of media coverage on attention levels in a setting with only observational data available, one needs a proper identification strategy to disentangle the effect of media coverage from the underlying event.

One option would be to use an instrumental variable approach, which allows to account for the problem of the simultaneity bias arising from an ordinary least squares estimation. This approach requires a properly chosen instrument, which needs to be correlated with the endogenous explanatory variable, but may not be correlated with the error term of the regression equation to be estimated. One application of this method in the context of media coverage is given by Eisensee and Strömberg (2007), who introduce the instrument "news pressure". This measure is derived from the length of the top news segments of the television evening news, which is a proxy for relevant news-worthy material. The intuition of this instrumental variable is based on the fact that important news (e.g. terrorism, war or general elections) are able to crowd out news coverage on the topics of interest, which in our study are fuel efficient technologies or gasoline prices. In this case, the occurrence of highly relevant events is exogenous to the event of interest, but affects the probability that the event of interest is covered by media as the total time of news broadcasts is limited. However, in our setup, this approach suffers from the weak instrument problem, as described by Bound et al. (1995), which means that the instrument only explains a small fraction of the variance in the first stage regression and the resulting estimates in the second stage are severely biased and may also be inconsistent.

Therefore, we implement an identification strategy which is similar to Engelberg and Parsons (2011) and exploits the variation in local news coverage for different geographical regions. Thus, the analysis in Section 2.4 is based on weekly panel data consisting of Google online searches, local newspaper coverage and gasoline prices for 19 metropolitan areas in the United States. Our technical approach is an approximation of the treatment and control group setting described above. In this setup, we explain the variation of local search behavior with local newspaper coverage and other control variables. We partially control for the underlying event by including gasoline price changes, national media coverage and year-fixed effects. We also control for time-constant characteristics of the metropolitan areas by using region-fixed effects. Then, we additionally include all individual local newspapers in each and every panel, which means that each local newspaper is allowed to have a spillover effect on all other regions. The local newspaper variable now captures the supplemental effect of a newspaper in its own local region compared to the effect on the other regions.

Panel data methods are usually designed for samples with a large number of individuals and a small number of time periods. In contrast, the panel data sets used in this chapter are characterized by a "large" number of time periods and a "small" number of geographical regions. As the number of time periods in the sample gets larger, modeling the serial correlation of the error process is of importance. Thus, additionally to ordinary least squares estimates with clustered standard errors, we use advanced panel estimation methods and inference, which are specifically designed for setups similar to ours. The main results are robust for the different procedures used. First, we employ a Prais-Winsten type feasible generalized least squares estimator with a panel-specific first-order autocorrelation structure and panel-corrected standard errors. Second, we also use Driscoll and Kraay (1998) standard errors accounting for general forms of cross-sectional correlations, autocorrelation and heteroskedasticity. The implementation of this estimator and its finite sample properties are further discussed by Hoechle (2007). These standard errors are suitable for situations with geographical regions having spatial correlations, such as in our setup with metropolitan areas and states.

Our results indicate that the gasoline price is a strong determinant of the consumers' attention to hybrid vehicles. Furthermore, especially unprecedented record gasoline prices have a distinct effect on attention levels. This finding can be explained by the theory of reference-dependent consumer choice, which was introduced by Tversky and Kahneman (1991). If consumers are loss averse and perceive a price increase above their reference point as a loss, their reaction will be stronger. We argue that the last historical record gasoline price serves as such a reference point for consumers.

We also find that local newspaper coverage on fuel efficient technologies and hybrid cars has a positive causal effect on the attention to hybrid vehicles. However, the influence of media is generally expected to be limited if consumers are aware and well informed about a specific topic. Hybrid vehicles are a relatively new technology, indicating that consumers can be assumed to be less informed and have no direct experience with the technology. In a supplementary analysis, we consequently extend the analysis of media effects to the more general topic of fuel economy and newspaper coverage of gasoline prices. Consumers observe the gasoline price regularly at the gas station and should therefore be well informed about the current price level. Our results show that there is a strong correlation between newspaper coverage on gasoline prices and search volumes for fuel economy. Nevertheless, we do not find a causal effect of news coverage for this setting with informed consumers. Apart from analyzing the effect of media coverage, we show that the attention to hybrid vehicles and fuel economy fluctuates strongly and systematically. Our findings suggest that both consumers and media react mostly to steep gasoline price increases and record gasoline prices.

In order to validate whether our measure of attention is relevant for the purchasing decision, we test if there is a robust relationship between search volumes and hybrid vehicles registrations. The analysis in Section 2.5 is based on monthly state-level panel data of hybrid vehicle registrations and market shares, online searches, gasoline prices and national media coverage. Our results indicate that search volumes are robustly related to sales data using a variety of specifications, control variables and fixed effects.

Our findings in this chapter have implications for both policymakers and firms. As it is a political goal to foster the diffusion of fuel efficient technologies like hybrid vehicles, informational campaigns may be a valuable tool to increase the consumers' awareness of such technologies. Currently, the main initiatives focus on monetary incentives. However, these monetary incentives, such as income tax rebates, are not very cost effective as shown by Beresteanu and Li (2011).

The finding that the consumers' attention has a fluctuating nature results in implications for car manufacturers. Depending on the current level of attention, marketing for hybrid vehicles could for example focus either on raising awareness in times of low interest or on providing information when consumers already pay attention. The interaction of revealed consumer attention and firms' marketing efforts are an interesting area for future research.

One limitation of this study is that our results regarding the causal influence of media on the consumers' search behavior is only as valid as our identification of the effect. Given that we analyze a highly complex setting involving endogeneity and simultaneity of the different variables, the causal interpretation of the influence of media is not without caveats. However, the descriptive and empirical results of our study are very robust, showing that both consumers and media do not react symmetrically to the gasoline price development. They rather respond to sustained periods of increasing gasoline prices and unprecedented record gasoline prices.

To summarize, we find that attention effects play a relevant role for the diffusion of new energy efficient technologies such as hybrid vehicles. Despite the fact that media coverage seems to influence the consumers' attention, the development of the gasoline price is the major determinant of the fluctuations in the search behavior.

After the analysis of consumer behavior related to the development of the gasoline price, we turn to the natural gas market in the next chapter. In the OECD countries and the European Union, natural gas is the second most important primary energy carrier after crude oil (BP, 2012b). Therefore, we attempt to improve the understanding of which factors influence the price development in natural gas markets.

In Chapter 3, we develop an econometric time series model for natural gas markets, which is suitable to analyze which factors are relevant for the price formation at the liberalized continental European natural gas hubs. In particular, we focus on Germany, which was the largest European natural gas importer in the year 2011 (BP, 2012b). However, due to our modeling choices and the high amount of European market integration, this approach provides new insights into the whole continental European natural gas market.[3]

In order to account for the endogeneity of the different variables in our setup, we employ a structural vector autoregressive (VAR) approach, which has its origins in macroeconomic analysis and was introduced by Sims (1980). Our model includes variables accounting for meteorological influences, natural gas supply disruptions, crude oil prices, coal prices, liquefied natural gas (LNG) imports, natural gas storage and natural gas prices. We use a weekly data frequency in order to be able to consider short-term influences of weather or supply interruptions.

One potential drawback of our empirical approach is that we have to make several assumptions about the data included in our model. First, due to our econometric approach, we have to abstract from the local gas infrastructure conditions and the existing pipeline structure. Second, for the calculation of the volumes affected by the three supply interruptions, we can only rely on our own estimation. However the data was collected from a range of different sources and evaluated with due diligence. Furthermore, our estimates were cross-checked with estimates from the literature and alternative sources.

The VAR approach allows us the historical decomposition of structural shocks in order to investigate the transmission channels and the price impact of gas supply interruptions like the Russian-Ukrainian natural gas dispute in the year 2009. Furthermore, the forecast error variance decomposition within a structural VAR model provides insights into the relative importance of the economic influences affecting the natural gas price over different horizons. Vector autoregressive models are frequently used for the modeling of energy markets, such as the well-known structural approach of Kilian (2009) for the crude oil market. The main advantage of these models is that they are able to properly account for the dynamic interdependencies of the underlying economic influences. While reduced-form VAR models are mainly useful for forecasting exercises, the structural

[3]For example, Robinson (2007) and Growitsch et al. (2012) show that the development of European natural gas prices indicates a high level of market integration.

approach delivers sound economic interpretations. However, this advantage comes at the cost of imposing identifying assumptions, which need to be plausible in order to derive meaningful results. Stock and Watson (2001) provide a detailed discussion about the strengths and weaknesses of the VAR methodology.

Within a structural VAR framework, the impulse response analysis is the main tool for tracking the influence of one variable on other variables in the system. In the reduced form of the VAR model, the variance-covariance matrix is non-diagonal, which means that it is not possible to analyze the impact of a shock in one variable alone. Therefore, the reduced-form model has to be transformed to the structural form, in which the variance-covariance matrix is diagonal, i.e. the structural error terms are not correlated. The impulse response is then the dynamic sequence of the change in one variable as the response to a one-time structural shock of another variable.

The response of the natural gas price to shocks of the included variables is consistent with economic theory. Extraordinary cold temperatures lead to increased gas prices due to a higher demand for gas in the heating sector. Similarly, a supply interruption leads to higher prices as the missing volumes have to be replaced by more expensive suppliers. Furthermore, there may also be scarcity effects driven by physical constraints. Shocks of the amount of imported LNG do not seem to have an impact on natural gas prices. This result may be caused by the fact that LNG does not yet have an important impact on the German market or by the fact that we have to use interpolated LNG imports as only monthly import data is available. The responses of the natural gas price to structural shocks in oil and coal prices are positive, indicating that increasing prices of other energy commodities also lead to rising natural gas prices.

Our results emphasize that it is important to allow for the interaction of the behavior of natural gas storage operators and gas prices, which is consistent with liberalized markets and efficient storage behavior. We find that a structural shock of storage, which can be interpreted as an additional storage injection or lower storage withdrawal than expected, leads to rising prices. Reversely, structural price shocks, which are price increases that cannot be explained by the fundamental variables in the model, lead to storage withdrawals as they induce storage operators to sell natural gas.

Our results of the decomposition of the forecast error variance show that supply disruptions and extraordinary temperatures have a strong effect on the German natural gas price, accounting for 34% of the forecast error variance for a horizon of one week. However, while these influences are rather short lived, crude oil and coal prices determine the long-term gas price development and account for 65% of the forecast error variance with a horizon of one year. This finding is driven by the fact that crude oil and coal prices account for the energy specific demand in our model.

Both the impulse response analysis and the decomposition of the forecast error variance of the natural gas price show that coal prices seem to be more relevant in explaining the development of the natural gas price compared to crude oil prices. This finding challenges the focus in the literature on the relationship between oil and gas prices, such as for example by Hartley et al. (2008) and Brown and Yücel (2008). Ramberg and Parsons (2012), however, also argue that crude oil prices are only able to explain a small part of the development of natural gas prices in the United States.

The proposed model is used for a historical decomposition of the price impact of the different structural shocks during situations of supply interruptions. The price impact of the Russian-Ukrainian gas dispute, resulting in major supply disruptions in January 2009, was partially offset by the negative price impact of the coinciding financial crisis and economic downturn. Our model indicates that a supply shortfall of this magnitude leads to a price increase of more than 30%. In contrast, the price increase during the supply disruption driven by the Libyan civil war in the spring of 2011 was rather moderate. The gas price increased by less than 15%, which can be decomposed to a direct effect of about 5% of the supply shortfall and an effect of up to 10% which was driven by precautionary demand. This demand for additional gas storage was probably driven by fears that the “Arab Spring” could spread to more important natural gas suppliers such as Algeria. Regarding the Russian supply disruptions in February 2012, our model suggests that the extremely low temperatures had a stronger impact on the observed price increase compared to the supply shortfall.

In summary, the impact of supply interruptions in the natural gas market has to be assessed with care. Due to the simultaneity of different supply and demand influences during the periods considered, the observable change in the gas price is not necessarily caused by the supply interruption itself. Our results also highlight that political events have a distinct impact on natural gas prices, but the importance of such interruptions for the general price development seems to be limited and should therefore not be overstated. However, for large and sustained supply interruptions, this conclusion would probably not hold as storage operators and alternative suppliers may not be able to compensate a prolonged shortfall of imports.

Considering the continental European energy markets, not only the natural gas supply was affected by political influences. Also the electricity sector was subject to major changes in regulation due to the political goal of decreasing the carbon emissions in the European Union by 20% until the year 2020 (Capros et al., 2011). In order to achieve this ambitious goal, the main policy instrument is an emission trading system, which was introduced in 2005 (Ellerman and Buchner, 2007). With this system, carbon emissions by electricity generators and in several other sectors have to be met with certificates, which are freely traded on exchanges.

In addition to these long-term goals and regulations regarding the European electricity market, especially one unexpected policy intervention had a pivotal impact. As a reaction to the nuclear accident in Fukushima, the German government decided to put an immediate nuclear moratorium in place, directly affecting eight nuclear power plants. This moratorium occurred at a time, when the security of electricity supply was already controversial due to the increasing capacities of intermittent electricity generation from renewable energy sources (Grave et al., 2012).

In Chapter 4, I analyze how the German electricity market reacted to the announcement of the nuclear moratorium in March 2011. In this context, the announcement of the nuclear moratorium can be seen as an unexpected and exogenous event, which allows to determine how efficiently information is processed in the liberalized electricity market. The event study in this chapter draws upon a large body of literature in finance, analyzing how asset prices respond to new information. Starting with Fama et al. (1969), the event study methodology has been frequently used to measure the impact of a specific event during a well-defined and short event window.

The analysis in this chapter consists of two steps. First, a model has to be specified in order to analyze the electricity market in general. This model serves as a benchmark to evaluate the development of the electricity price during the event window around the announcement of the nuclear moratorium. As electricity prices are closely tied to the prices of the input fuels, the price development of electricity cannot be analyzed separately. In the second step, the model can be used to evaluate the market's reaction, i.e. the change in electricity prices.

Due to the fact that electricity cannot be stored at reasonable costs, the supply and demand need to be balanced at any point in time. However, as the demand is seasonal and highly fluctuating, the power plant portfolio generally consists of several kinds of power generation technologies, which have distinct characteristics regarding their cost structure. As these technologies use different primary energy carriers, such as coal or natural gas, the marginal costs depend on the price development of the fuel used for electricity production. Therefore, the relationship between input fuel prices and electricity prices depends on the respective marginal fuel used at a certain point of time, which is typically natural gas for peak demand.

I suggest to use a semiparametric approach as a novel approach to model the German electricity supply and estimate the relationship between daily prices of electricity, natural gas and carbon emission allowances. The modeling choice of a semiparametric smooth varying coefficient model, which was introduced by Hastie and Tibshirani (1993), is driven by the idea to account for the described nonlinearities of the merit order of electricity supply. This model estimates the parameters of the fuel price sensitivity as a flexible function of the residual load. For example, the approach allows the reaction of the electricity price to an increase in the price of natural gas to be different for situations with a high load compared to situations with a lower load. Cai et al. (2009) and Xiao (2009) show that the semiparametric estimation procedure is also suitable for cointegrated variables. This property is relevant for the proposed setup as pretesting methods indicate a cointegration relationship between natural gas prices, carbon emission allowance prices and electricity prices. The importance to account for the nonlinear characteristics of input fuel prices and electricity prices is also highlighted by Zachmann (2012), who introduces a stochastic fuel switching model estimated with a Markov switching regression.

The smooth coefficient model is able to resemble the underlying power plant portfolio and indicates a technology switch from coal to gas fueled power plants at approximately 85% of the maximum residual load. This point is at around 60 gigawatt (GW) load of average daily peak generation, which is consistent with the actual German power generation capacities. The estimated input price sensitivities indicate that an increase of natural gas and carbon emission allowance prices of 1% leads on average to an increase in electricity prices of 0.75% for off-peak, 0.84% for base and 0.91% for peak load hours. These estimates suggest that fuel cost changes are passed through and are consistent with the findings in the literature.

In the second step, the semiparametric model is used for an event study of the German nuclear moratorium. On Monday, March 14^{th}, 2011 the German government announced that eight nuclear power plants had to be shut down immediately and for a period of three months. Following this announcement, the futures prices of electricity, natural gas and carbon emission allowances rose significantly. Theoretically, there are two effects that influence the electricity futures price: First there is a capacity effect of the removed nuclear electricity generation. Second, there is a fuel price effect as natural gas and carbon emission futures reacted as well. The semiparametric model is capable to disentangle both effects during the period of interest.

The results show that the market directly and efficiently reacted to the policy intervention as the estimated capacity effect had approximately the correct size and occurred immediately after the announcement. In the following trading days, the capacity effect diminished slowly to a stable level. The level of the persistent capacity effect was probably driven by the development of sound market expectations regarding the possibility of dynamic adjustment effects such as an increased flexibility of the power plant portfolio or international transmission. Furthermore, the futures contracts for the period after the official end of the moratorium suggest that the market expected an extension of the moratorium, which later turned out to be the actual policy decision.

One caveat of the analysis in Chapter 4 is that the results regarding the analysis of the nuclear moratorium depend on the modeling choice of the electricity market. The goal of the model proposed in this chapter is to account for the nonlinearities in the relationship between input fuel prices, residual load and electricity prices. However, different approaches to model the electricity market may lead to different results. This problem of the event study methodology is well known in the finance literature and thoroughly discussed by Dyckman et al. (1984) and Armitage (1995).

The approach used in this chapter is based on the assumption that spot prices and futures prices are closely tied by their common fundamentals of the electricity market equilibrium. Due to the limited storability of electricity, the futures prices serve as expected spot market prices. Concerning the link between spot and futures, several studies such as Viehmann (2011) and Longstaff and Wang (2004), find that there may exist biases for some hours. However, these biases are relatively small and have a different sign, being either positive or negative, depending on the hour considered. Therefore, if there is still such a bias for monthly, quarterly or yearly futures contracts, the bias is expected to be small and will therefore not affect the main conclusions in this chapter.

In comparison, an analysis of the impact of the moratorium using only spot prices is not very fruitful due to the following reasons. First, the price volatility in the spot market is rather high, possibly interfering with the real effect. Second, the amount of electricity generation capacity affected by the moratorium is well within the fluctuation of electricity generated by renewable energy sources. As argued by the European Commission (2011), at the time of the announcement of the moratorium, the availability of electricity production from renewable energy sources was rather high and therefore, the influence of the moratorium on the spot market was limited. Third, when only considering the spot market, it is not possible to measure the market's expectations for the time after the initial three-month period of the moratorium.

Analyzing only the futures market does not allow to link the observed price development to capacity effects. However, the results of a recent study by Fritz (2012), who analyzes the futures market, are consistent with the findings in Chapter 4. Using a vector error correction model for electricity, natural gas, coal and carbon emission allowance futures prices, Fritz (2012) finds an immediate price increase in the electricity price that cannot be explained by fuel price increases. The unexplained fraction of the increase in the electricity price is of a similar magnitude as the effect found in Chapter 4 and represents the capacity effect.

Chapter 2

Attention, Media and Fuel Efficiency

2.1 Introduction

The emissions of motor vehicles are one of the major sources of greenhouse gas emissions leading to climate change. For example, in the United States, the transportation sector accounts for 34% of the carbon dioxide emissions.[4] These emissions could be decreased with improved technologies that offer a better fuel efficiency.[5] For this reason, it is crucial to understand which factors are relevant for the diffusion of fuel efficient technologies.

We argue that the consumer purchasing decision process and the question when consumers are willing to invest in fuel efficiency play an important role in this context. As Allcott (2011) indicates, 40% of US consumers do not consider a vehicle's gasoline consumption when purchasing a car. Therefore, the amount of attention devoted to energy efficient vehicles and fuel costs should be a major determinant for the diffusion of new technologies. Following this rationale, we attempt to capture the dynamics of the consumers' attention to hybrid electric vehicles.[6] However, attention is not directly observable and thus, finding an adequate measure for attention is challenging. We make use of Google's search query data as a direct and observable proxy for the revealed

[4]Source: United States Department of Energy, "Emissions of Greenhouse Gases in the United States 2009", DOE/EIA-0573(2009), Figure 3, U.S. energy-related carbon dioxide emissions by sector, 2009.

[5]The fuel economy of a vehicle is defined as the output (miles) per input (gallons of gasoline). In contrast, fuel efficiency, as a form of thermal efficiency, is the ratio of energy used for propulsion compared to the total amount of energy consumed. Thus, a small vehicle with a high fuel economy could still be less fuel efficient than a larger vehicle with a lower fuel economy, e.g. because a vehicle with a heavier weight also requires more physical work to drive the same distance.

[6]We focus on hybrid electric vehicles as they are considered to be a promising technology for increasing fuel efficiency. Furthermore, Enkvist et al. (2007) indicate that increasing the fuel efficiency of vehicles is one of the least costly ways to reduce the overall global greenhouse gas emissions.

attention. By analyzing online search behavior, we effectively examine the consumers' process of gathering information about the topic to which they pay attention. Data on aggregate regional online search behavior is obtained from the service "Google Insights for Search", enabling us to track the development of the search volume of a specific query.

It is expected that there are two main channels that alter the attention devoted to environmentally friendly vehicles. First, as the reduced gasoline consumption is the main advantage of energy efficient vehicles, the gasoline price should be an important determinant of the consumers' attention devoted to hybrid vehicles. Tversky and Kahneman (1991) indicate that consumers also evaluate prices based on reference points. If the gasoline price is higher than such a reference point, consumers would consider a price increase as a loss and may show a stronger reaction due to loss aversion. Thus, unprecedented record gasoline prices could have an additional effect on the consumers' attention if the highest previous gasoline price is such a reference point. Second, consumers may react to media coverage of topics such as hybrid vehicles and gasoline costs.[7] We draw upon the agenda-setting theory by McCombs and Shaw (1972), arguing that mass media influences the public agenda by determining which topics are seen as important.

However, the causality of whether media covers topics of general interest or whether media determines the general interest is not always clear. For our case, it is difficult to identify the causal influence of media because the consumers' attention and media coverage are both directly affected by gasoline prices and other possibly unobserved factors. Similar to Engelberg and Parsons (2011), we circumvent this problem by observing the behavior of different geographical groups. These groups react to the same underlying event, but are exposed to different information sources, i.e. their local newspaper. Our analysis is based on a novel weekly panel dataset consisting of 19 metropolitan areas in the United States covering the years 2004 to 2011. We control for local gasoline prices, national television reports and national newspaper coverage. In order to estimate the causal effect of local newspaper coverage on our attention measure, we allow each local newspaper to have an effect on all other metropolitan areas. Thus, we estimate the supplemental effect that a newspaper has in its own region compared to the effect on all other regions. This identification strategy allows us to disentangle the underlying event and the causal media effect.

[7] This hypothesis is supported by several studies indicating that economic actions are affected by media coverage. For example, Eisensee and Strömberg (2007) analyze the impact of mass media coverage on the US relief for natural disasters. To identify the effect of media coverage, they use an instrument variable, which measures the availability of other newsworthy events that crowd out media coverage of marginally newsworthy natural disasters. Tetlock (2007) analyzes the relationship between the content of newspaper articles and stock market outcomes. He shows that the sentiment of media has a distinct impact on stock prices.

Our results indicate that the consumers' attention devoted to hybrid vehicles is affected by both channels. We find that local media coverage causally affects the consumers' attention and that consumers react to both gasoline price changes and unprecedented levels of the gasoline price. Building on these findings, we validate that our proxy for the attention to hybrid vehicles is relevant to the purchasing behavior. We use a panel dataset of monthly state-level hybrid vehicle registrations and market shares for the period covering the years 2006 to 2011 to show that our attention measure is robustly related to actual consumer purchasing decisions. Overall, our findings suggest that attention effects have a distinct impact on the market for hybrid vehicles.

This is the first study to analyze the determinants of the consumers' attention to a long-lived consumer good. Until now, most studies in the area focus on showing how attention effects influence economic decision making, but do not systematically analyze the determinants of the attention. The most advanced analysis of the impact of attention effects on economic choices is primarily in the finance literature. Barber and Odean (2008) show that the stock purchasing decision of individual investors is influenced by the attention to a certain choice. Given the scarcity of the resource attention and the large set of possible investments, attention-based decision making implies that investors are more likely to buy investments that grab their attention. Da et al. (2011) indicate that Google search queries are a valid direct measure of retail investor attention, which is found to affect the retail investors' behavior in financial markets.[8] In the context of consumer behavior, Chetty et al. (2009) show that the consumers' reaction to taxation depends on the salience of the tax. Masatlioglu et al. (2012) provide a theoretical framework for limited attention effects. Their model describes a decision process under the constraint of a limited consideration set and examines the implications for revealed preferences and revealed attention.

Our study also extends the literature on the consumer search behavior in reaction to gasoline price changes. There is a range of literature (see for example Chandra and Tappata (2011)) that focuses on the relationship between the consumer search behavior and the price dispersion between different gas stations, or more broadly the competition in gasoline markets. In contrast to these studies, we do not focus on the search behavior related to the gasoline purchasing decision, but rather on the long-term reaction, i.e. the search behavior accompanying the vehicle purchase. Lewis and Marvel (2011) find that the consumers' reaction to price changes is not symmetric. Consumers increase their search effort when faced with rising gasoline prices, but do not react strongly to falling

[8] There are several other studies about attention effects in financial markets. For example, DellaVigna and Pollet (2009) indicate the existence of weekday effects due to investors' limited attention. Gilbert et al. (2012) argue that inattention leads to a temporary market reaction to stale information. Engelberg et al. (2012) examine the market impact of television stock recommendations, which are interpreted as shocks to the retail investors' attention.

prices. Our findings are similar regarding the asymmetric consumer search behavior. Additionally, we identify a distinguished attention effect for record gasoline prices. This evidence is consistent with the results in the finance literature. For example, Yuan (2011) measures the impact of attention-grabbing events like record levels of the Dow Jones index and front page articles about the stock market. It is shown that attention influences trading behavior of individual investors. Similarly, Li and Yu (2012) show that psychological reference points of past record levels can also have an impact on aggregate stock market outcomes.

The remainder of the article is organized as follows: Section 2.2 describes the market for hybrid vehicles and discusses the consumers' purchasing motives. Section 2.3 gives detailed information about the construction of our unique dataset. In Section 2.4, we analyze how media coverage and gasoline prices affect the attention devoted to hybrid vehicles. In Section 2.5, we show that online search queries are a relevant measure and have a robust correlation with actual sales volumes. Finally, we give a short conclusion of our findings in Section 2.6.

2.2 Hybrid Vehicle Market and Consumer Attitudes

Hybrid electric vehicles have both an internal combustion engine and an electric motor. This combination allows improved fuel efficiency compared to similar non-hybrid vehicles because the combustion engine is mostly used to support the electric motor. The battery of the electric motor is recharged while driving with gasoline and also while recovering the braking energy. Thus, as for most fuel-efficient technologies, hybrid electric vehicles have a higher purchasing price due to the increased complexity of including advanced technological parts such as an electric motor, a lithium-ion battery and a braking energy recovery system. The upfront investment expenses result in lower gasoline consumption and lower costs during the lifetime of the vehicle. Therefore, the profitability of the investment in fuel efficiency depends on future gasoline prices.

In 1999, the Honda Insight was the first hybrid vehicle to be introduced in the United States. The Toyota Prius, still the best selling hybrid vehicle in the US, was introduced in 2000. However, in the first six years, only a total of 197,483 hybrid vehicles were sold. In the following two years, during 2005 and 2006, there were 462,347 hybrid vehicles sold in the US.[9] Even at the start of our sample period in December 2006, the market share of all hybrid vehicles was still at a rather low level of 1.65%. Thus, the hybrid car

[9]Source: US Department of Energy, `http://www.afdc.energy.gov/afdc/data/vehicles.html`

market can be considered a new market, which means that the initial awareness related to this market is relatively low.

Several studies show that the hybrid vehicle market is mainly driven by three factors: Gasoline prices, government subsidies and non-monetary factors like symbolic values or environmental concern. There are a range of studies focusing on the impact and effectiveness of government programs that foster the sales of hybrid vehicles. For example, Beresteanu and Li (2011) find that both high gasoline prices and tax incentives have a significantly positive effect on hybrid sales. Gallagher and Muehlegger (2011) present similar results and show that sales tax waivers have a much higher impact than income tax waivers, which are less salient and transparent. Chandra et al. (2010) find that government incentives have a positive effect on hybrid sales but are not very cost effective. Diamond (2009) indicates that gasoline prices may have a higher impact than government incentives.

The literature also identifies several distinct, non-monetary factors that influence the hybrid vehicle market. Kahn (2007) shows that environmental concern is one aspect that influences purchase decisions, as green party voters are more likely to buy hybrid vehicles. Heffner et al. (2007) argue that in addition to economic factors, hybrid car owners incorporate different symbolic values in their decision. These range from obvious stereotypes, like overall environmental concern, to other factors such as wanting to be seen as a moral and intelligent person, opposing war, opposing oil producers or possessing the latest technology. In this context, Griskevicius et al. (2010) find that social motives and concern for status are important factors for purchasing decisions in general. From a psychological perspective, seemingly altruistic behavior, like publicly demonstrating ownership of green products, can be seen as a costly signal to improve social status. Following this rationale, Sexton and Sexton (2011) show that the Toyota Prius benefits from its distinct recognizability as a hybrid car, which makes the Prius more attractive for status-concerned car buyers.

However, these non-monetary factors are subject to changes in the public agenda. Thus, the hybrid vehicle market should be affected by agenda-setting, in terms of media coverage increasing the general public awareness about the existence and the environmental benefits of hybrid cars.

Several considerations about the hybrid car market can also be extended to the more general topic of fuel efficiency. Despite the fact that the gasoline price is found to have an impact on consumer decisions, there is evidence that consumers are not able to fully assess the value of fuel efficiency. For example, Turrentine and Kurani (2007) use a survey approach to show that many consumers are not able to calculate the lifetime cost of their vehicle or to make informed decisions about the fuel efficiency of a car they would like to purchase. The authors point out that drivers know the price paid at the gas station a few weeks ago, but do not use a decision-making process that is consistent with economic assumptions and theories. Furthermore, consumers also assign a symbolic value to fuel efficiency. The consumers' decision process described by Turrentine and Kurani (2007) suggests that the attention devoted to the gasoline price and fuel efficiency should have an even stronger effect than the gasoline price itself. If vehicle buyers cannot assess the present value of the investment, non-monetary effects will have a stronger impact.[10]

The question of how consumers value fuel efficiency is a topic of ongoing discussion and research. Greene (2010) reviews 28 econometric studies from the years 1995 to 2010, which do not draw a conclusive picture whether consumers undervalue or overvalue fuel efficiency. The attention and media effects found in the present article are factors that need to be considered in such studies.

2.3 Data

In this study, two unique panel datasets for the United States are considered. Our empirical setup focuses on four types of data: Attention measures, media coverage, gasoline prices and vehicle registrations. In the main analysis, we use local news coverage and weekly online searches in 19 metropolitan areas in the US. The dataset is an unbalanced panel from January 4$^{\text{th}}$, 2004 to October 23$^{\text{rd}}$, 2011 and is used to determine the causal impact of local media coverage on attention. Additionally, we test whether there is a robust relationship between our measure of attention and actual sales volumes. For this purpose, we use monthly US state-level car registration data, which was kindly provided by R. L. Polk & Co. The panel for vehicle registration data ranges from December 2006 to February 2011. We analyze the number of hybrid vehicle registrations and the hybrid technology's market share.

As a proxy for attention, we use Google search query data as a direct measure of the public interest. Time series of regional search trends are available at "Google Insights for Search" and range back to January 2004.[11] We collect weekly search trends for the

[10] This view is also supported by Baker and Wurgler (2007), who show that investor sentiment has a stronger effect on stocks that are more speculative and difficult to arbitrage or value. This argument also holds for our setting, as vehicles are relatively illiquid assets and consumers have difficulties assessing the life-time fuel costs.

[11] Available at `http://www.google.com/insights/search`.

terms "hybrid" and "mileage" in the category "Autos and Vehicles".[12] These queries represent the interest in the technology of hybrid vehicles and in fuel economy in general. We obtain weekly search trends for the 19 metropolitan areas and additionally aggregate weekly state-level search trends in order to derive a monthly search measure for the analysis in Section 2.5. Google constructs the trend index by calculating the amount of search queries that are associated with the term of interest. That number is then divided by the total number of search queries within this period and region, which yields a time series of the relative interest for the search term. The final index scales this time series to have a maximum value of 100. Table 2.1 shows that search terms related to automotive fuel efficiency and hybrid vehicles have several million search queries per month.

Table 2.1: Average Monthly US Google Search Volume for Fuel Efficiency Related Terms

Keyword	Monthly search volume
mileage	3,350,000
hybrid	2,740,000
mpg	2,740,000
prius	1,000,000
fuel economy	450,000
fuel efficiency	246,000

Notes: Average monthly search volume according to Google Keyword Tool, which is available at `http://adwords.google.com/select/KeywordToolExternal`. The figures are for the category "Vehicles", English language, for the US only and were obtained on January 31, 2012. The reported volume is an estimate of the average monthly search volume during the last 12 months and is calculated by Google.

One benefit of this dataset is that the Google search query data reflects real search behavior and does not suffer from biases that may be introduced by survey methodology. Self-reporting about subjective questions, such as the current level of attention devoted to hybrid vehicles, can lead to substantial biases and inconsistencies. Bertrand and Mullainathan (2001) point out that subjective data should not be used as a dependent variable because the inherent measurement errors usually correlate with other relevant characteristics.

For the local news coverage, we construct a daily measure of the number of articles in large local newspapers. We focus on the newspapers in the 19 metropolitan areas listed in Table 2.2 and additionally use *USA Today* and *The New York Times* as a proxy for national newspaper coverage. The newspaper articles are obtained from the LexisNexis database. Our measure of the amount of news coverage is derived by summing the

[12]Google Insights for Search does not report a search index if the amount of searches is below a certain threshold. This happens frequently during the earlier years and for smaller states or metropolitan areas. Thus, we focus on the search trends for the terms "hybrid" and "mileage" as they represent the highest search volumes for each topic. Search volumes for other relevant terms are presented in Table 2.1.

number of relevant articles for each newspaper and time period. We also distinguish between articles regarding the topics of "gasoline prices" and those of "efficient vehicle technologies". The detailed search queries for both topics are described in Table A.1 in the Appendix and are structured to be a reasonable compromise between relevancy and completeness. We generate the newspaper coverage variable by counting the number of relevant articles for each newspaper and time period (i.e. weekly or monthly). Therefore, the purpose is not to analyze the content but rather to focus on the mere presence of media coverage. The methodology has the drawback that the sentiment of media coverage may be positive or negative, which may influence both the attention and sales impact. Regarding this point, Berger et al. (2010) show that new and less-known products benefit from both positive and negative publicity. Thus, we assume that all media coverage can be treated equally in our setup because hybrid vehicles are still a relatively new and less-known product.

Table 2.2: List of Newspapers Used in the Analysis

Metropolitan Area	State	Newspaper
Atlanta	Georgia	The Atlanta Journal Constitution
Austin	Texas	The Austin American Statesman
Boston	Massachusetts	Telegram Gazette
Chicago	Illinois	The Chicago Sun-Times
Denver	Colorado	The Denver Post
Detroit	Michigan	The Detroit News
Houston	Texas	The Houston Chronicle
Las Vegas	Nevada	Las Vegas Revue Journal
Los Angeles	California	The Orange County Register; The Daily News of Los Angeles
Madison	Wisconsin	Wisconsin State Journal
Minneapolis-Saint Paul	Minnesota	Star Tribune
New York	New York	The New York Post
Norfolk-Portsmouth	Virginia	The Virginian Pilot
Philadelphia	Pennsylvania	The Philadelphia Inquirer; Philadelphia Daily News
Salt Lake City	Utah	The Salt Lake Tribune
San Francisco	California	The San Francisco Chronicle
St. Louis	Missouri	St. Louis Post-Dispatch
Tampa	Florida	St. Petersburg Times; The Tampa Tribune
Washington	District of Columbia	The Washington Times
National	National	New York Times
National	National	USA Today

Notes: The choice of included newspapers depends on the availability of data in LexisNexis and the relevancy of each newspaper within a certain metropolitan area. Additionally, only metropolitan areas with sufficient available data from Google are considered. Given these binding restrictions, 19 metropolitan areas and their major newspapers are used in the analysis.

Additionally, we use data on television news coverage from the Vanderbilt Television News Archive. The Vanderbilt database provides access to the evening news of the four major US national broadcast networks: ABC, CBS, NBC, and CNN. We construct two daily time series of television news coverage, one for the topic of "gasoline prices and fuel economy" and one for "hybrid vehicles and efficiency technologies". For the first topic, we use the following keywords: Gasoline, gas price, mileage, gallon and mpg. For the second topic, we use the keywords: Hybrid and fuel efficiency. Then, we eliminate all duplicates within each topic and hand-check for the relevancy of each news segment. We generate our variables by counting the total number of news segments across all networks for each topic and for a given time period (i.e. weekly or monthly).

Two different datasets of gasoline prices are obtained from the US Energy Information Administration (EIA). In Section 2.4, for the analysis of the determinants of consumers' attention, we use weekly retail gasoline prices for all grades and formulations. Depending on data availability, we match our 19 metropolitan areas with gasoline prices on a regional or state level. For the analysis of the actual purchasing behavior in Section 2.5, we use the monthly state-level retail price of motor gasoline.

The time structure of the weekly gasoline prices and Google searches is as follows: The EIA measures the gasoline price on Mondays, for which reason the provided weekly data only reflects the gasoline price on this particular day. In contrast, the data provided by Google Insights for Search reflects the search behavior of the entire week (Sunday to Saturday). As the search behavior is supposed to follow the gasoline price development, the weekly queries are matched with the gasoline price of the following Monday. The gasoline price changes from the current week are reflected in the subsequent – and not the contemporaneous – gasoline price. All media variables are built from daily data and match the time structure of the Google searches. Table A.2 in the Appendix reports summary statistics for both panel datasets used for the analyses presented in Sections 2.4 and 2.5.

2.4 What Drives the Attention Devoted to Hybrid Vehicles?

In this section, we investigate which factors influence the attention devoted to hybrid vehicles. As outlined in the introduction, we focus on two main channels: The observable gasoline price and the media coverage concerning hybrid vehicles. The causal influence of both unprecedented record gasoline prices and local media coverage is of particular interest. However, one issue related to this analysis is that the effect of media is expected to be limited if consumers are well informed. As a robustness test, this hypothesis is tested in a supplementary analysis using the local newspaper coverage concerning gasoline prices and the online search queries for “mileage” as a proxy for the attention to fuel economy.

We begin with the analysis of the determinants of the consumer’s attention devoted to hybrid vehicles. Before proceeding with the regression analysis, the relationship between the relevant variables is discussed. Figure 2.1 shows the weekly US gasoline price in US Dollars per gallon, the number of television news segments covering hybrid vehicles, the sum of newspaper articles about hybrid vehicles or fuel efficiency in all sample newspapers and the search trend for “hybrid” for the time period from January 2004 to September 2011. The shaded areas indicate weeks with a high relative interest in hybrid vehicles.

Graphical inspection suggests that the variation of searches is closely connected to the gasoline price and news coverage. Figure 2.1 also shows that in 2005 and 2008, there were new record price levels that lead to the highest interest during the sample period. The actual search behavior far exceeds the amount of searches that can be explained as a proportional reaction to the gasoline price increase only. When the price drops after a period of very high prices, there is a strong sign of relief, which is mirrored by a plunge in consumers’ interest in hybrid vehicles. The graphical analysis also suggests that consumers and media react to price increases rather than to high price levels. Once the gasoline price stops rising, but remains at a high level, both consumers and media quickly lose their interest.

The periods of high attention levels always coincide with periods having steep gasoline price increases, record gasoline prices or a high media coverage on hybrid vehicles. However, there is one peak of news coverage in the first week of December 2008, which is not reflected in the Google searches. This peak of news coverage is due to the US Big Three car manufacturers’ bailout discussion and their CEOs using hybrid vehicles for the journey to the Senate hearing. Another event leading to increased news coverage on hybrid vehicles is the North American International Auto Show in Detroit, which takes place every year in January.

In the following part, we examine the impact of local media coverage and record gasoline prices on the attention devoted to hybrid vehicles. We thereby proceed in three steps. First, we describe the variables used in our setup, second we discuss our regression model specifications and third we present the results from estimating our regression models.

For our identification strategy, we rely on *local* newspaper coverage. Despite the omnipresence of the internet, local newspapers are usually read only within one city and its surroundings. Compared to media coverage on a national level, focusing on local media therefore allows to have varying media exposure for the same event and to subsequently observe the reactions of metropolitan areas which have been exposed to a different degree of media coverage. Thus, all regression models are estimated using panel data for 19 US metropolitan areas, which enables us to examine more precisely whether local newspaper coverage affects the attention to hybrid vehicles when controlling for other news coverage or time-fixed effects.[13] We make use of several control variables for national media coverage. For the specifications without time-fixed effects, we use national television news coverage on gasoline prices and on hybrid vehicles as controls. Additionally, we include the news coverage in two national newspapers, *USA Today* and *The New York Times*.

Gasoline price changes are expected to have a major influence on the attention devoted to hybrid vehicles. We include asymmetric specifications of gasoline price changes as rising and falling prices may have a different influence on attention.[14] There are three different time frames included: The change (i.e. log difference) during the current week, the short-term price movement (week t-2 to t-6) and the mid-term perspective (week t-7 to t-18). The results of Yuan (2011) indicate that record gasoline prices may have a distinct effect on attention. Thus, we include the variable “Record Price Length” to count the consecutive number of weeks with an unprecedented price level during a price surge.[15] The variable reflects the fact that the attention rises directly with the duration of an intense price increase.

Government incentives such as tax credits are not taken into account explicitly. However, our fixed effects specification controls for all state-specific incentives that do not vary over time. Furthermore, the time-fixed effects account for all federal incentives. As the hybrid vehicle market matures, government incentives become less substantial compared to the early phase before our sample period. Marketing expenditures could be another source of an omitted variable bias that may influence both the attention and the purchasing decision modeled in Section 2.5. There is no data available on regional marketing focusing on hybrid vehicles or fuel efficiency; however it is likely that large and influential marketing campaigns are targeted at a national audience and are thus captured by our time-fixed effects.

We estimate our regression models using five different specifications. In the first specification, we control for the gasoline price, national television coverage, national newspaper

[13] Note that our setup directly controls for the possibility that a local newspaper is also read by non-local readers and vice versa. A higher share of non-local readers makes it less likely to find a causal effect of local media coverage.

[14] This specification is consistent with the findings of Lewis and Marvel (2011).

[15] For instance, if there are five record prices in a row then the variable equals 5 in the last week. In order to account for minor gaps within such periods, the variable stagnates in case of a single week without an unprecedented price level if another record price follows afterwards. If - in our example - there has been a break in the fourth week, the variable would twice indicate that three weeks of record prices occurred and would end with a count of 4 in the last week.

coverage, year-fixed effects and time-invariant characteristics of metropolitan areas by fixed effects. However, we do not control for spillover effects of local news coverage in other metropolitan areas. Therefore, we estimate the average effect of local newspaper coverage, which can be interpreted as the correlation between newspaper coverage and online searches.

The second specification additionally includes *all* local newspapers as control variables. Thus, each local newspaper is also allowed to have an effect on the non-local metropolitan areas. Following Engelberg and Parsons (2011), the impact of local newspapers is now identified by the difference in the reaction between a newspaper's local and non-local readership. If there is a significant positive marginal effect of the local newspaper coverage, it can be concluded that local newspaper treatment has a causal effect on the readers' attention. For example, a newspaper may feature an article about the benefits of hybrid vehicle technology. The article could have an influence on the readership by increasing the awareness about hybrid vehicles and by encouraging the readership to search for more information online. In this case, there is an increased search volume in the metropolitan area with the newspaper coverage of the hybrid vehicle technology, whereas the metropolitan areas without a local news treatment do not exhibit an increased level of attention.

For robustness reasons, we also employ alternative estimation techniques and setups. The third specification includes time-fixed effects, for which reason only variables with local variation will be included. The fourth and fifth specification explicitly account for the underlying panel data structure, which is characterized by many time periods and relatively few units of observation (large T and small N). Using a panel consisting of regional groups, such as metropolitan areas, makes it important to control for cross-sectional correlation, as it is very unlikely that the patterns in different geographical areas are mutually independent. Besides accounting for this kind of spatial correlation, it is also necessary to adequately model the serial correlation of the error term as the number of time periods increases. The fourth specification therefore estimates the same model as the second specification, but uses a Prais-Winsten type feasible GLS panel estimator with a panel-specific AR(1) structure and panel-corrected standard errors. Alternatively, the fifth specification uses robust Driscoll-Kraay standard errors, which account for general forms of cross-sectional correlations, autocorrelation and heteroskedasticity.

Table 2.3 shows the panel regression results for our model with Google searches for "hybrid" as the dependent variable. The dependent variable measures the search volume in each of the 19 metropolitan areas. Our results show that local newspaper coverage of topics related to hybrid vehicles ("Local Newspaper Hybrid") has a significant impact on the consumers' attention, regardless of the specification. For specifications (2) - (5), the local newspaper variable measures the supplemental effect that each local newspaper has in its own region, which we interpret as a causal effect following Engelberg and Parsons (2011). Our results suggest that local newspapers influence the local attention devoted to hybrid vehicles, despite other information sources available. Television news coverage about gasoline prices has a significant correlation with the search volumes for hybrid. This finding is intuitive as the gasoline price affects the profitability of an investment in a hybrid vehicle. The effect of television news coverage regarding hybrid vehicles has a positive, but not conclusive, effect on the searches for hybrid.

The impact of record gasoline prices is significant in most specifications. This finding supports the hypothesis that consumers react to reference points. Following Tversky and Kahneman (1991), consumers perceive a price increase as a loss if it is above the reference point of the most recent record price. In this case, loss aversion leads to a stronger reaction in the amount of search volumes reflecting a higher level of attention.

An alternative explanation for the record price effect could be that the consumers' expectations of future gasoline prices are not consistent with the random walk hypothesis.[16] The profitability of an investment in automotive fuel efficiency depends on future gasoline prices. If consumers expect that trends of rising gasoline prices will continue in the future, the consumers' attention would rise disproportionately during periods of extended price increases. However, Anderson et al. (2011a) show that it is generally a reasonable approach to assume a no-change forecast for consumers' fuel price expectations, which is consistent with the random walk hypothesis. Nevertheless, our alternative explanation cannot be ruled out completely because Anderson et al. (2011a) still observe a large dispersion of individual forecasts during periods of extreme price fluctuations as seen in the year 2008.

In conclusion, the regression models indicate that consumers react to movements of the gasoline price by adjusting their search intensity. Additionally, unprecedented record gasoline prices and local media coverage raise the attention devoted to hybrid vehicles in a causal relationship.

We proceed with the supplementary analysis and examine whether local media coverage regarding gasoline prices likewise affects the attention devoted to fuel economy. As the gasoline price is directly observable, media coverage is expected to have a less distinct effect. The gasoline price is the most obvious factor that influences the attention devoted to fuel economy. When gasoline prices rise, consumers are likely to be forced to change their general consumption behavior. For example, Gicheva et al. (2010) and Ma et al. (2011) show that increases in gasoline prices lead to changes in the grocery purchasing

[16]The random walk hypothesis assumes that the current price is the best estimate for future prices regardless of the price history.

behavior due to changes in residual disposable income. The pressure to change general consumption patterns could also lead to an increased interest in fuel economy.

The variables for the supplementary analysis are displayed in Figure 2.2, which shows the weekly US gasoline price, the number of television news segments covering the gasoline price or fuel economy, the sum of newspaper articles about gasoline prices in all sample newspapers and the search trend for "mileage" for the time period from January 2004 to September 2011. The shaded areas indicate weeks with a high relative interest in fuel economy.

Similar to the setup for hybrid vehicles, the variation of searches for fuel economy is closely connected to the gasoline price and media coverage. Comparing Figures 2.1 and 2.2, the newspaper coverage of "hybrid vehicles and fuel efficiency" is noisier than the coverage of "gasoline prices". However, the topic of efficient technologies has a more general character and is not as closely tied to the gasoline price movement. Furthermore, the search trends for "mileage" and "hybrid" are very similar. This finding indicates that the increased fuel efficiency of hybrid vehicles is indeed perceived as the major advantage of hybrid vehicles.

In April 2006, there was a peak of television coverage on gasoline prices, with up to 35 relevant news segments in one week. During this time, several economic and political events occurred that constituted the increased television reporting. First, there was a strong increase of gasoline prices from \$2.41 on March 13$^{\text{th}}$ to \$2.96 on April 24$^{\text{th}}$. Second, on April 25$^{\text{th}}$, George W. Bush held a speech on energy policy, which was widely covered by the media. Lastly, discussions about oil companies' high profits and a windfall profit tax gained increased media attention.

Table 2.4 presents the results of regressing Google searches for "mileage" on media coverage, record gasoline prices and gasoline price changes. The basic setup of the regression model is the same as for the results shown in Table 2.3. However, all newspaper variables are now constructed to reflect the news coverage on gasoline prices.[17]

The results shown in Table 2.4 indicate that the relationship between the local news coverage concerning gasoline prices and the attention to fuel economy is as expected. Only in the first specification, there is a significant relationship between the two variables. As in Table 2.3, the first specification estimates the average effect of local newspaper coverage without controlling for other local news coverage in the remaining metropolitan areas or for time-fixed effects. Thus, we find a strong positive correlation between newspaper coverage and searches. However, when estimating effects with a causal interpretation (i.e. the supplemental regional effect of local newspaper coverage on the

[17] See Table A.1 for a precise definition of the relevant search terms.

attention devoted to mileage), the results indicate that the interest in searching for mileage is unaffected by media coverage. Therefore, it can be concluded that the treatment of local newspaper coverage in regards to gasoline prices has no causal influence on the attention devoted to fuel economy. However, the length of unprecedented gasoline prices has a positive impact on the attention level. This finding indicates that gasoline expenditures become a “top of mind” topic when the prices reach new all-time highs.

Overall, the aim of the main analysis is to examine which factors influence the attention devoted to hybrid vehicles. We demonstrate that both local media coverage and unprecedented record gasoline prices significantly increase the attention devoted to hybrid vehicles. The supplementary analysis examines whether local media coverage concerning gasoline prices similarly affects the attention devoted to fuel economy. We observe a strong correlation, but we do not find a causal effect. An intuitive explanation for this finding is that consumers can be assumed to be rather well informed about the current gasoline price, which can be easily observed at gas stations. Therefore, the media coverage concerning gasoline prices does not provide much additional information and has consequently no causal effect on attention. In contrast, hybrid vehicles are a relatively new fuel-efficient technology and consumers may not be fully aware of the existence and benefits of hybrid vehicles. Thus, media coverage has the ability to increase the amount of attention devoted hybrid vehicles.

The finding that media coverage alters the consumers’ attention to hybrid vehicles is of interest in two regards. First, this result indicates that consumers would most likely invest more in new, efficient technologies if they had a deeper knowledge of the topic. This insight may be of importance to both policymakers and car manufacturers dealing with the distribution of environmentally friendly vehicles. Second, and more generally, our finding is interesting concerning the role of the media as a part of an individual’s decision-making process. Our results seem to reject the hypothesis that the media merely replicates publically available information and does not influence the consumers’ considerations. However, the impact of media coverage depends on the specific topic considered and cannot be generalized for all circumstances.

TABLE 2.3: Panel Regression Results of the Impact of Local Media Coverage on the Interest in Hybrid Vehicles

Table 2.3
Hybrid Vehicle Technology and Attention

	Dependent Variable: Google Search Queries for Hybrid				
	(1)	(2)	(3)	(4)	(5)
Local Newspaper Hybrid	0.361 ***	0.203 **	0.216 **	0.085 ***	0.203 ***
	(0.037)	(0.090)	(0.092)	(0.031)	(0.042)
TV Gasoline	1.042 ***	0.908 ***		0.675 ***	0.908 ***
	(0.053)	(0.051)		(0.096)	(0.154)
TV Hybrid	0.681 ***	0.444 ***		0.188	0.444
	(0.113)	(0.115)		(0.320)	(0.480)
Record Price Length	0.796 ***	0.733 ***	0.145 *	0.722 ***	0.733 ***
	(0.077)	(0.074)	(0.083)	(0.107)	(0.243)
$\Delta GasPrice^{Pos}_{t,t-1}$	63.553 ***	61.742 ***	19.985 *	49.764 ***	61.742 *
	(8.439)	(7.993)	(9.611)	(12.936)	(33.328)
$\Delta GasPrice^{Neg}_{t,t-1}$	40.059 ***	44.100 ***	33.838 **	31.994 *	44.100
	(7.458)	(7.572)	(14.748)	(18.482)	(30.217)
$\Delta GasPrice^{Pos}_{t-2,t-6}$	55.285 ***	52.868 ***	23.278 **	43.906 ***	52.868 ***
	(4.170)	(4.020)	(8.226)	(7.984)	(11.935)
$\Delta GasPrice^{Neg}_{t-2,t-6}$	42.344 ***	39.086 ***	11.185 **	37.996 ***	39.086 ***
	(2.258)	(2.233)	(4.288)	(7.507)	(8.701)
$\Delta GasPrice^{Pos}_{t-7,t-18}$	24.284 ***	19.691 ***	13.518 ***	17.983 ***	19.691 ***
	(2.016)	(2.229)	(4.619)	(5.458)	(6.760)
$\Delta GasPrice^{Neg}_{t-7,t-18}$	11.096 ***	12.245 ***	10.359 ***	14.038 ***	12.245 ***
	(0.683)	(0.696)	(3.559)	(4.029)	(2.724)
Newspaper USA Today	−0.112 *	−0.191 ***		0.029	−0.191
	(0.057)	(0.057)		(0.128)	(0.161)
Newspaper NYT	0.290 ***	0.194 ***		0.006	0.194 *
	(0.024)	(0.024)		(0.064)	(0.096)
Intercept	25.173 ***	22.560 ***	30.225 ***	25.638 ***	22.560 ***
	(1.109)	(1.081)	(1.405)	(1.480)	(1.524)
R^2	0.630	0.649	0.812	0.471	0.649
N	7208	7208	7227	7208	7208
Newspaper Spillover Controls	NO	YES	NO	YES	YES
Metro-Fixed Effects	YES	YES	YES	NO	YES
Time-Fixed Effects	NO	NO	YES	NO	NO
Year-Fixed Effects	YES	YES	NO	YES	YES

Standard errors are clustered by metropolitan area in models (1), (2) and (3). Model (4) is estimated using a Prais-Winsten regression with a panel-specific AR(1) structure and panel-corrected standard errors. Driscoll-Kraay standard errors are used in model (5).
$*$, $**$, and $***$ represent significance at the 10%, 5% and 1% level, respectively.

TABLE 2.4: Panel Regression Results of the Impact of Local Media Coverage on the Interest in Fuel Economy

Table 2.4
Fuel Economy and Attention

	Dependent Variable: Google Search Queries for Mileage				
	(1)	(2)	(3)	(4)	(5)
Local Newspaper Gasoline	0.424 ***	−0.013	−0.006	−0.046	−0.013
	(0.095)	(0.081)	(0.080)	(0.029)	(0.039)
TV Gasoline	0.539 ***	0.252 ***		0.222 ***	0.252 **
	(0.051)	(0.058)		(0.076)	(0.103)
TV Hybrid	−0.094	−0.026		−0.059	−0.026
	(0.099)	(0.106)		(0.227)	(0.371)
Record Price Length	0.503 ***	0.378 ***	0.105	0.448 ***	0.378 *
	(0.092)	(0.081)	(0.140)	(0.086)	(0.207)
$\Delta GasPrice^{Pos}_{t,t-1}$	34.572 ***	9.961	10.317	9.272	9.961
	(8.322)	(7.788)	(9.551)	(9.906)	(19.059)
$\Delta GasPrice^{Neg}_{t,t-1}$	45.488 ***	75.996 ***	12.522	32.673 **	75.996 ***
	(8.451)	(10.276)	(12.849)	(14.571)	(23.765)
$\Delta GasPrice^{Pos}_{t-2,t-6}$	28.923 ***	18.629 ***	28.173 ***	19.000 ***	18.629 **
	(3.082)	(3.082)	(7.293)	(6.397)	(7.559)
$\Delta GasPrice^{Neg}_{t-2,t-6}$	40.106 ***	37.693 ***	22.808 ***	33.064 ***	37.693 ***
	(2.441)	(2.263)	(5.735)	(6.064)	(6.759)
$\Delta GasPrice^{Pos}_{t-7,t-18}$	17.215 ***	7.103 ***	13.207 ***	6.443	7.103
	(1.655)	(1.449)	(3.136)	(4.517)	(8.246)
$\Delta GasPrice^{Neg}_{t-7,t-18}$	12.765 ***	13.248 ***	16.820 **	14.137 ***	13.248 ***
	(0.703)	(0.696)	(7.679)	(3.261)	(1.931)
Newspaper USA Today	0.489 ***	0.259 ***		0.211 ***	0.259 *
	(0.033)	(0.031)		(0.080)	(0.140)
Newspaper NYT	0.387 ***	−0.169 ***		−0.036	−0.169
	(0.040)	(0.033)		(0.056)	(0.109)
Intercept	17.479 ***	17.636 ***	22.218 ***	18.709 ***	17.636 ***
	(1.063)	(1.034)	(2.104)	(1.210)	(1.259)
R^2	0.613	0.673	0.823	0.520	0.673
N	6956	6870	6973	6870	6870
Newspaper Spillover Controls	NO	YES	NO	YES	YES
Metro-Fixed Effects	YES	YES	YES	NO	YES
Time-Fixed Effects	NO	NO	YES	NO	NO
Year-Fixed Effects	YES	YES	NO	YES	YES

Standard errors are clustered by metropolitan area in models (1), (2) and (3). Model (4) is estimated using a Prais-Winsten regression with a panel-specific AR(1) structure and panel-corrected standard errors. Driscoll-Kraay standard errors are used in model (5).
$*$, $**$, and $***$ represent significance at the 10%, 5% and 1% level, respectively.

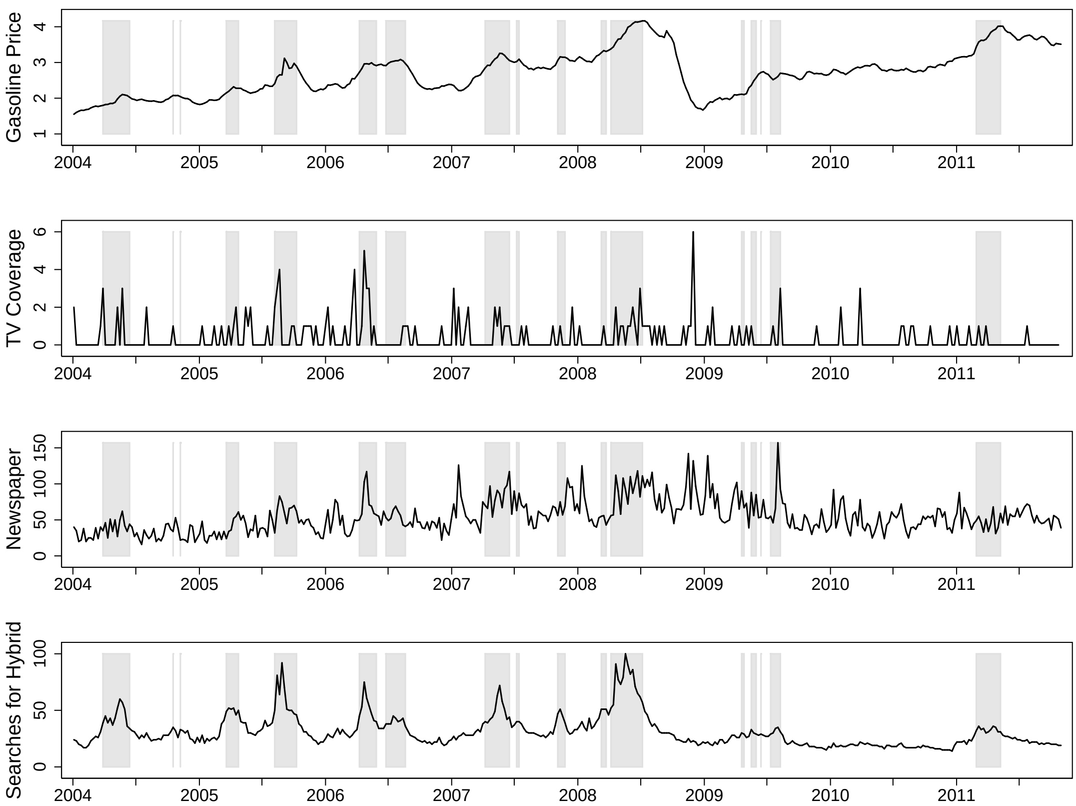

Figure 2.1: Gasoline Price, Media Coverage and Attention Devoted to Hybrid Vehicles

Notes: The first panel shows the weekly US retail gasoline price for all grades and formulations in US Dollars per gallon, the second panel shows the weekly sum of TV evening news segments about hybrid vehicles, the third panel shows the sum of newspaper articles about hybrid vehicles or fuel efficiency in all sample newspapers and the fourth panel shows the Google online search queries for "hybrid". The shaded area indicates weeks with a high attention to hybrid vehicles, which is defined as a Google search index that is above the overall median and in the highest tertile per year.

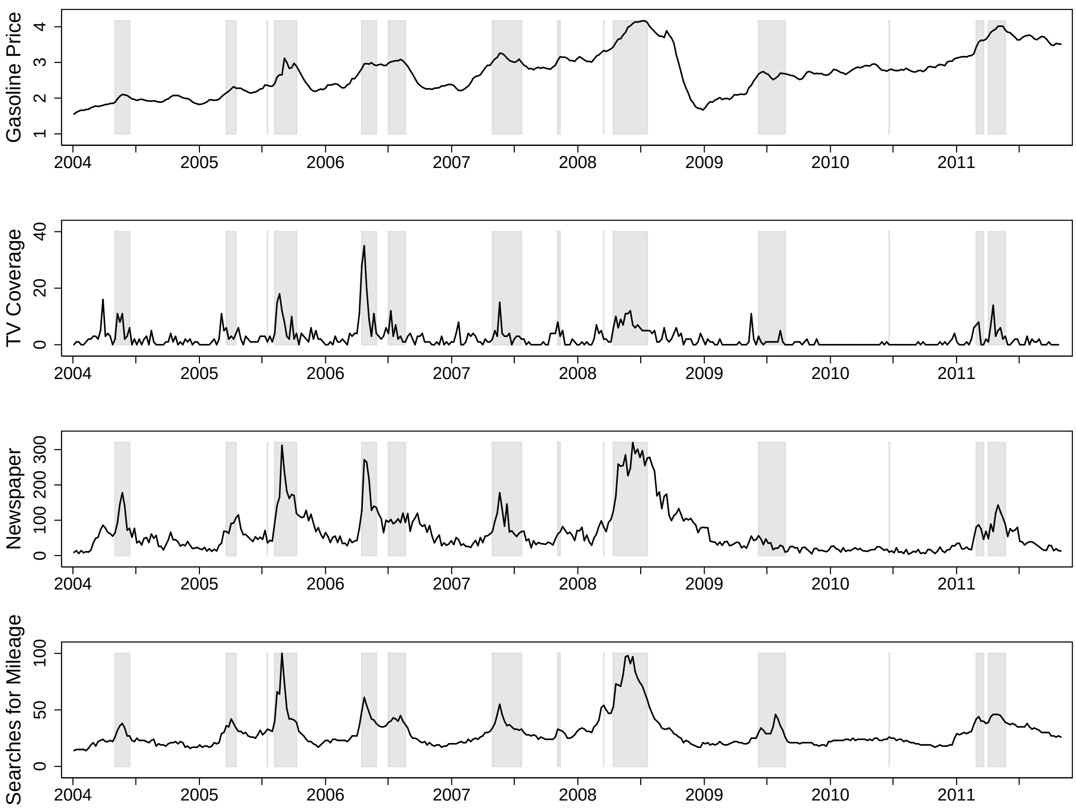

Figure 2.2: Gasoline Price, Media Coverage and Attention Devoted to Fuel Economy

Notes: The first panel shows the weekly US retail gasoline price for all grades and formulations in US Dollars per gallon, the second panel shows the weekly sum of TV evening news segments about gasoline prices or fuel economy, the third panel shows the sum of newspaper articles about gasoline prices in all sample newspapers and the fourth panel shows the Google online search queries for "mileage". The shaded area indicates weeks with a high attention to fuel economy, which is defined as a Google search index that is above the overall median and in the highest tertile per year.

2.5 Attention and Hybrid Vehicle Purchases

In this section, we examine the validity of our attention measure by analyzing the relationship between monthly state-level hybrid vehicle registrations and online search queries. First, the relation between our key variables is graphically illustrated. Figure 2.3 shows the monthly US retail gasoline price for all grades and formulations (in US Dollars per gallon), the Google online search queries for "hybrid" as a measure of attention, the monthly number of hybrid vehicle registrations in the US (in thousands per month) and the market share of hybrid vehicles (in %). The shaded area indicates months with a high attention.

The graphical analysis shows that the changes in the gasoline price and the search volume are closely related to both the total number and the market share of hybrid vehicle registrations. Figure 2.3 also reveals the effect of one-time events that have a major influence on the hybrid vehicle market. For instance, the impact of the Cash Allowance Rebate System (C.A.R.S.), commonly known as "Cash for Clunkers", can be seen in the increase of sales and hybrid vehicle market shares during July and August 2009. The drop in sales after March 2011 is partially due to supply chain problems resulting from the disastrous earthquake and tsunami in Japan.[18]

In the next step, we use monthly state-level registration data to examine the actual hybrid vehicle purchasing behavior. Table 2.5 shows the results of the regression analysis for the hybrid vehicle registrations as the dependent variable. Similarly, the results in Table 2.6 represent the same model specifications, but use the market share of hybrid vehicles as the dependent variable. The Google variable measures the monthly state-level search queries for "hybrid" and is supposed to mirror the consumers' attention related to hybrid vehicles. As both the dependent variables and the Google variables are transformed into logarithms, the regression parameters can be interpreted as elasticities. The variable "Record Price" is built as a dummy indicating months with an unprecedented high gasoline price.

In specification (1), we use state-fixed effects, year-fixed effects and control for national media coverage, gasoline price movements and record price levels. Specifications (4) and (5) include the same variables, but are estimated with a Prais-Winsten type panel estimator and Driscoll-Kraay standard errors, respectively. Specifications (2) and (3) include state- and time-fixed effects, and Specification (3) uses an alternative gasoline price variable, i.e. the logarithm of the gasoline price instead of price changes.

Focusing first on Table 2.5, we show that Google searches for "hybrid" have a significantly positive effect on hybrid vehicle registrations for all specifications. Our estimates

[18]These one-time events do not affect our analysis as the time-fixed effects account for such occurrences.

indicate that an increase of the search volume by 1% is associated with an increase of hybrid vehicle purchases in the range between 0.12% and 0.22%. Thus, it can be concluded that our attention measure is valid and robustly related to sales volumes.

The results of the regressions with the market share of hybrid vehicles as the dependent variable are shown in Table 2.6. The evidence for the relationship to our attention measure is positive, but not as strong as for the number of registrations. Given the definition of our Google variable, which reflects the number of search queries related to a topic, a less distinct relationship between searches and market shares is plausible. If the search queries for hybrid vehicles were expressed as a share of all search queries in the automotive category, we would expect a more distinct relationship with market shares rather than sales volumes.

The television news coverage on gasoline prices and fuel economy has a significantly positive effect on the number of hybrid vehicle registrations. However, the television news coverage on hybrid vehicles is not significant, which may be caused by the fact that the overall amount of news coverage is very low. In the regression with the market share of hybrid vehicles as the dependent variable, the results for television coverage are similar.

The results for the gasoline price variables are in line with economic intuition. Since the profitability of hybrid cars depends on the gasoline price, a positive association between these two variables is assumed. We find that rising gasoline prices have a positive impact on hybrid registrations and market shares. In model (3), which includes the logarithm of the gasoline price as well as state- and time-fixed effects, the record price variable has a significant coefficient while the logarithm of the gasoline price is insignificant.

Overall, the most credible specifications for both dependent variables indicate a positive relationship between our attention measure and hybrid vehicle registrations. Our results show that the variables used in the main part of our study, Section 2.4, are relevant for the hybrid vehicle market and thus valid proxies for the empirical analysis pursued.

Table 2.5: Panel Regression Results of the Impact of Attention on the Registrations of Hybrid Vehicles

Table 2.5
Hybrid Vehicle Registrations and Attention

	Dependent Variable: Log of # of Hybrid Registrations				
	(1)	(2)	(3)	(4)	(5)
ln(Google Hybrid)	0.222 ***	0.123 ***	0.121 ***	0.199 ***	0.222 ***
	(0.033)	(0.036)	(0.038)	(0.060)	(0.054)
TV Gasoline	0.008 ***			0.008 **	0.008 **
	(0.001)			(0.003)	(0.004)
TV Hybrid	0.005			0.010	0.005
	(0.004)			(0.011)	(0.015)
Record Price	0.001	0.027	0.036 **	0.056 *	0.001
	(0.017)	(0.017)	(0.018)	(0.029)	(0.031)
$\Delta GasPrice^{Pos}_{t,t-1}$	0.907 ***	0.663 ***		0.637 **	0.907 ***
	(0.141)	(0.195)		(0.309)	(0.309)
$\Delta GasPrice^{Neg}_{t,t-1}$	0.397 ***	−0.211		0.392	0.397
	(0.090)	(0.329)		(0.263)	(0.257)
$\Delta GasPrice^{Pos}_{t-2,t-3}$	1.670 ***	0.415 *		1.259 ***	1.670 ***
	(0.112)	(0.224)		(0.299)	(0.401)
$\Delta GasPrice^{Neg}_{t-2,t-3}$	0.699 ***	−0.228		0.366	0.699 ***
	(0.069)	(0.204)		(0.259)	(0.204)
$\Delta GasPrice^{Pos}_{t-4,t-6}$	0.334 ***	−0.075		0.301	0.334
	(0.067)	(0.157)		(0.233)	(0.252)
$\Delta GasPrice^{Neg}_{t-4,t-6}$	0.183 ***	0.211 *		−0.065	0.183
	(0.034)	(0.104)		(0.158)	(0.137)
USA Today Hybrid	−0.001			−0.004	−0.001
	(0.001)			(0.003)	(0.003)
NYT Hybrid	−0.002 ***			−0.000	−0.002
	(0.000)			(0.002)	(0.002)
USA Today Gas	0.004 **			−0.001	0.004
	(0.002)			(0.004)	(0.005)
NYT Gas	−0.006 ***			−0.003 *	−0.006 **
	(0.001)			(0.002)	(0.002)
ln(Gas Price)			0.061		
			(0.172)		
Intercept	5.215 ***	4.585 ***	4.612 ***	5.478 ***	5.215 ***
	(0.111)	(0.099)	(0.119)	(0.232)	(0.167)
R^2	0.502	0.967	0.967	0.965	0.502
N	2117	2117	2117	2117	2117
State-Fixed Effects	YES	YES	YES	NO	YES
Time-Fixed Effects	NO	YES	YES	NO	NO
Year-Fixed Effects	YES	NO	NO	YES	YES

Standard errors are clustered by state in models (1), (2) and (3). Model (4) is estimated using a Prais-Winsten regression with a panel-specific AR(1) structure and panel-corrected standard errors. Driscoll-Kraay standard errors are used in model (5).

$*$, $**$, and $***$ represent significance at the 10%, 5% and 1% level, respectively.

TABLE 2.6: Panel Regression Results of the Impact of Attention on the Market Share of Hybrid Vehicles

Table 2.6
Hybrid Technology's Market Share and Attention

	Dependent Variable: Log of Hybrid Technology's Market Share				
	(1)	(2)	(3)	(4)	(5)
ln(Google Hybrid)	0.094 ***	0.076 *	0.069 *	0.216 ***	0.094 *
	(0.028)	(0.039)	(0.038)	(0.057)	(0.052)
TV Gasoline	0.007 ***			0.005 *	0.007 *
	(0.001)			(0.003)	(0.004)
TV Hybrid	−0.004			0.006	−0.004
	(0.004)			(0.011)	(0.013)
Record Price	0.025 *	0.029 **	0.039 ***	0.019	0.025
	(0.014)	(0.012)	(0.012)	(0.028)	(0.025)
$\Delta GasPrice^{Pos}_{t,t-1}$	0.735 ***	0.962 ***		0.582 *	0.735 ***
	(0.121)	(0.175)		(0.297)	(0.248)
$\Delta GasPrice^{Neg}_{t,t-1}$	−0.391 ***	−0.349		−0.413 *	−0.391 *
	(0.090)	(0.373)		(0.236)	(0.224)
$\Delta GasPrice^{Pos}_{t-2,t-3}$	0.743 ***	0.358 *		0.537 *	0.743 **
	(0.123)	(0.205)		(0.289)	(0.356)
$\Delta GasPrice^{Neg}_{t-2,t-3}$	0.414 ***	−0.286		0.073	0.414 **
	(0.080)	(0.285)		(0.230)	(0.186)
$\Delta GasPrice^{Pos}_{t-4,t-6}$	0.226 ***	0.050		0.331	0.226
	(0.062)	(0.146)		(0.216)	(0.292)
$\Delta GasPrice^{Neg}_{t-4,t-6}$	0.021	−0.112		−0.172	0.021
	(0.034)	(0.136)		(0.139)	(0.096)
USA Today Hybrid	0.000			−0.001	0.000
	(0.001)			(0.003)	(0.003)
NYT Hybrid	−0.000			−0.001	−0.000
	(0.000)			(0.002)	(0.001)
USA Today Gas	0.007 ***			0.004	0.007 *
	(0.001)			(0.004)	(0.004)
NYT Gas	−0.006 ***			−0.004 **	−0.006 ***
	(0.000)			(0.002)	(0.002)
ln(Gas Price)			0.180		
			(0.168)		
Intercept	0.186 *	−0.460 ***	−0.466 ***	−0.061	0.186
	(0.098)	(0.118)	(0.120)	(0.217)	(0.150)
R^2	0.372	0.882	0.880	0.509	0.372
N	2117	2117	2117	2117	2117
State-Fixed Effects	YES	YES	YES	NO	YES
Time-Fixed Effects	NO	YES	YES	NO	NO
Year-Fixed Effects	YES	NO	NO	YES	YES

Standard errors are clustered by state in models (1), (2) and (3). Model (4) is estimated using a Prais-Winsten regression with a panel-specific AR(1) structure and panel-corrected standard errors. Driscoll-Kraay standard errors are used in model (5).

∗, ∗∗, and ∗∗∗ represent significance at the 10%, 5% and 1% level, respectively.

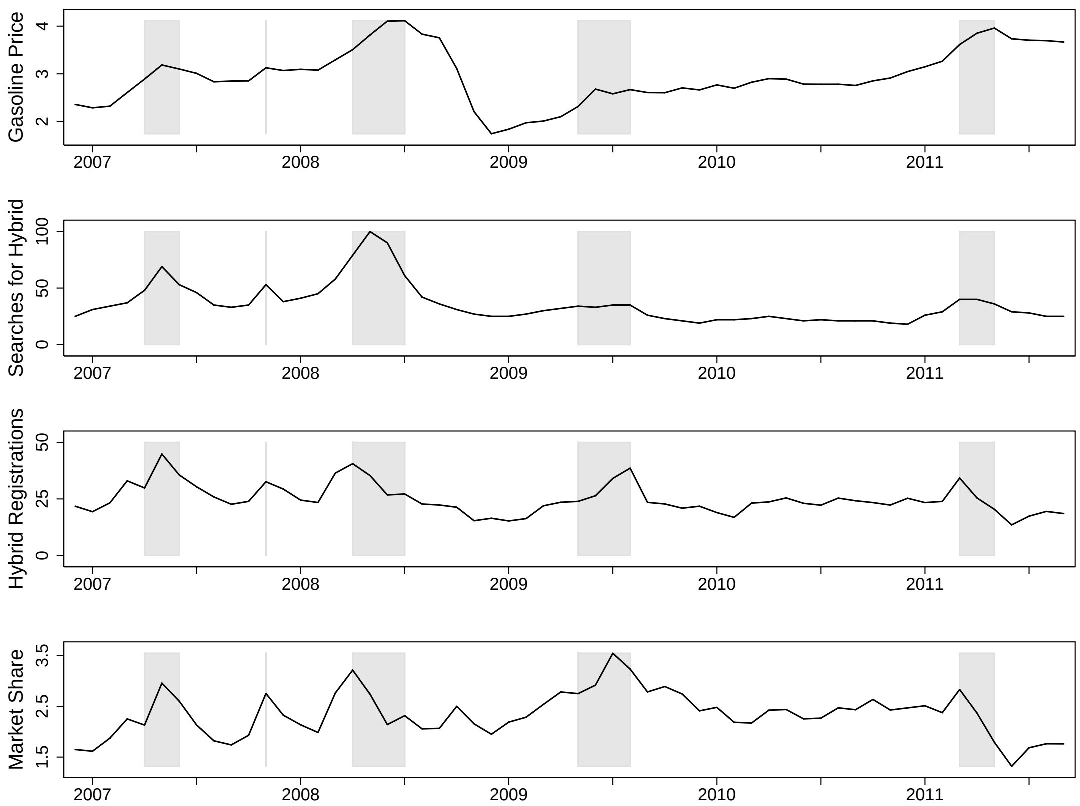

FIGURE 2.3: Gasoline Price, Attention and Registrations of Hybrid Vehicles

Notes: The first panel shows the monthly US retail gasoline price for all grades and formulations in US Dollars per gallon, the second panel shows the Google online search queries for "hybrid", the third panel shows the monthly number of hybrid vehicle registrations in the US (in thousands per month) and the fourth panel shows the market share of hybrid vehicles (in %). The shaded area indicates months with a high attention, which is defined as a Google search index that is above the overall median and in the highest tertile per year.

2.6 Conclusion

The study extends the research on consumer attention effects to the area of energy efficiency. Specifically, the analysis indicates which factors alter the consumers' attention devoted to fuel efficient technologies like hybrid vehicles. We use a novel panel dataset to show that the revealed consumer attention to hybrid vehicles depends on the gasoline price, unprecedented record gasoline price levels and media coverage. In our empirical setup, attention is measured by Google online search behavior. As search queries reflect real-life actions of millions of United States citizens, this data most importantly does not suffer from possible survey biases. The accuracy of our attention measure is validated by the robust relationship to the actual purchasing behavior. Given that we analyze a market for high-cost durable goods, a setting in which consumers should exhibit a high effort in decision making, the empirical findings from this study are also of relevance to economic decisions in other markets.

The finding that attention effects influence the diffusion of innovative and energy efficient technologies leads to important policy implications. In order to limit greenhouse gas emissions and to reduce the dependency on oil imports, fuel efficient technologies must become a "top of mind" topic in any vehicle purchasing decision. Initiatives aiming at increasing awareness and education about such technologies may be an important tool to foster the adoption of hybrid vehicles. A more general finding is that periods of rising gasoline prices are more effective at drawing temporary attention to fuel efficiency than periods of steadily high gasoline prices. In fact, volatile gasoline prices provoke strong reactions of both the media and consumers. Therefore, it can be inferred that volatile gasoline prices, as they occurred in the years 2005 to 2008, have a positive impact on the diffusion of green technologies.

Given that consumers' attention levels have a fluctuating nature, car manufacturers should consider the current level of the attention devoted to efficient vehicles when planning their marketing effort and campaign contents. During periods of steep gasoline price increases or record gasoline prices, consumers have a much higher interest and are more receptive to information about fuel efficient technologies.

Despite the fact that our study focuses on one specific market, the results have wide implications. We argue that firms should generally be aware of how and why their customers' attention fluctuates. Future research could highlight the interaction of marketing and attention as it is defined in our framework. Interesting questions include how marketing efforts are able to influence attention or how the efficiency of marketing campaigns depends on the current attention level.

Chapter 3

What Drives Natural Gas Prices? - A Structural VAR Approach

3.1 Introduction

The price of natural gas is of significant economic interest for various stakeholders. Not only does gas play a crucial role as a primary fuel in the residential and commercial heating market, but it also serves as an important input for industrial applications and electricity generation. Consequently, understanding the drivers of natural gas prices is relevant from both a macro and firm-specific perspective. However, the price formation at liberalized natural gas hubs is complex, since these markets are faced with a variety of fundamental demand and supply influences such as meteorological conditions, business cycles, international trade flows and substitution effects among energy commodities. Moreover, unforeseen disruptions in gas supply may induce significant repercussions in these markets. This holds true especially for the continental European natural gas market, which recently has been exposed to supply disruptions due to the Russian-Ukrainian gas transit dispute of January 2009, production outages caused by the Libyan civil war in the spring of 2011 and the cut in Russian gas deliveries in February 2012.

In this study, we focus on Germany, one of the largest European natural gas markets, which is heavily dependent on natural gas imports via pipelines and therefore provides an interesting setting for the investigation of the impact of supply disruptions on the gas price. For this purpose, we develop a structural vector autoregressive model (VAR) to investigate the effects of various fundamental variables on gas prices. The natural gas-related variables analyzed in this study include gas supply disruptions, weather conditions, storage activity and imports of liquefied natural gas (LNG). Moreover, the model yields insights into the relationship of the natural gas price and the prices of coal and crude oil, which we use as proxies for the energy specific demand.

The impulse responses provided by the VAR are consistent with economic theory and suggest that the natural gas price reacts to the underlying supply and demand characteristics. The natural gas price rises in reaction to supply interruptions and due to extraordinary cold temperatures increasing the heating demand. The response to structural shocks of storage follows with the idea that storage flows either serve as additional demand or additional supply in the respective period. Whereas coal prices have an immediate and persistent impact on natural gas prices, the crude oil price only affects natural gas prices after a substantial delay. The decomposition of the forecast error variance of the natural gas price highlights that supply disruptions and unexpected meteorological conditions have an important, but transitory, effect on gas prices. For medium- and long-term horizons, gas prices are mainly affected by both coal and crude oil prices.

To better understand the effects of natural gas supply interruptions, we use our VAR model to disentangle the historical structural shocks affecting the German gas market during the three recent supply shortfalls. Our results show that the positive price impact of the Russian-Ukrainian transit dispute of January 2009 was partly offset by the negative price pressure of the coinciding financial crisis and economic slowdown. The structural effects on gas prices during the Libyan civil war suggest that the increase of German wholesale gas prices was rather induced by precautionary demand of storages than by the actual supply shortfall to the European gas market. Furthermore, the sharp price spike in February 2012 was affected to a greater extent by the extremely low temperatures compared to the sudden shortfalls in Russian supply.

To our knowledge, we are the first to pursue an econometric analysis of the impact of supply shortfalls within the German gas market. A major contribution of our research is the identification of the distinct influences that affect gas prices in critical market situations. By disentangling the respective structural shocks, we are able to infer how the main fundamental variables interact in case of supply interruptions. Hence, we can distinguish the contribution of the different variables on gas prices. This is especially valuable since the observed natural gas price increases are caused not only by the supply shock, but also by various coinciding exogenous shocks of all variables. The proposed model therefore helps to provide new empirical insights into the security of supply for the European natural gas market. In this context, the relationship between Russia as a natural gas exporter and the European Union as an importer has attracted a substantial amount of research, such as the studies by Finon and Locatelli (2008), Goldthau (2008), Sagen and Tsygankova (2008) and Spanjer (2007). Morbee and Proost (2010) provide a theoretical framework for the relationship between European importers and Russia.

Also related to the security of gas supply, Giulietti et al. (2012) analyze how the outage of a major storage facility affects the natural gas market in the UK.

Our finding that coal prices have a significant impact on the natural gas market challenges the exclusive focus on crude oil as an explanatory variable for cross-commodity effects on gas prices, which is common in most of the empirical gas market research. For example, Hartley et al. (2008), Panagiotidis and Rutledge (2007) as well as Brown and Yücel (2008) use a cointegration framework and specify error correction models to capture the mechanisms among the markets for natural gas and crude oil both in the short run and the long run. However, the stability of the cointegration relationship has been questioned as there seems to be a decoupling of oil and gas prices as outlined by Ramberg and Parsons (2012), who find that the cointegration relationship between oil and gas prices in the United States is not stable over time. They also argue that the price of oil has only weak explanatory power for short-term gas price fluctuations. Economic reasons for a decoupling of oil and gas prices could be the increasing production of shale gas in the United States or the rise of liquid spot markets in Europe fostering gas-to-gas competition and therefore a slow but steady decline in oil-indexed contracts.

We also add to the literature in that our structural VAR approach allows for endogeneity of fundamental gas market variables, such as storage and LNG supplies. Most approaches, such as for example Brown and Yücel (2008), Mu (2007) or Ramberg and Parsons (2012), treat gas inventories as exogenous with respect to gas prices and do not account for the role of LNG. One exception is the study of Maxwell and Zhu (2011), which employs a reduced-form VAR and Granger causality tests to investigate the interdependency of LNG imports and the US gas market. The assumption of exogenous gas inventories implies that storage operators do not adjust flows according to market prices, which is a restrictive assumption for liberalized and efficient gas markets.

The remainder of this study is structured as follows: Section 3.2 describes the data used for our analysis. The structural VAR framework and the identification of our model are given in Section 3.3. The results of the impulse response analysis as well as the decomposition of forecast error variance are presented and discussed in Section 3.4. Section 3.5 provides a brief overview of the three recent gas supply interruptions affecting the German natural gas market and also contains the event studies of these situations. Section 3.6 concludes.

3.2 Data

Our data set comprises weekly data within the period from January 2008 to June 2012.[19] It consists of the NetConnect Germany (NCG) natural gas price, the Brent crude oil price, the North-Western-European coal price, the deviation from historical average heating degree days in Germany, German natural gas storage data, shortfalls of natural gas supplies to the European market and European LNG import data.[20] Figure B.1 in the Appendix displays all time series used for the analysis and Table 3.1 summarizes the definition of the variables used in this study. In the following, detailed descriptions concerning data sources and the construction of variables are provided.

Table 3.1: Variable Definitions

Variable	Description	Unit	Source
Heating degree days deviation (Temperature)	Deviation from historical heating degree days during the respective week	Degrees celsius	Deutscher Wetterdienst (DWD), German Meteorological Service
Supply Shortfall	Missing natural gas supply volumes due to specific events	Billion cubic meters (bcm)	Own estimates based on various sources
Price of Brent crude oil	Europe Brent spot crude oil price	Euro per barrel	Energy Information Administration (EIA)
Price of coal	Coal price for North-Western-Europe	Euro per ton	McCloskey
LNG imports to EU-27	Linearly detrended LNG import volumes for all EU-27 countries	Million cubic meters (mcm)	Eurostat
Storage	Difference between historical and actual weekly changes in the German natural gas storage utilization rate	Percentage points	Gas Infrastructure Europe (GIE)
Natural gas price	NetConnect Germany (NCG) day-ahead natural gas price	Euro per Megawatt hour	European Energy Exchange (EEX)

Notes: All time series are transformed to weekly data within the period from January 2008 to June 2012

The data set for the econometric analysis is rather comprehensive with seven variables included. The decision of variable selection is justified by the diversity of fundamental impacts on gas prices, which do not allow a more parsimonious model specification. As

[19]The first observation is the week ending on Friday February 1st, 2008 and the last observation is the week ending on Friday June 1st, 2012.

[20]For cases in which time series are available on a daily level, we generally construct five-, respectivly seven- day averages (depending on the number of trading days per week).

reference prices for the German gas market, we use day-ahead prices of the market area NCG quoted at the European Energy Exchange (EEX).[21] We rely on spot prices as we expect that some short-term impacts of crucial interest for our research question, such as temperature induced demand spikes or unexpected supply shortfalls, are reflected to a greater extent in the day-ahead than in the futures market. We focus on spot prices at NCG rather than at Gaspool because liquidity within the NCG-market area is higher and therefore prices in this market should represent more valid signals.[22]

We specify our model in weekly frequency since this allows both for an inclusion of storage data, which is only available on weekly frequency before 2011, while still enabling the modeling of rather short-term meteorological conditions. The choice of an appropriate frequency, with respect to weather and storage activity, has the consequence that we cannot rely on data of industrial production or gross domestic product as an approximation for the business cycle. However, spot prices of Brent crude oil, which capture the substitution relationship of oil and gas in the residential heating market as well as the still prevailing oil indexation of German gas imports, may also serve as a valid proxy for the macroeconomic environment.[23] Spot prices of coal for delivery in North-Western-Europe, as published by McCloskey, are used in the model. These values are included to capture the interaction of gas and coal within the electricity sector and therefore represent cross-commodity effects related to fuel substitution.[24] The natural gas, crude oil and coal price time series are transformed into their natural logarithms. As commonly done in the macroeconomic literature, for example in Kim and Roubini (2000), we estimate the VAR with log-level price data because we are not interested in any possible stationarity or cointegration properties itself, but rather on the economic relationships within the natural gas market. We do not make any further assumptions and proceed with a consistently estimated VAR in log-levels. This practice is supported by Sims et al. (1990) and Toda and Yamamoto (1995).

We also account for the fact that gas demand, especially in the residential space heating sector, is highly sensitive to temperature. However, in a liberalized gas market, storage operators are expected to exploit predictable seasonal demand variations. Therefore, only unexpected shifts in gas demand, which are caused by extraordinary short-term weather conditions, are expected to be relevant for the gas price formation. Consequently, we focus on deviations from the normal seasonal meteorological pattern as a

[21] Available at http://www.eex.com/en/Download/Market%20Data/Natural%20Gas%20-%20EEX

[22] In March 2012, the trading volume for H-gas was approximately 85,500 gigawatt hours (GWh) at the Gaspool Hub, while approximately 116,600 GWh were traded at NCG in the same period. The respective churn rates were 3.02 for Gaspool and 3.51 for NCG. This data is available at http://www.gaspool.de/hub_handelsvolumina.htmland http://datenservice.net-connect-germany.de/Handelsvolumen.aspx?MandantId=Mandant_Ncg

[23] See He et al. (2010). The oil price data is available at http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=RBRTE&f=D

[24] Available at http://cr.mccloskeycoal.com/story.asp?sectioncode=164&storyCode=34769

determinant of gas prices. Thus, in a first step, we construct the historical average seasonal series of heating degree days (HDD) using temperature data from the German Weather Service for Frankfurt am Main during 1949-1999.[25] In a second step, we calculate the deviations of observed HDD and their historical averages in order to estimate the effects of unexpected temperature conditions on gas prices.

We include storage data because storage operators are both part of the supply side (storage withdrawal) and the demand side (storage injection). Existing German underground gas storage sites can be split into two categories[26]: On the one hand, pore storages balance out the seasonal divergence of supply and demand during winter and summer months. Due to technical restrictions, they are rather inflexible in their operation and hence many of them may be unable to respond to short-term price signals. On the other hand, more flexible cavern storages offset short-term imbalances between gas supply and demand. The most straightforward modeling approach would be to only consider flows of sufficiently flexible storages, which can quickly adapt their withdrawal and injection activity according to price fluctuations. Unfortunately, storage flow data are neither available on a site-specific nor on a category-specific level for Germany, as only aggregated storage data is published. Therefore, we take an intuitive approach to separate the two aforementioned categories: Accounting for the fact that inflexible storages follow a rather strict seasonal pattern, whereas flexible storages do not, we first construct an average seasonal pattern of storage utilization based on data published by Gas Storage Europe.[27] We consider utilization rates instead of absolute volumes to control for changes in the total storage capacity. In a second step, we take the first differences of the average weekly utilization. These values are the changes in average utilization for each calender week (measured in percentage points of total storage volume) and represent the seasonal storage flows. Finally, we take the difference between these average seasonal changes in utilization and the actual change in each week as a proxy for the flows related to flexible storages. It is reasonable to assume that these storages create the deviation from the seasonal storage utilization pattern.

As the supply side is concerned, natural gas production data with monthly or weekly frequencies is not available. However, we account for the gas supplies with a supply shortfall variable, which represents gas volumes that are unexpectedly not delivered to the continental European market. Thus, the variable is equal to zero when no supply interruption occurs and amounts to the missing volumes, measured in billion cubic

[25] Available at `http://www.dwd.de/bvbw/appmanager/bvbw/`

[26] In addition to underground gas storages, many above ground gas storages exist in Germany. However, since the working gas volume is comparably small, they are of less importance compared to underground gas storage facilities.

[27] Available at `https://transparency.gie.eu.com/`

meters (bcm), during periods of supply shocks. We consider the impact of the Russian-Ukrainian transit dispute of 2009, the supply shortfalls caused by the civil war in Libya in 2011 and the lack of Russian gas supplies in February 2012.[28]

Beyond capturing supply interruptions via the supply shortfall approach presented above, we also draw upon the EU-27 LNG-imports provided by Eurostat as an indicator of current supply conditions.[29] Unfortunately, the import data is only available on a monthly frequency. Therefore, we apply linear interpolation to the data as we argue that any resulting errors from this procedure are expected to be rather small compared to the benefit of modeling LNG volumes entering the European gas market. Since the EU-27 LNG-imports exhibit a significant growth over time, we linearly detrend the variable by regressing the interpolated series against time.

The major European gas markets are highly interdependent, as shown by Robinson (2007) and Growitsch et al. (2012). Based on the empirical findings of these studies, we conclude that changes in supply volumes, no matter in which market area they originally occur, induce repercussions in other continental European gas markets. Therefore, we refer to supply shortfalls and LNG-imports on a European rather than only on a national level.

3.3 A Structural VAR for the German Natural Gas Market

We employ a structural vector autoregression for modeling the interdependencies between the main gas market fundamentals in order to explicitly examine the relevant transmission channels affecting the natural gas price. Accounting the exogeneity of some variables, we constrain certain feedback-effects by restricting their coefficients to zero.

The model in its reduced-form representation can be written as

$$y_t = v + A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t \tag{3.1}$$

where $y_t = (y_{1t}, \ldots, y_{Kt})'$ is a vector of K endogenous variables and p is the number of lags included in the model. The vector v is an intercept vector with K rows and the A's are $K \times K$ coefficient matrices. Furthermore $u_t = (u_{1t}, \ldots, u_{Kt})$ is a K-dimensional vector of reduced-form errors with the properties $E(u_t) = 0$, $E(u_t u_s') = \Sigma_u$ and $E(u_t u_s') = 0$

[28]Details about the crises and the calculation of the missing supply volumes are given in Section 3.5.
[29]Available at `http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_124m&lang=en`

for $s \neq t$, where Σ_u is an invertible $K \times K$ variance-covariance matrix. We specify the VAR model to have a lag length of two lags as indicated by the Schwarz Information Criterion.

However, since u_t reflects the instantaneous causality among the variables not accounted for in the reduced-form model, this representation does not allow an economic interpretation of the error term. For this purpose, the structural model has to be identified. The structural VAR has the representation

$$Ay_t = A_1^* y_{t-1} + \ldots + A_p^* y_{t-p} + \epsilon_t \tag{3.2}$$

or equivalently, adding $(I_k - A)y_t$ to both sides of the equation,

$$y_t = (I_K - A)y_t + A_1^* y_{t-1} + \ldots + A_p^* y_{t-p} + \epsilon_t \tag{3.3}$$

where I_K represents the identity matrix of order K, A is an $K \times K$ matrix of instantaneous interaction among the variables and A_i^* is equal to AA_i for $i = 0, \ldots, p$. Moreover, $\epsilon_t = (\epsilon_{1t}, \ldots, \epsilon_{Kt})'$ is a row-vector of dimension K representing structural errors with variance-covariance matrix Σ_ϵ. As the instantaneous causality of the variables is captured by A, Σ_ϵ is diagonal. Hence, the errors of the structural representation can be assigned to a single variable and therefore be interpreted in terms of economic theory. The identification of the structural form is based on restrictions placed on the instantaneous coefficient matrix A. To derive the structural representation, a total of $K(K+1)/2$ restrictions must be imposed.

We choose a recursive identification structure as the starting point for our model. However, in case the recursive identification diverges from our economic expectations, we deviate from the recursive ordering and impose restrictions that are more appealing from an economic point of view. The instantaneous restrictions imposed for the identification of the structural VAR model are summarized in Table 3.2.

Since weather is apparently exogenous with respect to the other included variables, deviations from historical heating degree day averages are ordered first within the matrix of instantaneous interaction.

The supply shortfall variable, accounting for absent gas deliveries to the European market, also exhibits exogenous character. However, historical evidence suggests that supply shortfalls of Russian gas are more likely during peak demand periods.[30] Consequently,

[30]The experienced shortfalls of Russian gas supply to Western Europe in 2009 and 2012 both occurred during extraordinary cold weather conditions. This may be a consequence of Gazprom's priority to satisfy domestic demand.

TABLE 3.2: Identification of the Contemporaneous Matrix

	Temp-erature	Supply Shortfall	Crude Price	Coal Price	LNG	Storage	Gas Price
Heating degree days deviation	⋆	0	0	0	0	0	0
Supply Shortfall	⋆	⋆	0	0	0	0	0
Price of Brent crude oil	⋆	⋆	⋆	0	0	0	0
Price of coal	⋆	0	⋆	⋆	0	0	⋆
LNG imports to EU-27	⋆	⋆	0	0	⋆	⋆	⋆
Storage	⋆	⋆	⋆	⋆	0	⋆	⋆
Natural gas price	⋆	⋆	⋆	⋆	⋆	⋆	⋆

Notes: Each row of this table indicates an equation in the VAR model with the respective dependent variable. Each column indicates the instantaneous impact of a variable in each equation. The ⋆ denotes that a parameter is estimated from the data and that the model allows for an instantaneous relationship, whereas a 0 indicates that the according parameter is restricted to zero.

we leave the instantaneous influence of temperature deviations on supply shortfalls unrestricted.

As the price of crude oil is concerned, it appears intuitive to let it instantaneously react to the supply shortfall variable as gas supply disruptions frequently go hand in hand with a shortened supply of crude oil. A recent example of this phenomenon is the case of the civil war in Libya in 2011, which affected both natural gas and crude oil production. Furthermore, extraordinary cold weather periods increase the demand for heating oil in Europe and possibly increase the price of Brent crude oil through this channel. Therefore, we do not restrict the impact of heating degree days on the crude oil price.

The price of coal is assumed to be instantaneously affected by weather conditions (via an increase in power demand). Additionally, accounting for the role of crude oil as a global benchmark commodity and the character of gas as a substitute for coal, it seems reasonable to assume a contemporaneous impact of oil and gas prices on the price of coal.

The first variable directly related to the German gas market is the EU-27 import of LNG. Unexpected weather conditions as well as supply shocks are likely to evoke significant changes in natural gas market fundamentals and hence the demand for LNG volumes. Therefore, we do not place any restrictions on the respective coefficients. Furthermore, LNG imports are expected to be affected by gas prices and storage flows. Regarding the necessary restrictions for identifying this equation, we argue that the instantaneous impact of coal and oil prices are of less, if any, relevance. Hence we restrict these coefficients to zero.

It is necessary to account for the endogeneity of storage flows with respect to changes in gas prices. Gas storages are likely to react instantaneously to changes in gas prices since inter-temporal price arbitrage is the economic rationale of any commercial storage operator. Additionally, storage flows are expected to balance temporary divergence of supply and demand caused by any unforeseen shifts in market conditions (i.e. weather, supply surprises or cross-commodity effects). Thus, we allow for the direct effects of gas prices, coal prices, oil prices, unexpected temperatures and supply shortfalls on storage flows. Finally, since the German gas price is of main interest to our research, no restrictions are placed on the equation of this variable. This allows for a comprehensive analysis of the instantaneous impacts of all variables considered in the model on the price of natural gas.

As the instantaneous restrictions required for identification are based on economic theory, we use them also for lagged relationships with the following exceptions: First, the supply shortfall variable is set to be strictly exogenous, i.e. not affected by lagged temperature changes. Second, we allow for cross-commodity price effects in all directions because, from our perspective, there is no need to impose strict exogeneity to crude oil prices a priori. Third, the process of heating degree days is modeled as a first-order autoregressive process and has no lagged influence on crude oil and coal prices. We argue that temperature effects on commodity prices exhibit short-term character. Additionally, we allow LNG imports, storage and natural gas prices to depend on lags of all other variables. Table 3.3 summarizes the parameter restrictions on the lagged relationships.

Table 3.3: Lag Restrictions in the VAR Model

	Temp-erature	Supply Shortfall	Crude Price	Coal Price	LNG	Storage	Gas Price
Heating degree days deviation	$\star$/0	0	0	0	0	0	0
Supply Shortfall	0	0	0	0	0	0	0
Price of Brent crude oil	0	$\star$	$\star$	$\star$	0	0	$\star$
Price of coal	0	0	$\star$	$\star$	0	0	$\star$
LNG imports to EU-27	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$
Storage	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$
Natural gas price	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$	$\star$

Notes: Each row of this table indicates an equation in the VAR model with the respective dependent variable. Each column indicates a lagged impact of a variable in each equation. The $\star$ denotes that a parameter is estimated from the data, whereas a 0 indicates that the according parameter is restricted to zero.

The restrictions placed on lagged relationships imply different regressors within the VAR-framework. The existence of different explanatory variables makes the ordinary least squares estimator inefficient, as pointed out by Zellner (1962), since the error term of the reduced-form representation contains instantaneous correlation among the variables. Accordingly, we explicitly account for the correlation between the variables when estimating the reduced-form model using feasible generalized least squares (FGLS).

The estimation of the structural model in the second step is based on the variance-covariance matrix of the reduced-form residuals estimated via FGLS. The structural-form parameters are nonlinear with respect to the reduced-form parameters and therefore only iterative algorithms, instead of a closed-form solution, can be applied. Hence, we estimate the structural-form parameters using the scoring algorithm of Amisano and Giannini (1997), as proposed by Lütkepohl (2005).

3.4 Results

The structural moving average (MA) representation of our model can be used to infer impulse response functions. Dropping the intercept term, as it is of no interest for the analysis, allows the structural MA-form to be written as

$$y_t = \sum_{i=0}^{\infty} \Theta_i \epsilon_{t-i} \tag{3.4}$$

where ϵ has the properties as described in Section 3.3. The Θ_i-matrices can be calculated using the previously estimated structural coefficient matrices and contain the dynamic multipliers within the system. Hence, the response of variable j, i periods after an impulse of variable k is reflected in $\theta_{jk,i}$, the jk-th element of Θ_i. The impulses have the size of one standard deviation as we use the square roots of the estimated structural variance-covariance matrix for the calculation of responses. Following Lütkepohl (2005), who emphasizes the problematic finite sample properties of asymptotic confidence intervals for impulse responses, we rely on numerical resampling methods to derive error bands. We refer to Hall's 95-percentage bootstrap intervals using 1000 draws (see Hall (1995)). We generate responses of the natural gas price on impulses of all other variables, thus exploring the dynamic effects of gas market fundamentals on the price development. Figure 3.1 presents the estimated impulse response functions for the natural gas price.

The impulse responses of the natural gas price are consistent with economic reasoning. Extraordinary cold weather results in an immediate and strong increase in the natural gas price. This increase is significant but lasts only for two weeks, indicating that temperature deviations have rather short-term effects on gas prices. Supply disruptions, approximated by the structural innovations of the supply shortfall variable, also cause a rise in the natural gas price. This result is consistent with both historical market conditions, e.g. the price spikes in January 2009 and February 2012, and economic theory. The missing volumes are replaced by more expensive sources of supply to satisfy the rather price-inelastic gas demand. Furthermore, the impact on the natural gas price

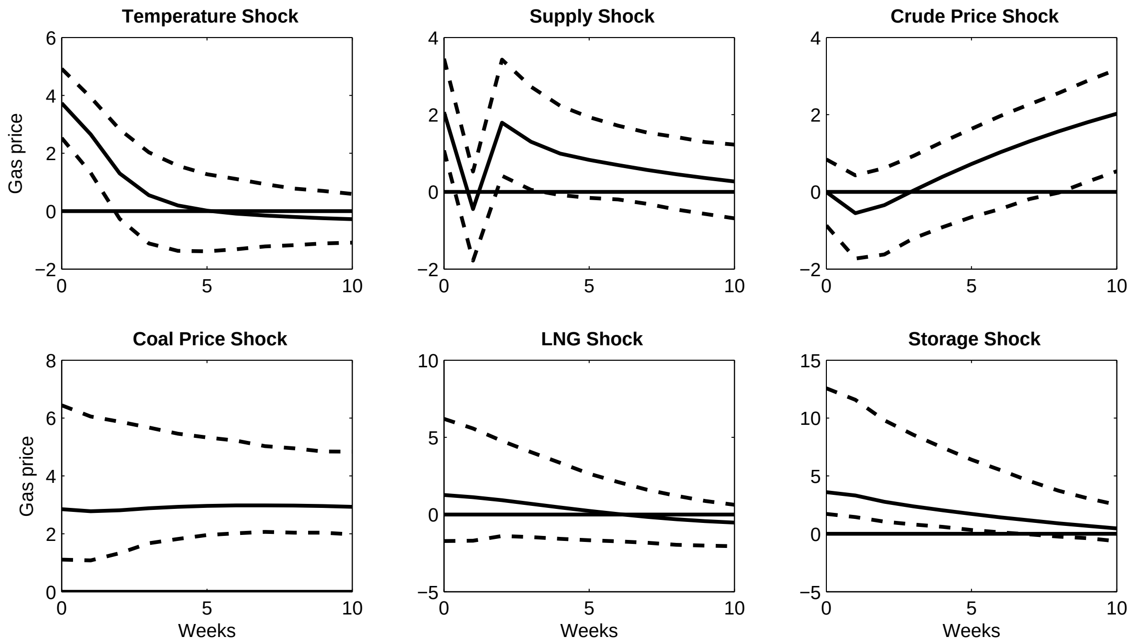

FIGURE 3.1: Responses of the Natural Gas Price

Notes: The impulse responses (solid lines) are based on one standard deviation of the respective structural shock. They can be interpreted as the percentage change in the natural gas price as a reaction to a standardized shock of the respective variable. Confidence intervals (dashed lines) are bootstrapped as Hall's 95-percentage bootstrap interval using 1000 draws.

could also be attributed to the uncertainty of future supply conditions resulting in spot purchases (e.g. storage injection as a consequence of anticipated price increases).

The derived structural response functions of the natural gas price, with respect to oil and coal prices, provide evidence of significant interdependencies among energy commodities. The price of gas responds positively to shocks of both oil and coal prices. However, the pattern with which oil and coal influence the natural gas prices is fundamentally different. The impact of coal prices on gas prices occurs instantly and remains stable over time. In contrast, oil prices only affect natural gas prices after a substantial time delay.[31]

The strong interdependency of coal and gas prices can be attributed to different features of European energy markets. First, the fuel-competition of the primary energy carriers gas and coal in the electricity sector may induce a positive cross-price elasticity of these commodities. Consequently, a rise in coal prices implies an increased demand for gas and therefore a resulting price increase. Second, since the spot prices used in this study comprise the North-Western European coal price and the German natural gas price, they reflect the same regional economic dynamics. Therefore, they are both economically and geographically closely related to one another.

[31]This finding is also supported by the correlations of price returns. While the returns of gas and coal prices have a correlation coefficient of 0.2088, the correlation of oil and gas returns is 0.0486 and insignificant. The two-tailed 5% critical value is 0.1305 for 226 observations.

In contrast, the physical link of crude oil and natural gas exhibits rather long-term character, since direct substitution is effectively limited to the residential heating sector. Moreover, as indicated by He et al. (2010), oil prices may serve as an indicator for the current state of the global macroeconomic environment, which potentially differs from the European business cycle in the short-run. However, in the long run, the European economy is unlikely to decouple from the global economic conditions and thus oil prices should serve as a valid indicator for the business cycle driven industrial demand for natural gas. Moreover, as oil-indexed long-term contracts still prevail in German gas imports, a certain degree of long-run correlation between these two commodity prices seems plausible.

Next, the influence of the endogenous gas market variables on the natural gas price is discussed. There is no clear effect of a LNG import shock on the natural gas price, which may be caused by the use of interpolated monthly LNG import data. A positive structural shock of storage contributes to rising gas prices, as the injected volumes increase the spot market demand. Intuitively, a positive structural shock of storage can be interpreted as an abnormal storage injection or as a storage withdrawal that is smaller than presumed from the current market situation.

Although our focus is on the determinants of the natural gas price, we briefly discuss the structural responses of LNG imports and storage, since they are a novelty in econometric research on European gas markets. The respective impulse responses are presented in Figure B.2 in the Appendix. The impulse response analysis shows that extraordinary low temperatures lead to storage withdrawals. This mechanism is caused by an increase in the temperature-sensitive natural gas demand in the residential and commercial heating sector. The additional demand has to be satisfied by gas withdrawal from storage facilities. The reaction of storage flows to supply disruptions is rather volatile and does not reveal a clear pattern. The response of storage flows to structural shocks in the natural gas price is consistent with the economic objectives of storage operators because higher natural gas prices intuitively incentivize storage operators to withdraw natural gas. The determinants of LNG imports are estimated with large error bands. Thus, there seems to be no clear pattern how the included fundamental gas market variables influence the amount of imported LNG.

In the following discussion, we return to the investigation on the impact of different fundamental influences on the natural gas price. In order to analyze the relative contribution of the variables considered in the modeling framework, we perform a forecast error variance decomposition using the results of the estimated structural VAR model.

Based on the structural MA-representation of the VAR model, the contribution of innovations in variable k to the error variance of an h-step forecast of variable j can be written as

$$\omega_{jk,h} = \sum_{i=0}^{h-1} e_j' \theta_i^2 e_k / MSE[y_{j,t}(h)] \tag{3.5}$$

with

$$MSE[y_{j,t}(h)] = \sum_{i=0}^{h-1} \sum_{k=1}^{K} \theta_{jk,i}^2 \tag{3.6}$$

as the mean squared error (MSE) of h-step forecasts for variable j and e_k as the k-th column of an identity matrix of order K. Consequently, in our model framework, $\omega_{7k,h}$ represents the fraction of gas price variance that can by explained by the structural innovations of another variable included in the model.

Table 3.4: Forecast Error Variance Decomposition for the Natural Gas Price

Forecast Horizon	Temp -erature	Supply Shortfall	Crude Price	Coal Price	LNG	Storage	Gas Price
1	0.26	0.08	0.00	0.15	0.03	0.24	0.24
2	0.23	0.05	0.00	0.17	0.03	0.26	0.25
4	0.16	0.07	0.00	0.22	0.03	0.26	0.26
8	0.11	0.06	0.02	0.33	0.02	0.23	0.23
12	0.09	0.05	0.07	0.39	0.02	0.19	0.19
26	0.05	0.02	0.30	0.37	0.02	0.12	0.12
52	0.04	0.02	0.39	0.26	0.01	0.14	0.14

Table 3.4 shows the estimated shares of the variance of the natural gas price accounted for by the structural innovations of each variable. The results are both intuitive and consistent with the economic arguments provided above. In the short run, supply disruptions and unexpected temperature deviations are of major importance for the natural gas price and explain 34% of its fluctuation. However, the impact of these effects is rather short lived and hence, their influence diminishes over time. For longer horizons, the forecast errors of gas prices can be explained more precisely by developments related to the coal and oil markets. The variation in coal prices reaches its maximum explanatory power in medium-term horizons (12 to 26 weeks), while the long-term gas price development (up to 52 weeks) is heavily affected by variations in oil prices. With a forecast horizon of half a year, the aggregated effects of changes in coal and oil prices account for 67% of the gas price variance. Furthermore, our results indicate that storage flows have an important short-term influence on gas prices, a finding that is consistent with the fact that storage facilities balance the occuring demand and supply fluctuations

in the natural gas market. In contrast, the explanatory power of LNG imports on the gas price is weak for all time horizons.

Both the impulse response analysis and the decomposition of the forecast error variance indicate that coal prices are more relevant than crude oil prices in explaining the natural gas price in the short term. While recent literature, for example Brown and Yücel (2008), Ramberg and Parsons (2012) and Hartley et al. (2008), focuses on the relationship between crude oil and natural gas prices, our results highlight that for an improved understanding of gas price dynamics, attention should also be paid to the interdependencies of gas and coal markets.

3.5 Event Studies of Supply Interruptions: Historical Decomposition of Structural Shocks

In this section, we examine the price impact of the three major interruptions in gas supply since the year 2008. First, we analyze the import disturbances from Russia in January 2009, which were caused by a dispute between Russia and Ukraine about the conditions of gas transit. Second, the Libyan production outage in the spring of 2011 due to a civil war is investigated. Third, we explore the withheld exports by Russia in February 2012.

Two difficulties regarding our analysis are that the nature of these supply shocks is not perfectly equivalent and that the gas infrastructure also changes over time. For example, the Russian-Ukrainian gas transit dispute could have a different impact if it occurred after the commissioning of the Nord Stream pipeline.[32]

In order to harmonize the impact of these different disruptions, we attempt to objectify the magnitude by calculating approximative values for the volumes of supply shortfall. Taking into account the high degree of integration among European national gas markets, as shown by Robinson (2007), Renou-Maissant (2012) and Growitsch et al. (2012), we argue that one unit of production or import shortfall to the European market results in similar economic effects for all cases and locations of the gas shortage. The method has the advantage that the estimated effect of supply shocks, as derived from our model, has a generalizable interpretation. This property is desirable because future supply shocks are inherently uncertain with respect to the time and location of their occurrence.

[32]The Nord Stream pipeline directly connects Russia with Germany through the Baltic Sea and therefore bypasses the transit route of the Ukrainian corridor. Thereby, Russia increases its own bargaining position towards transit countries as pointed out by Hubert and Ikonnikova (2011).

While the three supply disruptions analyzed in this study are of political nature, technical defects could also potentially lead to supply disruptions from politically stable exporters. An illustrative example for such a major technical malfunction is the fire at the Rough gas storage facility, which prevented access to 80% of the total UK storage capacity in the year 2006 and was analyzed in detail by Giulietti et al. (2012).

The proposed structural VAR model is able to disentangle the different fundamental effects during the supply disruptions described above. The technical procedure of our analysis is generally the same for all three event studies of the respective supply shocks. We determine the first week in which the specific situation begins and calculate the impact of the relevant structural shocks on the natural gas price. For this purpose, we do not only use the shock in the first week, which would be similar to an impulse-response analysis, but extract the actual sequence of the relevant structural shocks to infer the accumulated impact in each period. As an indicative benchmark, we also show the actual development of the natural gas price in each plot.[33]

3.5.1 The Russian-Ukrainian Gas Conflict of 2009

The Russian-Ukrainian gas dispute of 2009 is one of the most prominent examples of political supply risks related to natural gas imports from Russia. In January 2009, natural gas transits from Russia into Western Europe were disrupted for about two weeks as Russia and the Ukraine could not find an agreement on transit charges. According to Lochner (2011), who analyzes this crisis in detail, Russia at this time accounted for 25% of the natural gas supplies to the European Union, 65% of which were transported through Ukraine. Our estimates of the supply shortfalls during this crisis are based on the supply statistics of Naftogaz Ukrainy reprinted in Pirani et al. (2009). The transit volumes declined from 318.4 million cubic meters (mcm) on January 1st, 2009 to a complete stop on January 7th. The gas flows were interrupted until January 20th and regained normal levels on January 22nd. In order to calculate the volume of missing deliveries, we take the volume of gas transported on January 1st as a reference case and consider volumes below that level as supply shortfall. To measure losses between January 20th and January 22nd, we linearly interpolate to the pre-crisis volumes to be reached on January 22nd.

Following this procedure, the calculated lacking transit volumes amount to 4932.1 mcm in total. To test for robustness, we compare this estimate with the Eurostat Russian

[33]The actual change in the natural gas price also depends on structural shocks before the time period analyzed. However, in the historical decomposition of the event studies, these shocks prior to the event are not included in the relative contribution of each influence during the specific event considered. Therefore, the relative influences during the crisis itself do not necessarily provide an optimal fit of the actual change in the natural gas price, which is therefore only included for illustrative purposes.

natural gas exports to EU-27 countries. The exports reported in January 2009 are 4585.9 mcm lower than in January 2008, 4793.7 mcm lower than in January 2010 and 5119.2 mcm lower than in January 2011. This comparison indicates that our estimates are of meaningful magnitudes. As a second robustness test of our approach, we compare our estimates of lacking deliveries with the simulation-based estimate derived by Lochner (2011). According to that analysis, the affected daily gas transits via Ukraine account to 303.5 mcm on a normal winter day, which is close to the value found in our methodology.

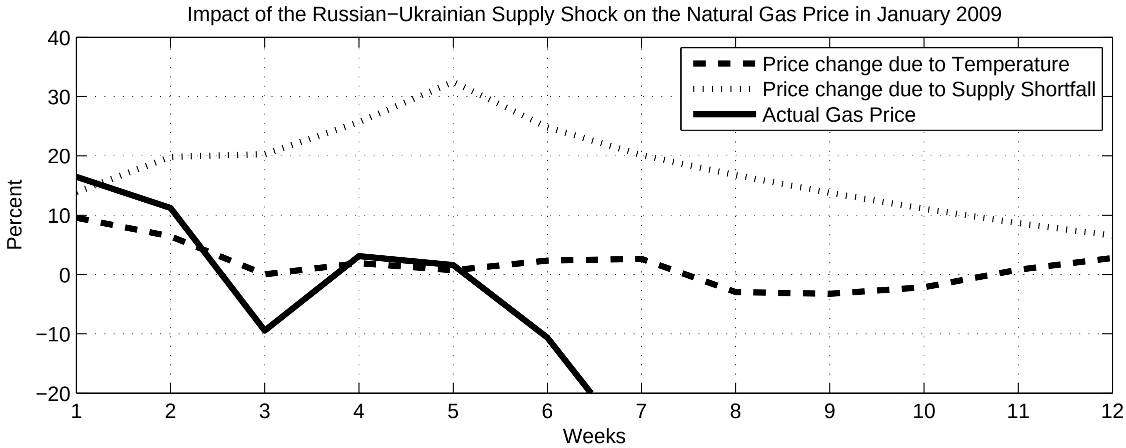

FIGURE 3.2: Historical Decomposition of Structural Influences During the Russian-Ukrainian Gas Dispute of January 2009

Notes: Week 1 refers to the week ending on Friday January 9th, 2009

Figure 3.2 shows the fundamental drivers of gas prices during the Russian-Ukrainian dispute of January 2009 and for a period of 12 weeks. The shortfall of natural gas supplies accounts for an increase in the gas price of more than 30% and is therefore the main driver of the observed price spike. Increased demand due to unusually low temperatures accounts for 10% of the price increases and is especially of importance during the first two weeks. To summarize, the natural gas price follows the fundamental signals both from supply (interruption of imports) and demand (extraordinary low temperatures) closely.

However, the actual increase in the gas price was less than what would have been implied by the sudden supply shortfall and extreme temperature when setting all other influences to zero. This is due to the fact that the Russian-Ukrainian gas dispute occurred during the financial crisis and the natural gas price was already following a negative trend. During this time, the financial crisis and the global economic downturn constituted a distinctive influence on all commodity markets.

Therefore, we investigate the price impact during a longer period surrounding the supply disruption. Figure 3.3 shows the weekly development of the natural gas price for the six months after the bankruptcy of Lehman Brothers on September 15th, 2008. In this figure, the spike in natural gas price in week 17 is driven by the start of the Russian-Ukrainian dispute in January 2009. The extended time window illustrates that while the short-term impact of the supply shock is substantial, it only had a short-lived impact on the overall downward sloping trend of the natural gas price. The results of this event study confirm our previous finding that the long-term development of the natural gas price crucially depends on the economic climate and closely follows the benchmark commodity prices of oil and coal.

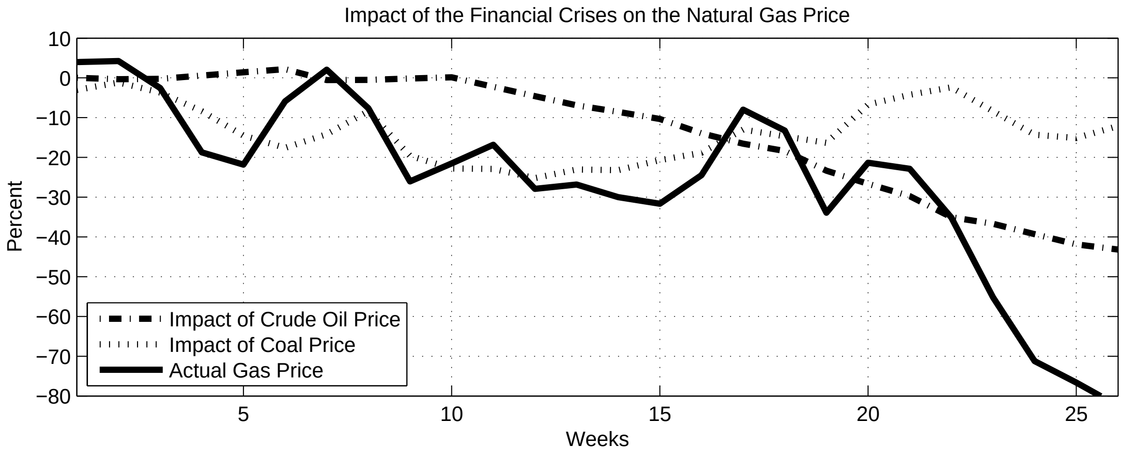

Figure 3.3: Historical Decomposition of Structural Influences During the Financial Crisis Following the Bankruptcy of Lehman Brothers on September 15th, 2008

Notes: Week 1 refers to the week ending on Friday September 19th, 2008. The price increase in week 17 reflects the beginning of the Russian-Ukrainian gas dispute of January 2009.

3.5.2 The "Arab Spring" and the Civil War in Libya 2011

In February 2011, the civil unrest of the so-called "Arab Spring" spread to Libya and resulted in a civil war with foreign military intervention. This turmoil lead to an interruption of natural gas production in Libya. Although Germany does not directly import natural gas from Libya, the shortfall of Libyan exports also indirectly affected the market. Lochner and Dieckhöner (2012) point out that Italy compensated for the Libyan imports by using storage withdrawals and additional imports via Austria and Switzerland, highlighting the integration of European natural gas markets. The shortfall of Libyan production therefore indirectly affects the German natural gas market because natural gas flows from Russia were diverted to Southern Europe and could consequently not be delivered to German consumers.

In order to estimate the supply shortfall, we use monthly Eurostat export data from Libya to Italy, which is Libya's main customer in the EU. We linearly interpolate from monthly to weekly frequency and define the supply shortfall as the difference between the actual exports and the exports before the interruption. According to Lochner and

Dieckhöner (2012), delivery via the Greenstream pipeline to Italy was interrupted from February 22nd to October 13rd, 2011. This period is consistent with Eurostat data indicating no exports to the EU between March and September 2011. As Italy was able to compensate the Libyan supply shortfalls by additional imports from Russia, we only consider the missing Libyan gas volumes until the mid of April 2011 as a shock.[34]

In addition to the actual supply shortfall, there were also other indirect effects on the natural gas market. First, there was an additional risk that the Arab Spring could spread to Algeria and thus disrupt the Algerian natural gas production. In this case, as Lochner and Dieckhöner (2012) point out, the consequences for the European natural gas market would have been more severe. Second, the Arab Spring also affected the crude oil market both directly and indirectly. Libya is a relevant crude oil exporter and the market, according to news coverage, accounted for the risk that the Arab Spring could spread to other more important crude oil producers in the Middle East. Baumeister and Kilian (2012) discuss how the negative supply shock in Libya, as well as a precautionary demand shock driven by the political unrest resulting in a stocking up of crude oil, contributed to the increase in the real price of oil.

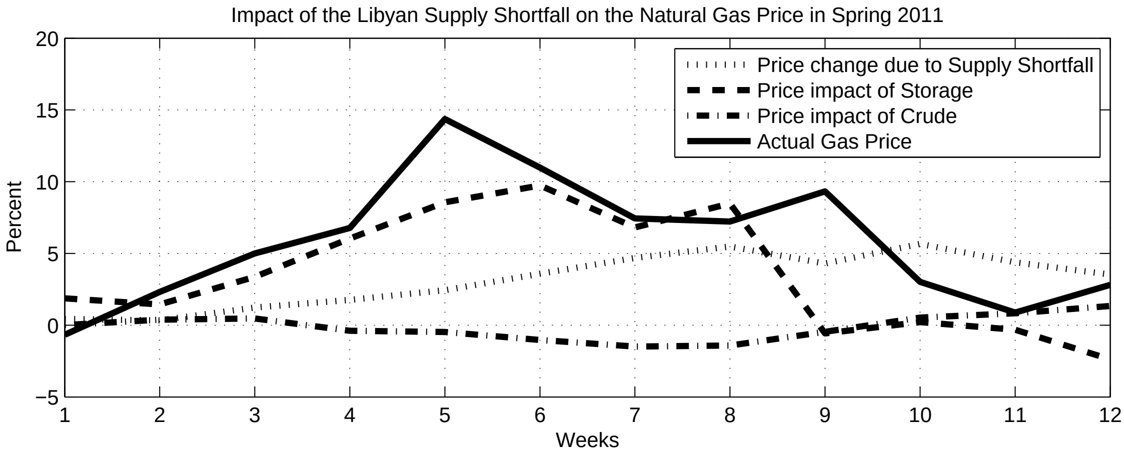

FIGURE 3.4: Historical Decomposition of Structural Influences During the Supply Shortfall After the Libyan Civil War in the Spring of 2011

Notes: Week 1 refers to the week ending on Friday February, 18th, 2011

Figure 3.4 shows the impact of the Libyan supply shortfalls in Spring 2011. Due to the relatively small amount of supply shortfalls, the direct impact on the gas price is rather weak. Furthermore, our analysis indicates that the development of the crude oil price does not seem to be a major explanatory factor for the German gas price increase during

[34]Lochner and Dieckhöner (2012) argue that the lack of imports from Libya were mainly compensated by increased imports via the Austrian TAG pipeline carrying Russian natural gas deliveries. However, as it takes approximately two weeks for Russian gas to be physically transported to Italy, the compensation mechanism of delivering additional gas via pipelines from Russia was mainly relevant after the first few weeks of the interruption.

the Libyan civil war in 2011. Yet, due to the political instability and risks associated with Algeria as a larger natural gas exporter, the increased precautionary demand for storage leads to increased gas prices. Such behavior is typical for energy markets during situations of uncertainty or turmoil in supplying countries, as shown by Kilian and Murphy (2010) using the Iranian Revolution in the year 1979 as one example.

3.5.3 Supply Interruptions of Russian Natural Gas Deliveries in February 2012

In late January 2012, unusually low temperatures increased the domestic Russian gas demand for a sustained period of time. As the cold weather spread to Central and Western Europe, Russia found itself unable to meet its export commitments and thereby induced supply shortages and price spikes at various European gas hubs. However, there is a lack of quantitative estimates regarding the amount of the shortfall of supply during February 2012. In order to calculate a reasonable estimate, we draw upon different sources including the Dow Jones TradeNews Energy, the ICIS Heren European Gas Markets report and a report by Henderson and Heather (2012). Details regarding the information in these sources is given in Table B.1 in the Appendix. The estimates of supply interruptions are mostly in the range of 10 and 30%, but vary depending on the date, geography or company considered. Given this wide range of estimates, we assume a shortfall of 20% in the first two weeks of February 2011 and assume a normal weekly delivery volume of 2.5 bcm to the EU as indicated by Eurostat data.

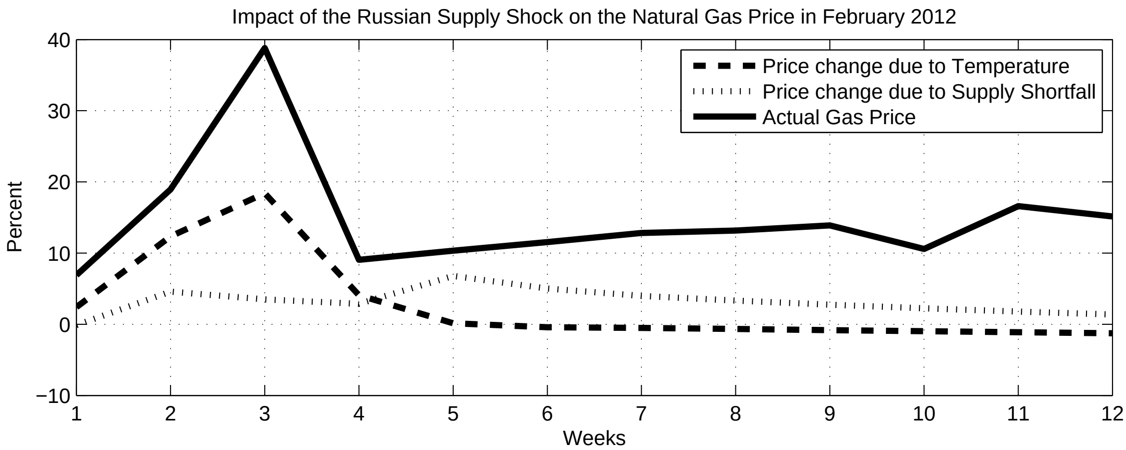

FIGURE 3.5: Historical Decomposition of Structural Influences During the Russian Supply Shortfall in February 2012

Notes: Week 1 refers to the week ending on Friday January 27$^{\text{th}}$, 2012

In Figure 3.5, we analyze the period of reduced Russian supplies in February 2012 coinciding with extraordinary cold temperatures. Our results indicate that the abnormally low temperatures can explain a bigger share of the actual price increase than the relatively small amount of supply shortfall. Consequently, we conclude that the price increase was rather driven by a positive demand shock than by the temporary cut in gas supplies.

3.6 Conclusion

In this study, we introduce a novel approach to model the economics of natural gas prices. Our structural model allows us to appropriately account for the dynamics within the natural gas market as well as for the relationship to other commodity markets. The empirical results for Germany show that abnormal temperatures and supply shocks only affect the natural gas price in the short term. However, in the long term, the price development is closely tied to crude oil and coal prices, which capture both the business cycle and the energy specific demand.

The structural model allows us to perform a historical decomposition of the shocks affecting the natural gas price. We focus on the three major recent supply interruptions, namely the Russian-Ukrainian gas dispute of 2009, the Libyan supply shortfall in the spring of 2011 and the withheld Russian exports in February 2012. We explicitly analyze the specific contribution of the main fundamental variables on gas price development in these periods. Our findings can be used to draw conclusions about how the security of gas supply can be improved by different measures. The results of our structural model indicate that while supply shortfalls have a significant impact on the German gas market, their effect on gas prices may be overestimated since some of the discussed shortfalls occurred simultaneously with extraordinary demand conditions. These conditions comprise both extremely low temperatures and precautionary demand resulting from the anticipation of further supply interruptions, as pointed out in Section 3.5.

Consequently, the objective to improve the security of German gas supplies should not only focus on supply-sided measures such as a diversification of gas imports, but could also address flexibility options on the demand side of the market. A further extension of temperature-indexed interruptible contracts for industrial customers could be a conceivable measure to target demand flexibility. Modifications in the current market design for gas storages could keep these facilities available despite narrowing seasonal price spreads.

Our model provides a comprehensive and innovative framework for further research on more specific economic mechanisms within gas markets. Additionally, it could be easily extended to a European scope or other geographical regions. However, the current application is still restricted by the limited data available for the European gas markets.

Chapter 4

Understanding the Determinants of Electricity Prices and the Impact of the German Nuclear Moratorium in 2011

4.1 Introduction

Electricity is a homogeneous good that cannot be stored at reasonable economic costs. However, the demand is highly seasonal and needs to be satisfied at all times. Hence, it is most efficient to generate electricity with a mixture of various technologies with different properties regarding capital costs and marginal costs. These technologies also differ in terms of input fuels and carbon emissions.

Therefore, how input price variations affect the electricity price critically depends on the marginal technology used; and the marginal technology used depends on the level of the residual demand.[35] The present paper tries to investigate exactly this effect. To illustrate the point, consider the "merit order", i.e., an ordering of fossil power plants from those with low marginal cost (like lignite or hard coal) to high marginal cost (natural gas). If the residual demand is low (e.g. because electricity demand is low in the night; or because there is a lot of wind feed-in), the marginal power plant will be a coal fired power plant, and we expect that changes in the gas price will not affect the electricity price. This will be the case only if demand is high. The approach in

[35] The residual demand is the electricity demand minus the feed-in of renewables, like wind or solar power.

the present paper allows to identify how the fuel price effects vary with the size of the residual demand.

This is analyzed empirically using data from the German electricity market and applying a semiparametric cointegration model. In order to measure how the fuel price sensitivity changes throughout the merit order, it is necessary to use a model that allows the parameters of the fuel price sensitivity to vary freely. The semiparametric varying smooth coefficient model, which was introduced by Hastie and Tibshirani (1993), allows for straightforward analysis of the relationship between fuel price sensitivity and load. The main advantage of the model is that the nature of the varying effect is directly derived from the data, which means that there is no need for ad-hoc assumptions or restrictive functional specifications. Recent work by Cai et al. (2009) and Xiao (2009) shows that such a model can be used to estimate the nonlinear functional coefficients of a cointegration relationship. The application of this estimator is novel for modeling the dynamics of electricity markets. This method indicates a technology switch from coal to gas fueled power plants at around 60 gigawatt (GW) average non-wind daily peak generation. The estimated input price sensitivities are used to simulate the merit order for different natural gas and carbon price scenarios.[36]

The usefulness of this approach can be illustrated by analyzing a specific policy intervention like the German nuclear power suspension in March 2011. After the incident in Japan's Fukushima nuclear power plant, the German government decided to put the so called "Nuclear Moratorium" in place. Seven nuclear power plants, all built before 1980, had to be switched off from 03/15/2011 to 06/15/2011 to examine the security of these plants. After the announcement, the market reacted with immediate price increases of electricity, gas and carbon emission allowance futures. Using only these futures prices, the proposed model is able to split the electricity price increase into a fuel price component and a capacity effect. It is also possible to measure the expectations of the market for the period after the end of the moratorium. The results of the event study show that the market accounts for most of the capacity effect during the period of the moratorium and expects that several nuclear power plants remain closed. This expectation proved to be correct as all affected nuclear power plants were permanently decommissioned after the end of the moratorium.

The approach in this paper relates to two distinct strands of the literature on empirical modeling of energy prices. The first strand focuses solely on the electricity market and tries to resemble the stochastic characteristics of the typical price patterns. Driven by capacity constraints, hourly and daily prices have a high volatility and spikes. There are

[36] Carbon prices refer to EU emission allowance certificates under the European Emission Trading Scheme phase II.

also hourly, daily and monthly seasonalities that reflect demand patterns of consumers and industry. The two most prominent approaches are the "Mean Reverting Jump Diffusion Model" and the "Markov Regime Switch Model", which are both described by Weron et al. (2004). These models can also be extended by additionally accounting for fundamental factors like load (see Mount et al. (2006), Kanamura and Ohashi (2007)). However, this class of models has the drawback that the relationship between the electricity price and input fuel prices is not analyzed.

The second strand of literature consists of studies that broadly analyze the interdependencies between different energy commodities, but fail to account for the aforementioned specific fundamentals of the electricity market. Mohammadi (2009) uses a vector error correction model (VECM) to analyze the long-term relationship between fuel prices and electricity prices in the US. Mjelde and Bessler (2009) indicate that fossil fuels are weakly exogenous and electricity prices adapt to re-establish the equilibrium. Similar results hold for the European electricity markets. Bosco et al. (2010) employ a set of robust tests to show that European electricity time series have a unit root and are cointegrated. Electricity prices seem to share a common trend with gas prices, but not with oil prices. Ferkingstad et al. (2011) also find that gas prices have strong instantaneous and lagged causal effects on electricity prices, while coal and oil prices are less important. Furthermore, coal, oil and gas prices are weakly exogenous. Fell (2010) finds evidence that the effect of fuel prices varies with the level of demand. The author estimates a VECM for the Scandinavian electricity spot market and several inputs. The short-term impact of the carbon price on the electricity price is higher in off-peak hours than in peak hours. Coulon and Howison (2009) account for this effect by directly modeling different parts of the supply stack. The actual bids are split into clusters, which are governed by different fuels.

The present paper advances the current literature by showing how exactly the natural gas and carbon price sensitivities vary with load. It fills the gap between models that focus on idiosyncratic effects of the electricity market and models that focus broadly on interdependencies between energy markets. The remainder of this paper is organized as follows. Section 4.2 describes the data sets that are used for the analysis. Section 4.3 outlines the semiparametric varying coefficient cointegration model and discusses the empirical results. This part includes the semiparametric estimates of the gas and carbon price sensitivity functions as well as the predicted merit order simulation for different input price scenarios. In Section 4.4, the proposed semiparametric model is used to analyze the market impact of the German nuclear moratorium in March 2011. The conclusion is given in the final section.

4.2 Data

This study focuses on electricity, natural gas and carbon prices in Germany. The data consists of daily observations from 2008/04/01 to 2010/09/29. All price time series were obtained from the European Energy Exchange (EEX). This analysis uses day-ahead base, peak and off-peak electricity prices on weekdays. The peak block covers the hours from 8 am to 8 pm, while the off-peak block covers the remaining time. The base block is the daily average price. Daily day-ahead EEX gas prices are quoted from July 2007 onwards. Both Gaspool and NetConnect Germany (NCG) contracts are traded, but I choose NCG because of the higher liquidity in this market. NCG gas prices are denominated in Euro/MWh and will be used as an indicator for the gas market as a whole. For carbon prices, the EEX Carbix index of the EU Emission Trading Scheme phase II is used.[37] All prices are transformed into their natural logarithms.

Lignite, coal and oil prices are not included for several reasons. First, the oil fueled electricity generation capacity in Germany is rather small, as it is shown in Table 4.1. Moreover, the trading and transportation properties of the coal market do not match the daily frequency setup of this study. Lignite is not actively traded and is usually not the marginal technology, which also holds for nuclear power. Adjustments for electricity ex- and imports as well as reservoir power stations can be neglected, because the observed relationship between load, input prices and electricity prices implicitly accounts for their influence. Several comparable studies, including Fezzi and Bunn (2009) and Zachmann and von Hirschhausen (2008), choose a similar approach and focus on the cointegration relationship between electricity, gas and EU emission allowance prices. The analysis of detailed cross-commodity relationships for a system of all different energy commodities is not the aim of this study, but can be found in Ferkingstad et al. (2011) and Mjelde and Bessler (2009).

Germany's diversified technology and fuel mix is shown in Table 4.1. Electricity from renewable energy sources enjoys a preferred feed-in policy. The remaining load is covered by other technologies and cross-border exchange. Nuclear and lignite fueled plants satisfy the base load, while coal and especially gas fueled power plants cover the peak demand during the day. Generators have to buy EU emission allowances for their carbon emissions.

[37]The gas prices are taken from the trading day that is closest to delivery to match the trading structure of the electricity market. Carbon spot prices are taken from the same trading day as the gas prices. The delivery day of gas and electricity contracts is the same.

TABLE 4.1: The German Electricity Generation Portfolio by Technology

Technology	Installed Capacity (in MW)
Wind	25,848
Nuclear	20,441
Lignite	20,375
Coal	16,158
Gas	13,094
Solar	10,392
Oil	1,826
Hydro	1,678
Waste	496
Total	110,307

Source: German Federal Ministry of Economics and Technology, 2010.

ENTSO-E provides hourly load data for Germany.[38] Wind forecasts and realized wind production were obtained by aggregating publically available data from the major transmission system operators (TSO), Amprion, 50Hertz and Transpower.[39] Wind power production from EnBW has been neglected because of the unavailability of forecasts and the small capacity.[40] Daily wind in-feed and load data was derived by averaging the quarter-hourly and hourly data. Day-ahead load forecasts are necessary to model day-ahead electricity prices. I assume that the realized load is the best proxy for this variable, because there is no publically available and generally accepted load forecast. The realized load is adjusted by the official wind production forecasts of the major TSOs. This adjusted load is called residual load. Summary statistics of the price and load variables are given in Table 4.2.

TABLE 4.2: Summary Statistics

Variable	Unit	Mean	Median	Minimum	Maximum	Std. Dev.
Base Electricity	€/MWh	53.71	47.68	17.06	131.40	18.71
Peak Electricity	€/MWh	65.03	55.92	33.15	177.49	24.45
Off-peak Electricity	€/MWh	41.67	38.73	-11.25	87.08	13.61
EU Emission Allowance	€/t CO2	16.30	14.53	8.02	28.75	4.74
NCG Gas	€/MWh	17.91	17.14	6.90	32.04	6.82
Base Residual Load	MW	53,449	53,446	37,773	63,978	4,332
Peak Residual Load	MW	59,303	59,394	41,445	69,255	4,619
Off-peak Residual Load	MW	46,973	46,951	33,566	60,699	4,309

For the event study of the impact of the nuclear moratorium, a range of different EEX future contracts are used for a period from 2012/02/28 to 2012/04/18. The analysis

[38]ENTSO-E is the abbreviation for the European network of transmission system operators for electricity. Data is publically available from `www.entsoe.eu`.

[39]The data can be downloaded from: `www.amprion.net/en/wind-feed-in`, `www.50hertz.com/en/1983.htm` and `www.transpower.de/site/en/Transparency`.

[40] EnBW accounted for 1.86% of the total German wind power production in August 2010. Data was obtained from `www.enbw-transportnetze.com`.

includes monthly electricity futures settlement prices with delivery in April, May and June 2011, quarterly futures with delivery in the second, third and fourth quarter of 2011 and yearly futures for 2012 and 2013. The analyzed electricity and gas prices are futures with the same delivery period. The carbon price is the EU emission allowance future for delivery in mid-December of the corresponding year.

4.3 Semiparametric Varying Coefficient Model

This section analyzes the relationship between natural gas, carbon emission allowances and electricity prices. Given the fact that electricity is generated with different technologies, the relationship between fuel prices and the electricity price should depend on the marginal technology used. It is necessary to assume that fuel price changes are passed through to electricity markets. In this case, the carbon sensitivity for coal driven parts should be higher than for gas. The dependence on gas prices should be higher for periods with high load.

Thus, I use a semiparametric varying-coefficient model, which was introduced by Hastie and Tibshirani (1993) as a generalized class of regression models. It measures explicitly how the fuel price sensitivity varies with load, which means that the model directly accounts for the underlying merit order. It is very flexible, because it does not assume any functional specification of how the fuel price sensitivity varies, but estimates it directly from the data. The model is given as

$$Y_i = \beta(Z_i)' X_i + u_i \tag{4.1}$$

which seems to be rather specific. However, the model is very flexible, because Z is a vector of so-called effect modifiers. The beta coefficients vary freely as a smooth function depending on the effect modifier. This function does not need any further specification and is estimated only from the data. The model proposed by Hastie and Tibshirani (1993) is a static approach that is not necessarily capable of estimating parameters in a time series context.

The literature on energy markets suggests that fuel prices and electricity prices are cointegrated. There is a unilateral effect from fuel prices to electricity prices in all markets. These results are robust for different regions and model setups.[41] Thus, the

[41] Mohammadi (2009) finds that there is one cointegration vector in his model for annual electricity, gas and coal prices in the US. The error correction term is only significant for electricity. Mjelde and Bessler (2009) use weekly data and find that only electricity and uranium prices adapt to re-establish the equilibrium in the long-run relationship. Using a different methodology, Ferkingstad et al. (2011) find a strong causal link from gas prices to electricity prices, while the German electricity market does not have a causal effect on any fuel market. Fezzi and Bunn (2009) analyze daily spot prices and show that

existence of a cointegration relationship is relevant for the following analysis and also has to be examined in this article. The Johansen test indicates that there is exactly one cointegration relationship and that both gas and carbon prices are weakly exogenous. These prices do not adapt to the long-term equilibrium, indicating that the electricity price follows the natural gas and carbon prices in a unilateral relationship. Thus, it is possible to estimate this relationship in a single equation model with the electricity price as endogenous variable. As the Johansen cointegration analysis and the obtained findings are standard in the literature, the results of this preliminary step are presented in Appendix B.

Recent studies by Cai et al. (2009) and Xiao (2009) expand the semiparametric approach and analyze the properties of similar varying coefficient models for nonstationary time series and cointegration settings. Xiao (2009) proves that a kernel estimator of the varying cointegration coefficients is super-consistent. A kernel estimator is used to estimate this regression by locally weighing all observations with $K\left(\frac{z_t - z}{h}\right)$. The estimator of $\widehat{\beta}$ is defined as

$$\widehat{\beta}\,(z) = \arg\min_{\beta} \sum_{t=1}^{n} K\left(\frac{z_t - z}{h}\right)\left\{y_t - x_t'\beta\right\}^2 \tag{4.2}$$

In this paper, the kernel estimator and bandwidth selection of the semiparametric varying smooth coefficient model is implemented as given in Li and Racine (2007) and in the np package by Hayfield and Racine (2008). The semiparametric varying smooth coefficient model is then given as $y_t = \beta(z_t)'x_t + u_t$. The electricity price is defined as y_t, while x_t is a matrix of a constant and of gas and carbon prices. The regression coefficient $\beta\,(z_t)$ is a vector of unspecified smooth functions of z, which is the residual load.[42] In this model, the gas and carbon price dependence of the electricity price varies with the effect modifier z. This means that the cointegration coefficients change throughout the assumed underlying merit order.

I estimate different models for base, peak and off-peak electricity prices to account for different underlying fundamentals. The semiparametric cointegration coefficients for gas and carbon are shown in Figure 4.1. These functions measure the input price sensitivity of the electricity price depending on the residual load.[43]

A visual inspection shows that the parameters vary throughout the merit order and that there are two distinct parts. The first part has a higher carbon sensitivity, while the

gas and carbon prices drive the electricity price in the UK. Furió and Chuliá (2012) use forward prices of Spanish electricity, Brent crude oil and Zeebrugge natural gas. Similarly to the other studies, they also find a cointegration relationship where causation runs from fuel prices to the electricity market.

[42] In Xiao (2009), the process z_t is required to be stationary, which is the case for all residual load processes of the base, peak and off-peak blocks. See Table C.1 in the Appendix for the according unit root tests.

[43] Due to the estimation procedure, parameters at the fringe of the load spectrum are unstable and therefore omitted in the graphs.

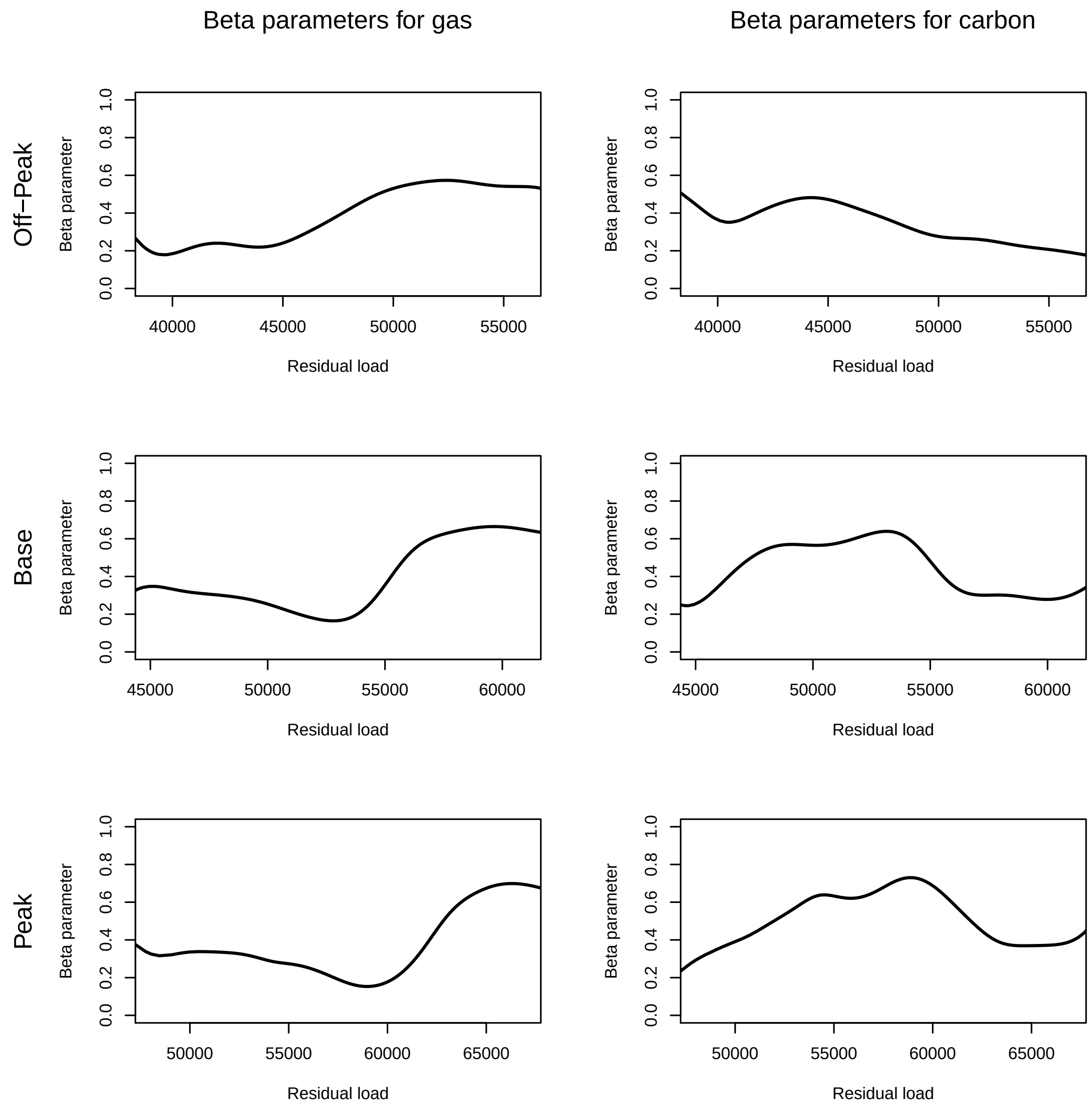

Figure 4.1: Semiparametric Cointegration Parameter Estimates of Fuel Prices

Notes: This figure shows the estimated semiparametric cointegration coefficients for off-peak, base and peak electricity prices. The parameters are a smooth function that depends on the residual load in MW. The coefficients for natural gas are displayed in the left column and the parameters for carbon emission allowances are in the right column.

second part has a higher gas sensitivity. The transition point lies at around 55 GW average daily residual load for the base electricity price and at around 60 GW average residual load for the peak block. The position of the shifting coefficients reflects the German generation portfolio. Nuclear, lignite and coal based electricity production has a total capacity of approximately 57 GW. These technologies are generally assumed to have lower marginal costs than gas based production. The model indicates that the gas driven part of the merit order has a generation capacity of approximately 10 GW. This estimate is also highly consistent with the power plant portfolio, as there is a total gas fueled capacity of around 13 GW in Germany.

One needs to be careful with an economic interpretation of pass-through rates in this model. Gas and carbon prices are used as a proxy for input prices as a whole. Thus, the direct effect of each variable itself might be misleading. Rickels et al. (2010) find a positive effect of the coal and oil prices on the carbon price, which may be caused by a common factor of general demand for energy. To measure a meaningful pass-through rate, I determine how the electricity price increases when the input prices as a whole increase by one percent. The mean of the sum of the parameter vectors is 0.745% for off-peak, 0.835% for base and 0.906% for peak. The first and third quartiles are within bounds of 0.05 percentage points below and above the point estimates. These values can be interpreted as the pass-through rate multiplied by the portion that fuel costs contribute to the total marginal costs. Given this interpretation, it makes sense that the estimate is higher for peak, because the fuel costs are relatively more important. The results of this analysis suggest that fuel price changes are passed through.

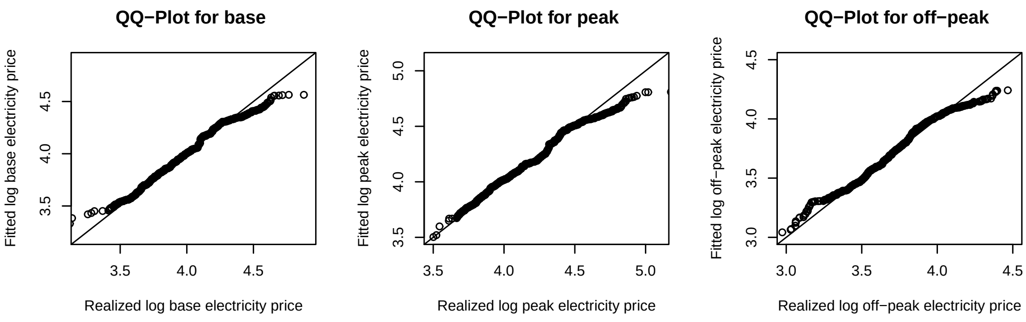

FIGURE 4.2: QQ-plot of the Fit of the Semiparametric Model

As a robustness test, the comparable parametric VECM estimates of the cointegration vector are 0.51 for gas and 0.36 for carbon (see Table C.2 in the Appendix). These estimates are also consistent with the results of Fezzi and Bunn (2009). Using a similar setup for the English market, they find cointegration parameters of 0.66 for gas and 0.32 for carbon. The differences might be driven by a higher ratio of gas production in the UK.

The QQ-plots in Figure 4.2 show a good fit of the semiparametric model. It is able to resemble the pricing behavior for normal price levels, but underestimates the highest prices. This probably happens due to a scarce capacity effect that causes a price premium that cannot be explained by fuel price changes.

The estimates of the semiparametric model can be used to predict the changes of the merit order for different gas and carbon price scenarios. Load-varying beta parameters translate into flexible shifts of the merit order. Figure 4.3 shows the estimated base electricity prices depending on load and input prices. The graph on the left illustrates equal gas and carbon prices that vary from 10 Euro to 25 Euro, which is a realistic scenario for the observed period. The right graphs show the merit order for varying gas prices while holding the carbon price fixed. Due to the semiparametric estimates, the gas price has a stronger impact on the electricity price if the load is high.

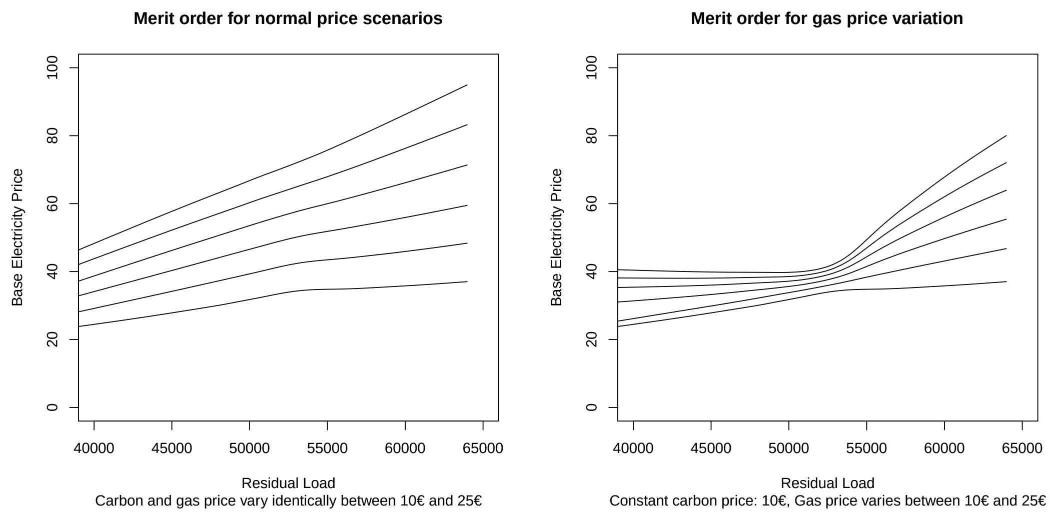

FIGURE 4.3: Simulated Merit Order for Different Natural Gas and Carbon Price Scenarios

Notes: This figure illustrates the fitted merit order conditional on varying gas and carbon prices. The fitted base electricity price (in Euro/MWh) is derived using the semiparametric cointegration coefficients shown in Figure 4.1. The chart on the left shows the merit order for gas and carbon prices varying identically between 10 and 25 Euro per MWh and per ton, respectively (in steps of 3 Euro). For the chart on the right, the carbon price is fixed at 10 Euros per ton and the gas price varies between 10 and 25 Euros per MWh.

The model is capable of explaining the observed electricity prices with a flexible and simple approach. The relationship between electricity, natural gas and carbon prices is motivated by the underlying power plant portfolio. In the next section, the model is used to analyze the impact of an unexpected and sudden change of the power plant portfolio.

4.4 Analysis of the German Nuclear Moratorium in 2011

On Friday, 11 March 2011, a heavy earthquake and tsunami hit Japan and severely damaged the nuclear power plant in Fukushima. Following these disastrous events, the German government surprisingly decided to put a nuclear suspension in place. The decision for a moratorium of three months length was announced publically on the evening of Monday, 14 March 2011. This policy intervention immediately removed seven nuclear power plants from the market. The EEX reacted with a steep price increase of electricity futures, which is shown in Figure 4.4. Similarly, also the gas and carbon futures prices rose, probably because the market expected an increasing demand for fossil fuels, which are used to offset the suspended nuclear capacities.

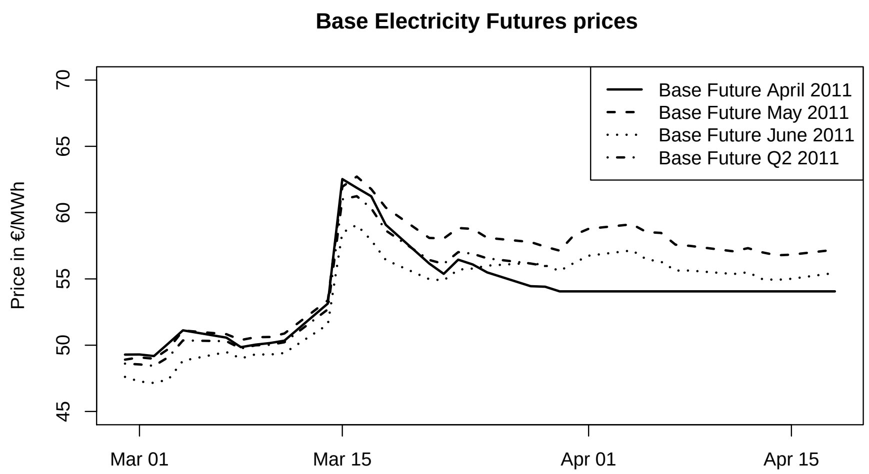

Figure 4.4: Base Electricity Futures Prices at the Time of the Announcement of the Nuclear Moratorium

Notes: This figure shows the EEX market reaction for base electricity futures that are directly affected by the nuclhear moratorium. The moratorium was announced on the 14 March 2011.

In this section, I conduct an event study in order to assess the impact of the nuclear moratorium. According to Binder (1998), event studies are used to test if a market efficiently incorporates information and to analyze the event's price impact on some securities. Classical event studies in finance focus on measuring the abnormal returns around a firm specific or economy wide event of interest. MacKinlay (1997) gives an overview about event study methods, which all start by defining the event of interest and the event window, during which the impact of the event is measured. The event of interest is the announcement of the moratorium and the event window is chosen to be 10 trading days before and 25 trading days after the announcement. Given an instant daily price increase of roughly 15%, the mere existence of a moratorium effect is obvious for the electricity futures. As a consequence, this event study focuses on analyzing the impact of the different influences that cause the electricity prices to rise. The method proposed in this study allows to determine whether the market efficiently accounts for the new information.

In theory, there are two separate shifts of the merit order for the according electricity futures with delivery between March 2011 and June 2011.[44] First, the supply curve is shifted left by about 6 GW, because nuclear generation capacity with low marginal costs is removed from the system. This effect is called the capacity effect of the moratorium. Second, the increased gas and carbon futures prices result in an upwards shift of the merit order.

The event study is conducted in the following way. In order to isolate the capacity effect for a certain electricity futures contract, I compare the observed electricity futures price and the predicted merit order for the contract before and after the moratorium. The semiparametric cointegration model, as discussed in Section 4.3, is used to predict the merit order, i.e. the counterfactual electricity price function conditional on residual load.[45] Due to the varying beta coefficients, the observed natural gas and carbon emission allowance futures prices are sufficient to derive such a merit order curve for an electricity futures contract.[46] As the predicted merit order only accounts for the change in gas and carbon futures prices, it is possible to derive the capacity effect of the moratorium. First, the merit order of the electricity futures contract is predicted using the observed settlement prices of the according natural gas and carbon futures on a trading day before the moratorium. Then, the settlement price of the electricity future on the same trading day is used to determine the implied expected demand, which is defined as the residual load that is necessary to justify the observed electricity futures price. This is achieved by calculating the intersection of the predicted merit order and the actual observed electricity futures settlement price. In the second step, the same procedure is repeated for electricity, gas and carbon futures prices observed on a trading day after the moratorium. The difference of the implied expected demand before and after the moratorium is the capacity effect.

[44]The futures market is well suited to analyze the impact of the moratorium because futures prices reflect the expectations of all market participants. Furthermore, the derivatives markets of the EEX have a sufficiently high liquidity as the trading volumes are about two to five times higher than at the spot markets. Therefore, most institutions focus on the futures market to analyze the impact of the moratorium (e.g. see EEX (2011) and European Commission (2011)). The influence on the day-ahead market was less distinct because the suspended capacity was comparable to the normal fluctuations of renewable electricity production. During the time of the announcement of the moratorium, there was a high availability of renewable electricity generation capacity. Thus, the effect on the day-ahead market was small and short lived (see European Commission (2011)).

[45]Generally, cointegration is seen as a long-term framework, but in this context it is reasonable to assume that the stable long-term relationship is relevant for the price expectations at the futures market.

[46]The event study uses unadjusted futures prices in levels. The model is calibrated with data from the day-ahead market with seven days per week to match the delivery structure of the base futures.

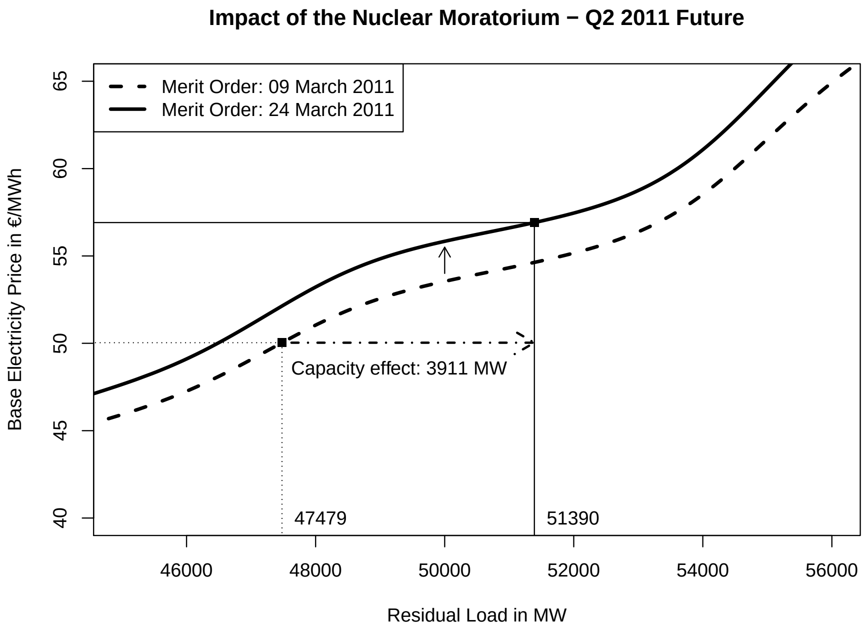

Figure 4.5: Derivation of the Capacity Effect of the Nuclear Moratorium

Notes: The merit order is derived by using the previously calibrated semiparametric model as well as gas and carbon futures settlement prices on a specific trading day. Due to the rising gas and carbon futures prices, the merit order shifts upwards from March 9 to March 24. While the fuel price effect accounts for an electricity price increase of less than 3 Euro, the actual futures price rose by 7.15 Euro. The capacity effect is determined by calculating the residual load that would justify the actual electricity futures prices on each of both trading days and then taking the difference between the implied residual load before and after the moratorium.

This procedure is illustrated in Figure 4.5, which shows as an example how the capacity effect is derived in this study. The capacity effect is determined for the Q2 2011 base electricity futures contract and the period between March 9 and March 24. The merit order shown in this figure is calculated with the semiparametric model using the natural gas futures prices for delivery in Q2 2011 and the carbon emissions allowance futures price for delivery in mid-December 2011 as inputs. The dashed bold line is the predicted merit order derived from the futures settlement prices traded on March 9. The implied expected residual load for the setup in Figure 4.5 can be calculated by taking the intersection of the merit order and the observed electricity futures settlement price on the same trading day. This expected residual load for Q2 2011 amounts to 47.5 GW on 9 March 2011, which is close to the 2008 - 2010 average of 48.3 GW. Driven by the moratorium, the gas and carbon futures prices rise and shift the Q2 2011 merit order upwards, as it is shown by the bold line representing the merit order for the gas and carbon futures prices traded on March 24. This gas and carbon price effect accounts for an electricity price increase of less than 3 Euro. However, from March 9 to March 24, the Q2 2011 electricity futures settlement price rose from 49.75 Euro to 56.90 Euro. This observed change of the electricity futures price is used to determine the capacity effect of the nuclear moratorium by looking at the merit order on each of both trading days and asking which residual load would justify the actual electricity futures price. The difference between this implied residual load before and after the moratorium is the capacity effect. It can be interpreted as the additional demand that would be necessary to drive the electricity price to the observed level if the nuclear moratorium had not been imposed. For the setup shown in the graph of the Q2 2011 future, the capacity effect amounts to 3.9 GW.

However, Figure 4.5 displays only the capacity effect for one single futures contract and for the comparison of two arbitrary trading days. Thus, in the next step, the same procedure is used to calculate the capacity effect for different electricity futures and the full range of trading days in the event study window. Figure 4.6 shows the development of the capacity effect over time and for futures contracts with different times to maturities. For example, in order to calculate the moratorium's capacity effect for the Q2 2011 futures contract traded on March 24, I compare the implied expected demand for the contract on this trading day with the implied expected demand for the same futures contract on all trading days before the announcement of the moratorium. Finally, the average of these capacity effects between March 24 and each of the trading days before the moratorium is displayed in Figure 4.6 as the capacity effect for the Q2 2011 contract on March 24.

The top panel of Figure 4.6 displays the capacity effect for directly affected futures. On Monday, 14 March 2011, the first trading day after the Fukushima events, the prices of the electricity, gas and carbon futures rise. However, the capacity effect, which measures the abnormal price increase of electricity futures, shows no indication of previous information about the moratorium. There is no evidence for a capacity effect before 15 March 2011. Then, in direct response to the moratorium, all futures contracts immediately account for the shut capacity of about 6 GW. The market efficiently reacts to the moratorium by adding a capacity effect premium to the electricity price in order to reflect the missing generation capacity. In the following days, the capacity effect declines first, but remains at a rather stable level after this drop. This decline might have been caused by the fact that the market agents did not anticipate a nuclear moratorium and thus needed some time to develop sound forecasts. After a few trading days, the market agents expect that a part of the capacity effect will be mitigated by dynamic factors like the flexibility of the power plant portfolio or international transmission.

The framework also allows measuring the market's expectations for the time after the end of the moratorium in June 2011. The middle and bottom panel of Figure 4.6 show the capacity effect for several futures with delivery after the moratorium. For the quarterly future with delivery in Q3 2011, the development of the capacity effect reveals

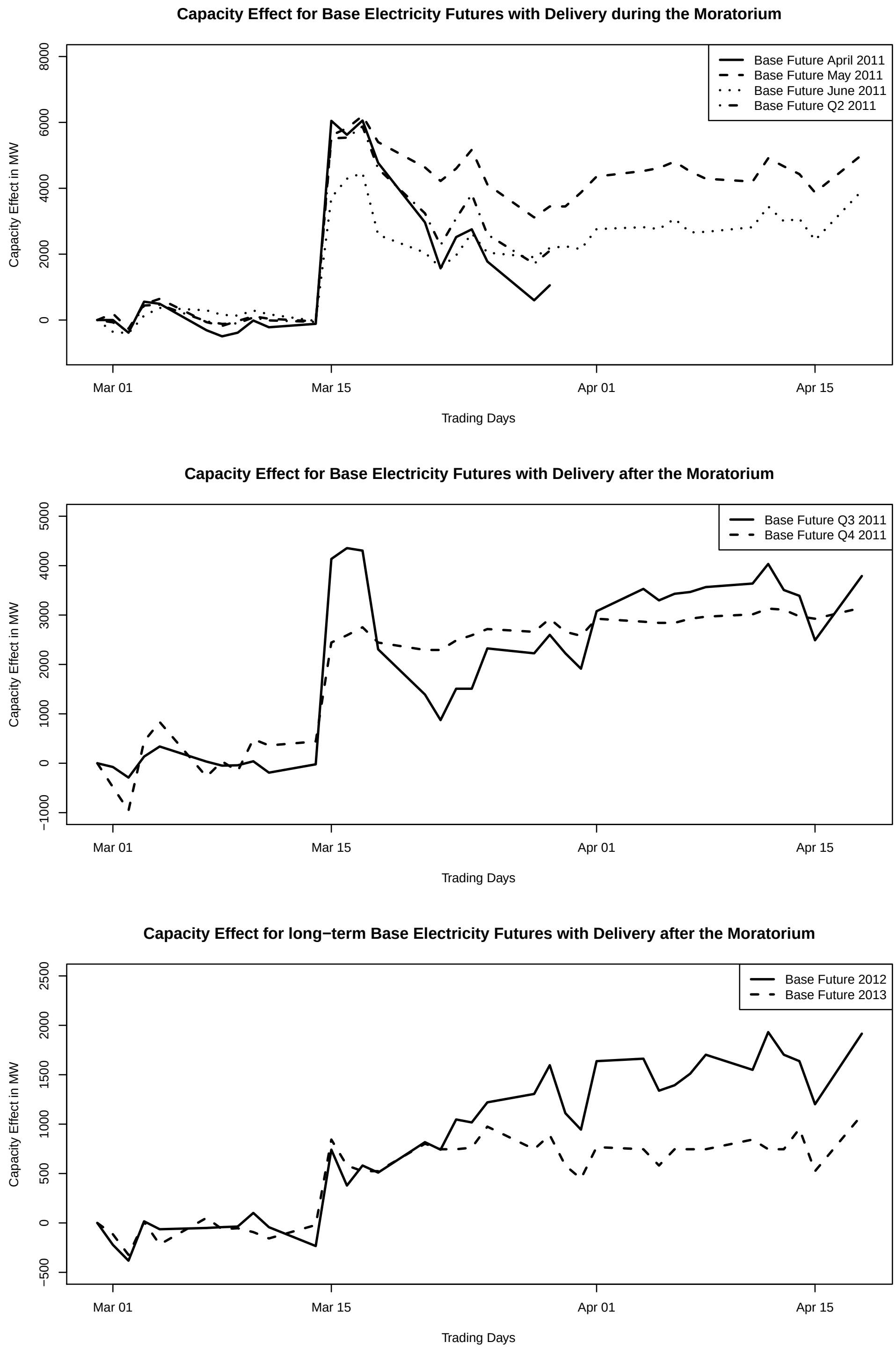

FIGURE 4.6: Implied Capacity Effect of the Nuclear Moratorium

Notes: This figure shows the implied capacity effect (in MW) that is caused by the nuclear moratorium. Only the futures illustrated in the top panel are directly affected by the moratorium. The capacity effect is calculated with the same procedure that is depicted in Figure 4.5.

an unsteady reaction, which is lasting for a few trading days, before sound expectations have developed. Then, the market expects a capacity effect of roughly 3-4 GW for the time after the moratorium. The capacity effect for the following quarter is at a very similar level, but more stable over time. The yearly futures for 2012 and 2013 also reveal a more settled picture. There is no panic reaction and the markets quickly adjust to a stable level of around 1 GW missing nuclear capacity.

Generally, the capacity effect for futures with delivery during and directly after the moratorium is rather similar. Thus, there is an impact that is expected to be permanent. It is difficult to quantify the expected number of nuclear power plants to remain closed down as there is some uncertainty introduced by dynamic effects. These effects could be a change of the maintenance schedule, endogenously added new generation capacity, changes of international transmission and demand responses. This dynamic adjustment process mitigates some of the capacity effect. Second, weighted expectations for different political scenarios might be reflected in the prices. If market participants think that several scenarios are realistic, the estimated capacity effect will reflect an average expectation that might not be a realistic scenario itself.

Given these considerations, there are two possible explanations for the decaying capacity effect: (1) that the moratorium of 6 GW has an expected capacity effect of only 1 GW in 2013 due to dynamic adjustment effects, or (2) that the market expects that the probability of an extension of the moratorium decreases with the time to maturity and is relatively low for 2012 or 2013.[47]

However, there is still consistent evidence for the existence of a capacity effect for all futures with delivery after the end of the moratorium. Thus, one can conclude that the market on average correctly expects an extension of the moratorium with several nuclear power plants remaining closed down after the announced end in June 2011.

4.5 Conclusion

There are two main contributions of this paper. First, it shows that the relationship between the input fuel prices and the electricity price varies with load and reflects the underlying merit order. This result is potentially useful for other markets with different

[47] The finding that the capacity effect decays with the time until delivery might also be partially driven by the well-known Samuelson (1965) effect that commodity futures with a longer time to maturity are less volatile. In this case, both the electricity, gas and carbon futures for 2012 and 2013 would react less to new information than futures for 2011. However, this can also be explained economically, as the long-term futures are not directly affected by the moratorium and additionally would allow more time for dynamic adjustment effects.

production technologies and inputs. One example are commodity markets, where local conditions lead to different mining or extraction technologies.

Second, the paper provides a framework to assess the impact of the German nuclear moratorium in 2011. The market incorporates the new information efficiently and correctly expects that several power plants will remain shut off after the moratorium. Furthermore, it anticipates that dynamic adjustment processes will mitigate some of the capacity effect. However, these results are not necessarily applicable for additional plant closures, which could affect the security of supply or lead to substantial capacity premium effects.

The approach in this paper could be improved and extended in several ways. It would be desirable to include other fuels to get a more granular picture of the nonlinear fuel price effects. It would also be interesting to test and compare the fuel price effects for various markets with different dominating technologies. Accounting for a possible scarce capacity premium, which seems to exist, would also improve the model.

Due to the semiparametric approach, the demand elasticity is not included explicitly. However, Fezzi and Bunn (2010) show that it is preferable to model demand as an endogenous variable. The analysis of the nuclear moratorium focuses on the German futures market, but does not include the day-ahead market or indirect price effects on other European markets. The impact on these markets and the response of input fuel prices to the moratorium provide an interesting area for future research.

Appendix A

Supplementary Material for Chapter 2

TABLE A.1: LexisNexis Database Search Queries for all Newspapers

Panel A. LexisNexis search command related to hybrid vehicles and fuel efficiency
fuel efficiency OR (fuel W/2 standard) OR (efficient W/10 mileage) OR (ALLCAPS (CAFE) W/10 (standard OR fuel OR efficient OR regulation)) OR (gas W/2 guzzler) OR (electric W/2 (car OR vehicle)) OR ((plug W/2 in) W/2 (car OR vehicle)) OR (hybrid W/2 (car OR vehicle)) OR toyota prius OR ((toyota OR Honda OR Hyundai Or Lexus OR Ford) W/2 Hybrid)

Notes: The search query should take into account both the completeness and the relevancy of the found articles. It reflects news coverage concerning fuel efficiency, electric vehicle technology, hybrid vehicles and related regulation standards. The command $W/2$ indicates that two words are in the text within 2 words distance. The command $ALLCAPS$ requires a word to be written in capital letters.

Panel B. LexisNexis search command related to gasoline prices
(gas! OR pump) W/4 (cost OR price) W/6 (record OR high OR soar! OR ris! OR surg! OR climb! OR jump! OR spik! OR peak OR expensive OR sink! OR low! OR drop! OR plung! OR down! OR fall! OR fell OR declin! OR cheap! OR tumbl! OR crash!) NOT W/seg (jet OR airline OR kerosine OR kerosene OR shale OR natural)

Notes: The search query should take into account both the completeness and the relevancy of the found articles. It reflects news coverage concerning gasoline price movements and levels without focusing on either rising or sinking prices. The syntax as follows: ! is used as a wild card, e.g. $surg$! includes surging. The command $W/4$ indicates that two words are in the text within 4 words distance. $NOTW/seg$ does not allow the following word to be in the same segment within one article.

Table A.2: Summary Statistics

Panel Dataset for Section 2.4					
	Mean	Std. Dev.	Min.	Max.	N
Google Hybrid	30.404	14.922	7	100	7227
Google Mileage	28.747	13.701	8	100	6984
Local Newspaper Hybrid	2.294	2.872	0	56	7771
Local Newspaper Gasoline	2.908	3.846	0	37	7760
TV Hybrid	0.373	0.797	0	6	7752
TV Gasoline	2.387	3.717	0	35	7752
Newspaper USA Today Hybrid	2.824	1.963	0	9	7771
Newspaper NYT Hybrid	8.335	4.755	0	27	7771
Newspaper USA Today Gasoline	3.308	3.468	0	20	7771
Newspaper NYT Gasoline	6.672	6.386	0	40	7771
Record Price Length	0.998	3.007	0	25	7771
$\Delta GasPrice^{Pos}_{t,t-1}$	0.01	0.017	0	0.228	7771
$\Delta GasPrice^{Neg}_{t,t-1}$	-0.009	0.016	-0.134	0	7771
$\Delta GasPrice^{Pos}_{t-2,t-6}$	0.033	0.043	0	0.315	7771
$\Delta GasPrice^{Neg}_{t-2,t-6}$	-0.025	0.055	-0.438	0	7771
$\Delta GasPrice^{Pos}_{t-7,t-18}$	0.068	0.08	0	0.403	7771
$\Delta GasPrice^{Neg}_{t-7,t-18}$	-0.046	0.116	-0.841	0	7771

Notes: The dataset consists of weekly observations for the 19 metropolitan areas listed in Table 2.2 and ranges from January 4th, 2004 to October 23rd, 2011.

Panel Dataset for Section 2.5					
	Mean	Std. Dev.	Min.	Max.	N
ln(Market Share Hybrid Registrations)	0.726	0.492	-1.565	2.249	2117
ln(Hybrid Registrations)	5.825	0.995	3.401	9.218	2117
ln(Google Hybrid)	3.227	0.416	2.015	4.508	2117
TV Hybrid	1.529	1.636	0	7	2117
TV Gasoline	7.787	8.98	0	38	2117
USA Today Hybrid	13.92	5.093	5	31	2117
NYT Hybrid	37.041	10.112	19	66	2117
USA Today Gasoline	12.846	13.228	1	56	2117
NYT Gasoline	26.372	27.068	1	112	2117
Record Price	0.258	0.438	0	1	2117
$\Delta GasPrice^{Pos}_{t,t-1}$	0.039	0.048	0	0.253	2117
$\Delta GasPrice^{Neg}_{t,t-1}$	-0.03	0.079	-0.539	0	2117
$\Delta GasPrice^{Pos}_{t-2,t-3}$	0.038	0.049	0	0.253	2117
$\Delta GasPrice^{Neg}_{t-2,t-3}$	-0.033	0.081	-0.539	0	2117
$\Delta GasPrice^{Pos}_{t-4,t-6}$	0.06	0.081	0	0.382	2117
$\Delta GasPrice^{Neg}_{t-4,t-6}$	-0.063	0.151	-0.975	0	2117
ln(Gas Price)	0.829	0.23	0.036	1.375	2117

Notes: The dataset consists of monthly state-level observations from December 2006 to February 2011.

Appendix B

Supplementary Material for Chapter 3

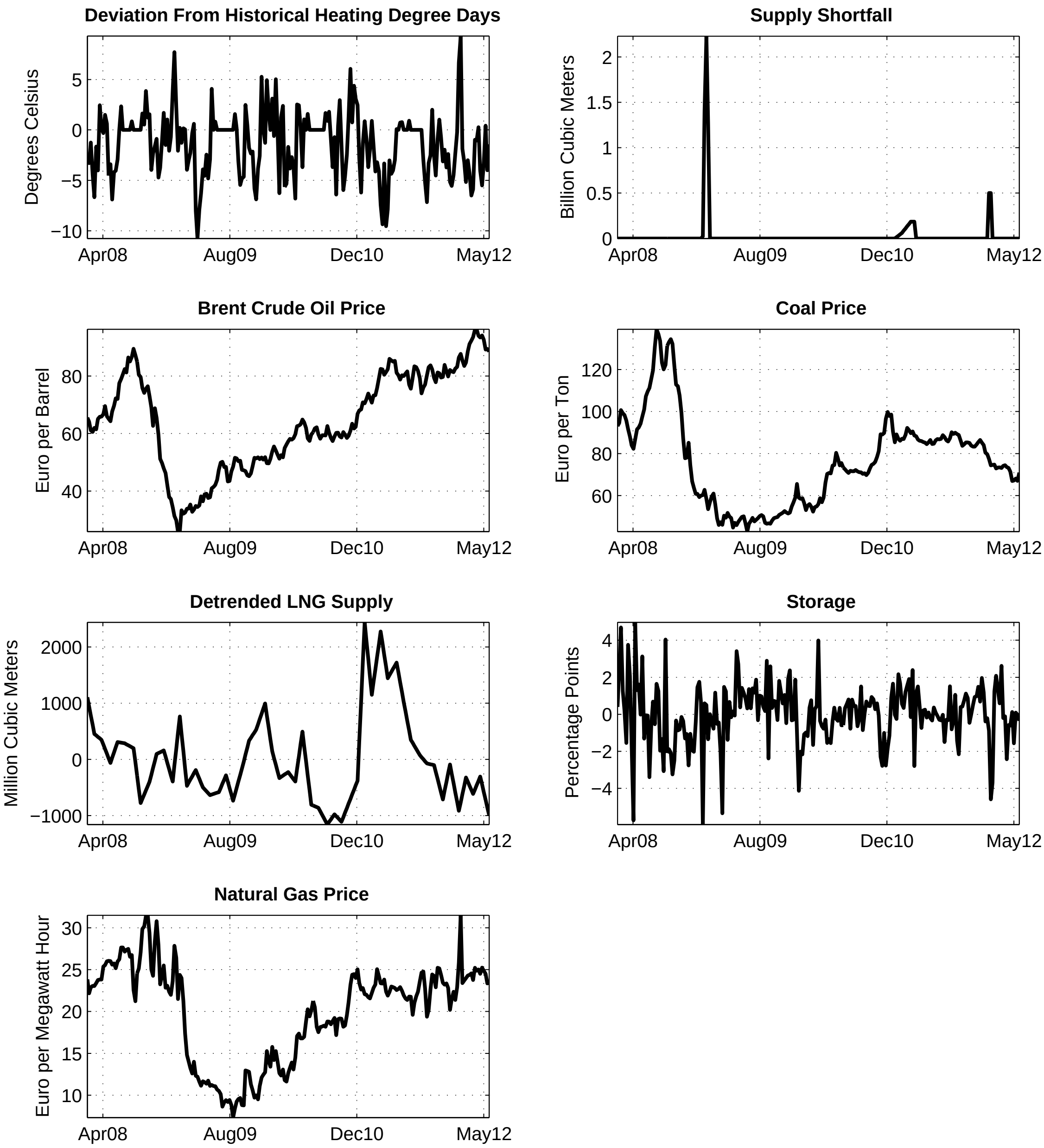

FIGURE B.1: Plots of the Time Series Used for the Analysis

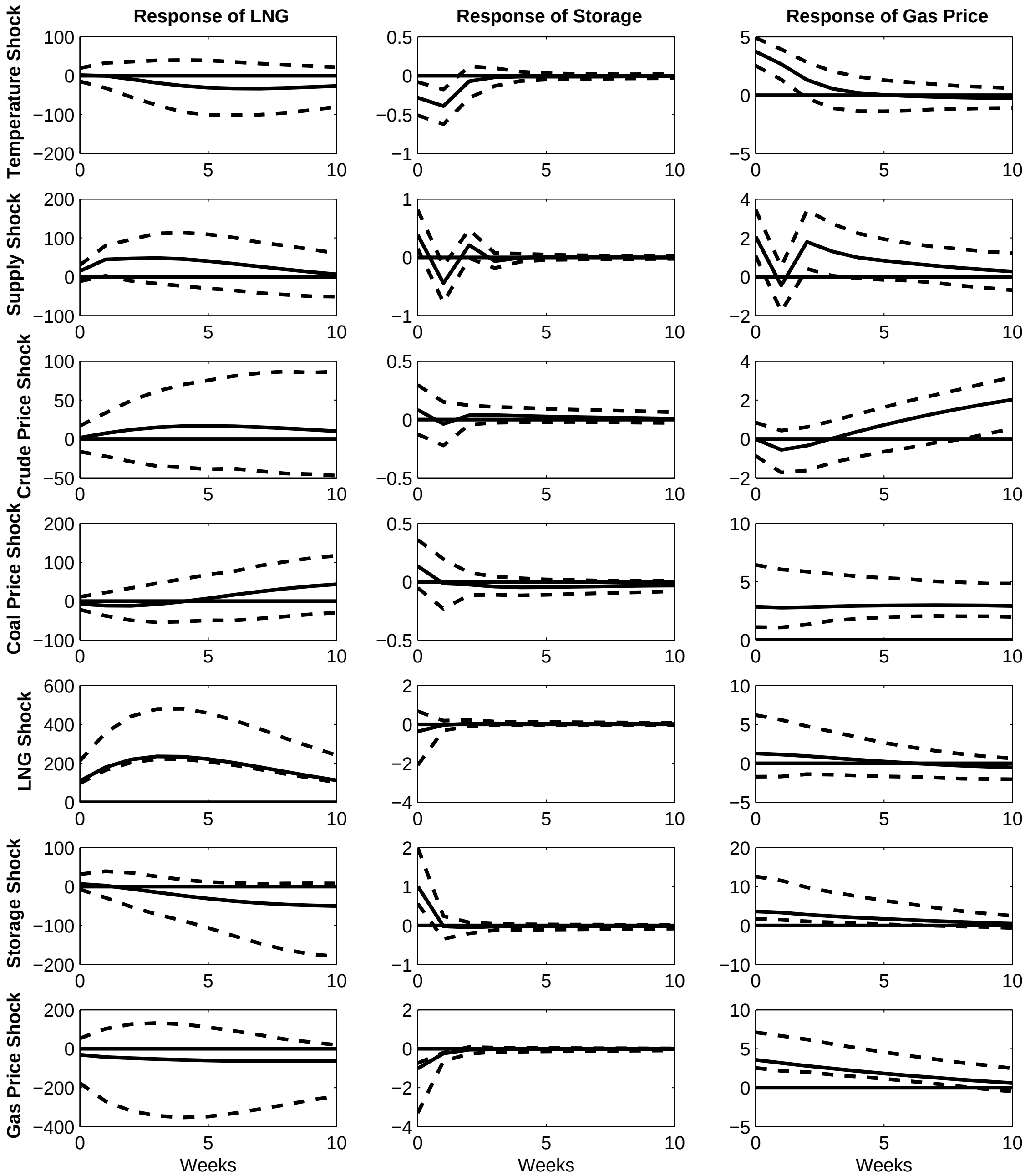

FIGURE B.2: Responses of LNG, Storage and the Natural Gas Price

Notes: The impulse responses (solid lines) are based on one standard deviation of the respective structural shock. The response of LNG is measured in million cubic meters (mcm), the response of deseasonalized storage utilization is measured in percentage points and the response of the natural gas price is measured in percent. Confidence intervals (dashed lines) are bootstrapped following Hall's 95-percentage bootstrap interval using 1000 draws.

Table B.1: Summary of Sources, Russian Supply Shortfall of February 2012

Source	Publication Date	Time Period	Affected Location	Supply Disruption	Original Source
DJ Tradenews	02/02/12	01/31/12	Europe	1.5% less	Gazprom Employee
DJ Tradenews	02/03/12		E.ON Ruhrgas, Germany	None	Company
DJ Tradenews	02/03/12		Italy	11.6% less	
DJ Tradenews	02/03/12		Italy, Poland, Slovakia	8% to 10% less	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/03/12		Hungary, Czech Republic	Less	
DJ Tradenews	02/03/12		RWE Supply & Trading, Germany	30% less	Company
DJ Tradenews	02/03/12		Wingas, Germany	Less	Company
DJ Tradenews	02/03/12		OMV, Hub Baumgarten, Austria	30% less expected	Company
DJ Tradenews	02/06/12		PGNiG, Poland	7% less	Company
DJ Tradenews	02/06/12		E.ON Ruhrgas, Germany	Approximately one third less	Company
DJ Tradenews	02/06/12	02/02/12	Austria	30% less	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/06/12	02/02/12	Italy	24% less	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/06/12	02/02/12	Poland	8% less	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/06/12	Currently	Italy, Greece, Austria, Poland, Slovakia, Hungary, Bulgaria, Romania	Less	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/07/12		Germany, Romania, Italy	Less	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/07/12		Bulgaria, Slovakia, Hungary, Poland, Austria, Greece	No disruptions	Speaker of Günther Oettinger, European Comission
DJ Tradenews	02/08/12	Previous week	Europe	15% less	Alexander Medvedev, Gazprom
DJ Tradenews	02/13/12		E.ON Ruhrgas, RWE and Wingas, Germany	Less deliveries, but rising	Company
ICIS Heren EGM	02/15/12		Europe	About 10% below contractual levels	Gazprom
ICIS Heren EGM	02/15/12	Beginning of February	GDF Suez, France	30% less	Company
ICIS Heren EGM	02/15/12	02/06/12	GDF Suez, France	20% less	Company
ICIS Heren EGM	02/15/12	01/31/12	Slovakia	8% to 10% less	
ICIS Heren EGM	02/15/12	02/02/12	SPP, Slovakia	36% less	Company
DJ Tradenews	02/21/12		Europe	No disruptions anymore	Alexander Medvedev, Gazprom
Henderson and Heather (2012)	April 2012	02/02/12 to 02/07/12	Italy	11% - 29% less	Snam Rete Gas

Notes: DJ Tradenews refers to the Dow Jones TradeNews Energy publication available at `http://www.djnewsletters.de/produkte/commodities/energie/dow-jones-tradenews-energy.html`. ICIS Heren EGM refers to the ICIS Heren European Gas Market report available at `http://www.icis.com/energy/gas/europe/`.

Appendix C

Supplementary Material for Chapter 4

TABLE C.1: Augmented Dickey Fuller Unit Root Tests

Variable	Level			1st diff.		
	statistic	p-value	lags	statistic	p-value	lags
Base Electricity	-2.25	0.19	9	-11.73	0.00	8
Peak Electricity	-2.17	0.22	9	-11.65	0.00	8
Off-peak Electricity	-2.58	0.10	9	-12.35	0.00	8
NCG Gas	-0.45	0.52	1	-19.63	0.00	1
EU Emission Allowance	-0.65	0.43	0	-10.98	0.00	5
Base Residual Load	-3.82	0.00	9			
Peak Residual Load	-3.12	0.03	15			
Off-peak Residual Load	-3.01	0.03	10			

Notes: The null hypothesis of the ADF test is that there is a unit root in the considered time series. Lag lengths are determined by the Akaike Information Criterion (AIC). Whether to include a trend or constant was decided by checking the significance of the trend/constant parameters at a 5% significance threshold.

Table C.2: Johansen Cointegration Analysis of Electricity, Gas and Carbon Prices

Panel A. Cointegration Tests

Rank	Trace test statistic	p-value
Base electricity, gas, carbon		
0	120.48	0.000
1	15.56	0.200
2	3.93	0.435
Peak electricity, gas, carbon		
0	103.08	0.000
1	15.82	0.187
2	4.05	0.417
Off-peak electricity, gas, carbon		
0	169.89	0.000
1	15.27	0.215
2	3.81	0.454

Notes: The Johansen test is used to test for the existence and rank of a possible cointegration relationship between the three I(1) variables electricity, gas and carbon. The constant is restricted to lie in the cointegration space, as there is no indication for trends in the data. The lag length is determined by the Schwarz Information Criterion (SIC). The trace statistic for rank j tests the null hypothesis of rank $r = j$ against $r > j$.

Panel B. Analysis of the Cointegration Parameters

	α-Vector		β-Vector	
	Parameter	t-stat.	Parameter	t-stat.
Base	-0.297	-10.58	1	-
Gas	0.012	1.06	-0.51	-9.29
Carbon	-0.002	-0.27	-0.36	-4.50

Notes: The α-parameters indicate if and at which speed the variable of interest reacts to a disequilibrium in the long-term relationship. In the equations for gas and carbon, the α-parameters are not significant and thus, the gas and carbon prices are treated to be weakly exogenous. The estimates of the β-vector are significant, which shows that both gas and carbon prices are part of the stable long-term relationship and important drivers of the electricity price.

Bibliography

Allcott, H. (2011). Consumers' perceptions and misperceptions of energy costs. *American Economic Review*, 101(3):98–104.

Amisano, G. and Giannini, C. (1997). *Topics in Structural VAR Econometrics*. Springer.

Anderson, S. T., Kellogg, R., Sallee, J. M., and Curtin, R. T. (2011a). Forecasting gasoline prices using consumer surveys. *American Economic Review*, 101(3):110–14.

Anderson, S. T., Parry, I. W. H., Sallee, J. M., and Fischer, C. (2011b). Automobile fuel economy standards: Impacts, efficiency, and alternatives. *Review of Environmental Economics and Policy*, 5(1):89–108.

Armitage, S. (1995). Event study methods and evidence on their performance. *Journal of Economic Surveys*, 9(1):25–52.

Baker, M. and Wurgler, J. (2007). Investor sentiment in the stock market. *Journal of Economic Perspectives*, 21(2):129–152.

Barber, B. M. and Odean, T. (2008). All that glitters: The effect of attention and news on the buying behavior of individual and institutional investors. *Review of Financial Studies*, 21(2):785–818.

Barsky, R. B. and Kilian, L. (2004). Oil and the macroeconomy since the 1970s. *The Journal of Economic Perspectives*, 18(4):pp. 115–134.

Baumeister, C. and Kilian, L. (2012). Real-Time Analysis of Oil Price Risks Using Forecast Scenarios. Bank of Canada Working Paper, Bank of Canada.

Bentzen, J. (2007). Does OPEC influence crude oil prices? Testing for co-movements and causality between regional crude oil prices. *Applied Economics*, 39(11):1375–1385.

Beresteanu, A. and Li, S. (2011). Gasoline prices, government support, and the demand for hybrid vehicles in the United States. *International Economic Review*, 52(1):161–182.

Berger, J., Sorensen, A. T., and Rasmussen, S. J. (2010). Positive effects of negative publicity: When negative reviews increase sales. *Marketing Science*, 29(5):815–827.

Bertrand, M. and Mullainathan, S. (2001). Do People Mean What They Say? Implications for Subjective Survey Data. *American Economic Review*, 91(2):67–72.

Binder, J. (1998). The Event Study Methodology Since 1969. *Review of Quantitative Finance and Accounting*, 11:111–137.

Bosco, B., Parisio, L., Pelagatti, M., and Baldi, F. (2010). Long-run relations in European electricity prices. *Journal of Applied Econometrics*, 25(5):805–832.

Bound, J., Jaeger, D. A., and Baker, R. M. (1995). Problems with instrumental variables estimation when the correlation between the instruments and the endogeneous explanatory variable is weak. *Journal of the American Statistical Association*, 90(430):pp. 443–450.

BP (2012a). *BP Energy Outlook 2030.* BP p.l.c., London. Available online.

BP (2012b). *BP Statistical Review of World Energy June 2012.* BP p.l.c., London. Available online.

Brown, S. P. A. and Yücel, M. K. (2008). What drives natural gas prices? *The Energy Journal*, 29(2):45–60.

Cai, Z., Li, Q., and Park, J. Y. (2009). Functional-coefficient models for nonstationary time series data. *Journal of Econometrics*, 148(2):101–113.

Capros, P., Mantzos, L., Parousos, L., Tasios, N., Klaassen, G., and Ierland, T. V. (2011). Analysis of the EU policy package on climate change and renewables. *Energy Policy*, 39(3):1476 – 1485.

Chandra, A., Gulati, S., and Kandlikar, M. (2010). Green drivers or free riders? An analysis of tax rebates for hybrid vehicles. *Journal of Environmental Economics and Management*, 60(2):78 – 93.

Chandra, A. and Tappata, M. (2011). Consumer search and dynamic price dispersion: An application to gasoline markets. *The RAND Journal of Economics*, 42(4):681–704.

Chetty, R., Looney, A., and Kroft, K. (2009). Salience and taxation: Theory and evidence. *American Economic Review*, 99(4):1145–77.

Coulon, M. C. and Howison, S. (2009). Stochastic Behaviour of the Electricity Bid Stack: From Fundamental Drivers to Power Prices. *The Journal of Energy Markets*, 2(1).

Da, Z., Engelberg, J., and Gao, P. (2011). In search of attention. *The Journal of Finance*, 66(5):1461–1499.

DellaVigna, S. and Pollet, J. M. (2009). Investor inattention and Friday earnings announcements. *The Journal of Finance*, 64(2):709–749.

Diamond, D. (2009). The impact of government incentives for hybrid-electric vehicles: Evidence from US states. *Energy Policy*, 37(3):972 – 983.

Driscoll, J. C. and Kraay, A. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *The Review of Economics and Statistics*, 80(4):549–560.

Dyckman, T., Philbrick, D., and Stephan, J. (1984). A comparison of event study methodologies using daily stock returns: A simulation approach. *Journal of Accounting Research*, 22:pp. 1–30.

EEX (2011). Market Monitor by the Market Surveillance of EEX Q1 & Q2 / 2011. Market surveillance report, European Energy Exchange.

EIA (2012). Annual energy review 2011. Technical Report DOE/EIA-0384(2011), U.S. Environmental Protection Agency.

Eisensee, T. and Strömberg, D. (2007). News droughts, news floods, and U. S. disaster relief. *The Quarterly Journal of Economics*, 122(2):693–728.

Ellerman, A. D. and Buchner, B. K. (2007). The European Union Emissions Trading Scheme: Origins, Allocation, and Early Results. *Review of Environmental Economics and Policy*, 1(1):66–87.

Engelberg, J. and Parsons, C. A. (2011). The causal impact of media in financial markets. *The Journal of Finance*, 66(1):67–97.

Engelberg, J., Sasseville, C., and Williams, J. (2012). Market Madness? The Case of Mad Money. *Management Science*, 58(2):351–364.

Enkvist, P.-A., Nauclér, T., and Rosander, J. (2007). A Cost Curve for Greenhouse Gas Reduction. *The McKinsey Quarterly*, 2007(1):35–45.

European Commission (2011). Quarterly Report on European Electricity Markets. Market Observatory for Energy 4(1), European Commission.

Fama, E. F., Fisher, L., Jensen, M. C., and Roll, R. (1969). The adjustment of stock prices to new information. *International Economic Review*, 10(1):pp. 1–21.

Fell, H. (2010). EU-ETS and Nordic Electricity: A CVAR Analysis. *The Energy Journal*, 31(2):1–26.

Ferkingstad, E., Loland, A., and Wilhelmsen, M. (2011). Causal modeling and inference for electricity markets. *Energy Economics*, 33(3):404–412.

Fezzi, C. and Bunn, D. W. (2009). Structural interactions of European carbon trading and energy prices. *The Journal of Energy Markets*, 2(4):53–69.

Fezzi, C. and Bunn, D. W. (2010). Structural Analysis of Electricity Demand and Supply Interactions. *Oxford Bulletin of Economics and Statistics*, 72(6):827–856.

Finon, D. and Locatelli, C. (2008). Russian and European gas interdependence: Could contractual trade channel geopolitics? *Energy Policy*, 36(1):423 – 442.

Fritz, A. (2012). European electricity and interrelated futures markets: A cointegrated vector autoregressive analysis. EWL Working Papers 1205, University of Duisburg-Essen, Chair for Management Science and Energy Economics.

Furió, D. and Chuliá, H. (2012). Price and volatility dynamics between electricity and fuel costs: Some evidence for Spain. *Energy Economics*, 34(6):2058 – 2065.

Gabaix, X., Laibson, D., Moloche, G., and Weinberg, S. (2006). Costly information acquisition: Experimental analysis of a boundedly rational model. *The American Economic Review*, 96(4):pp. 1043–1068.

Gallagher, K. S. and Muehlegger, E. (2011). Giving green to get green? Incentives and consumer adoption of hybrid vehicle technology. *Journal of Environmental Economics and Management*, 61(1):1 – 15.

Gicheva, D., Hastings, J., and Villas-Boas, S. (2010). Investigating income effects in scanner data: Do gasoline prices affect grocery purchases? *American Economic Review*, 100(2):480–84.

Gilbert, T., Kogan, S., Lochstoer, L., and Ozyildirim, A. (2012). Investor inattention and the market impact of summary statistics. *Management Science*, 58(2):336–350.

Giulietti, M., Grossi, L., and Waterson, M. (2012). A Rough Analysis: Valuing Gas Storage. *The Energy Journal*, 33(4).

Goldthau, A. (2008). Rhetoric versus reality: Russian threats to European energy supply. *Energy Policy*, 36(2):686 – 692.

Grave, K., Paulus, M., and Lindenberger, D. (2012). A method for estimating security of electricity supply from intermittent sources: Scenarios for Germany until 2030. *Energy Policy*, 46(0):193 – 202.

Greene, D. L. (2010). How consumers value fuel economy: A literature review. Technical Report EPA-420-R-10-008, U.S. Environmental Protection Agency.

Griskevicius, V., Tybur, J. M., and Van Den Bergh, B. (2010). Going green to be seen: status, reputation, and conspicuous conservation. *Journal of Personality and Social Psychology*, 98(3):392–404.

Growitsch, C., Stronzik, M., and Nepal, R. (2012). Price convergence and information efficiency in German natural gas markets. EWI Working Papers 2012-5, Energiewirtschaftliches Institut an der Universitaet zu Koeln.

Hall, P. (1995). *The Bootstrap and Edgeworth Expansion*. Springer Series in Statistics. Springer.

Hamilton, J. D. (1983). Oil and the Macroeconomy since World War II. *Journal of Political Economy*, 91(2):pp. 228–248.

Hartley, P. R., Medlock, K. B., and Rosthal, J. E. (2008). The relationship of natural gas to oil prices. *The Energy Journal*, 29(3):47–66.

Hastie, T. and Tibshirani, R. (1993). Varying-Coefficient Models. *Journal of the Royal Statistical Society. Series B (Methodological)*, 55(4):pp. 757–796.

Hayfield, T. and Racine, J. S. (2008). Nonparametric Econometrics: The np Package. *Journal of Statistical Software*, 27(5):1–32.

He, Y., Wang, S., and Lai, K. K. (2010). Global economic activity and crude oil prices: A cointegration analysis. *Energy Economics*, 32(4):868 – 876.

Heffner, R. R., Kurani, K. S., and Turrentine, T. S. (2007). Symbolism in California's early market for hybrid electric vehicles. *Transportation Research Part D: Transport and Environment*, 12(6):396 – 413.

Henderson, J. and Heather, P. (2012). Lessons from the February 2012 European gas "crisis". Oxford Energy Comment, Oxford Institute for Energy Studies.

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *Stata Journal*, 7(3):281–312(32).

Hubert, F. and Ikonnikova, S. (2011). Investment options and bargaining power: The Eurasian supply chain for natural gas. *The Journal of Industrial Economics*, 59(1):85–116.

Kahn, M. E. (2007). Do greens drive hummers or hybrids? Environmental ideology as a determinant of consumer choice. *Journal of Environmental Economics and Management*, 54(2):129 – 145.

Kahneman, D. (1973). *Attention and effort*. Prentice-Hall series in experimental psychology. Prentice-Hall.

Kanamura, T. and Ohashi, K. (2007). A structural model for electricity prices with spikes: Measurement of spike risk and optimal policies for hydropower plant operation. *Energy Economics*, 29(5):1010–1032.

Kilian, L. (2008). Exogenous Oil Supply Shocks: How Big Are They and How Much Do They Matter for the U.S. Economy? *The Review of Economics and Statistics*, 90(2):216–240.

Kilian, L. (2009). Not all oil price shocks are alike: Disentangling demand and supply shocks in the crude oil market. *American Economic Review*, 99(3):1053–69.

Kilian, L. and Hicks, B. (2012). Did unexpectedly strong economic growth cause the oil price shock of 2003-2008? *Journal of Forecasting*, forthcoming.

Kilian, L. and Murphy, D. (2010). The role of inventories and speculative trading in the global market for crude oil. CEPR Discussion Papers 7753, C.E.P.R. Discussion Papers.

Kilian, L. and Vigfusson, R. J. (2011). Nonlinearities in the oil price–output relationship. *Macroeconomic Dynamics*, 15:337–363.

Kim, S. and Roubini, N. (2000). Exchange rate anomalies in the industrial countries: A solution with a structural VAR approach. *Journal of Monetary Economics*, 45(3):561 – 586.

Lewis, M. S. and Marvel, H. P. (2011). When do consumers search? *The Journal of Industrial Economics*, 59(3):457–483.

Li, J. and Yu, J. (2012). Investor attention, psychological anchors, and stock return predictability. *Journal of Financial Economics*, 104(2):401 – 419.

Li, Q. and Racine, J. (2007). *Nonparametric Econometrics: Theory and Practice*. Princeton University Press.

Lippi, F. and Nobili, A. (2012). Oil and the macroeconomy: A quantitative structural analysis. *Journal of the European Economic Association*, 10(5):1059–1083.

Lochner, S. (2011). Modeling the European natural gas market during the 2009 Russian-Ukrainian gas conflict: Ex-post simulation and analysis. *Journal of Natural Gas Science and Engineering*, 3(1):341 – 348.

Lochner, S. and Dieckhöner, C. (2012). Civil unrest in North Africa - Risks for natural gas supply? *Energy Policy*, 45(0):167 – 175.

Longstaff, F. A. and Wang, A. W. (2004). Electricity forward prices: A high-frequency empirical analysis. *The Journal of Finance*, 59(4):1877–1900.

Lütkepohl, H. (2005). *New Introduction to Multiple Time Series Analysis*. Springer.

Ma, Y., Ailawadi, K. L., Gauri, D. K., and Grewal, D. (2011). An empirical investigation of the impact of gasoline prices on grocery shopping behavior. *Journal of Marketing*, 75(2):18 – 35.

MacKinlay, A. C. (1997). Event Studies in Economics and Finance. *Journal of Economic Literature*, 35(1):13–39.

Malkiel, B. G. and Fama, E. F. (1970). Efficient capital markets: A review of theory and empirical work. *The Journal of Finance*, 25(2):383–417.

Masatlioglu, Y., Nakajima, D., and Ozbay, E. Y. (2012). Revealed attention. *American Economic Review*, 102(5):2183–2205.

Maxwell, D. and Zhu, Z. (2011). Natural gas prices, LNG transport costs, and the dynamics of LNG imports. *Energy Economics*, 33(2):217 – 226.

McCombs, M. E. and Shaw, D. L. (1972). The agenda-setting function of mass media. *Public Opinion Quarterly*, 36(2):176–187.

Mjelde, J. W. and Bessler, D. A. (2009). Market integration among electricity markets and their major fuel source markets. *Energy Economics*, 31(3):482–491.

Mohammadi, H. (2009). Electricity prices and fuel costs: Long-run relations and short-run dynamics. *Energy Economics*, 31(3):503–509.

Morbee, J. and Proost, S. (2010). Russian Gas Imports in Europe: How Does Gazprom Reliability Change the Game? *The Energy Journal*, 31(4):79–110.

Mount, T. D., Ning, Y., and Cai, X. (2006). Predicting price spikes in electricity markets using a regime-switching model with time-varying parameters. *Energy Economics*, 28(1):62–80.

Mu, X. (2007). Weather, storage, and natural gas price dynamics: Fundamentals and volatility. *Energy Economics*, 29(1):46 – 63.

Neumann, A. (2009). Linking Natural Gas Markets - Is LNG Doing its Job? *The Energy Journal*, Volume 30(Special Issue):187–200.

Panagiotidis, T. and Rutledge, E. (2007). Oil and gas markets in the UK: Evidence from a cointegrating approach. *Energy Economics*, 29(2):329–347.

Pirani, S., Stern, J., and Yafimava, K. (2009). *The Russo-Ukrainian Gas Dispute of January 2009: A Comprehensive Assessment*. Oxford Institute for Energy Studies.

Ramberg, D. J. and Parsons, J. E. (2012). The weak tie between natural gas and oil prices. *The Energy Journal*, 33(2).

Renou-Maissant, P. (2012). Toward the integration of European natural gas markets: A time-varying approach. *Energy Policy*, 51(0):779 – 790.

Rickels, W., Görlich, D., and Oberst, G. (2010). Explaining European Emission Allowance Price Dynamics: Evidence from Phase II. Kiel Working Papers 1650, Kiel Institute for the World Economy.

Robinson, T. (2007). Have European gas prices converged? *Energy Policy*, 35(4):2347 – 2351.

Sagen, E. L. and Tsygankova, M. (2008). Russian natural gas exports - Will Russian gas price reforms improve the European security of supply? *Energy Policy*, 36(2):867 – 880.

Samuelson, P. A. (1965). Proof that properly anticipated prices fluctuate randomly. *Industrial Management Review*, 6(2):41–49.

Sexton, S. E. and Sexton, A. L. (2011). Conspicuous Conservation: The Prius Halo and Willingness to Pay for Environmental Bona Fides. *UC Center for Energy and Environmental Economic Working Paper Series*, 29.

Sims, C. A. (1980). Macroeconomics and reality. *Econometrica*, 48(1):pp. 1–48.

Sims, C. A., Stock, J. H., and Watson, M. W. (1990). Inference in linear time series models with some unit roots. *Econometrica*, 58(1):pp. 113–144.

Spanjer, A. (2007). Russian gas price reform and the EU-Russia gas relationship: Incentives, consequences and European security of supply. *Energy Policy*, 35(5):2889 – 2898.

Stock, J. H. and Watson, M. W. (2001). Vector autoregressions. *The Journal of Economic Perspectives*, 15(4):pp. 101–115.

Tetlock, P. C. (2007). Giving content to investor sentiment: The role of media in the stock market. *The Journal of Finance*, 62(3):1139–1168.

Thoenes, S. (2011). Understanding the determinants of electricity prices and the impact of the german nuclear moratorium in 2011. EWI Working Papers 2011-6, Energiewirtschaftliches Institut an der Universitaet zu Koeln.

Thoenes, S. and Gores, T. (2012). Attention, media and fuel efficiency. EWI Working Papers 2012-11, Energiewirtschaftliches Institut an der Universitaet zu Koeln.

Toda, H. Y. and Yamamoto, T. (1995). Statistical inference in vector autoregressions with possibly integrated processes. *Journal of Econometrics*, 66(1-2):225 – 250.

Turrentine, T. S. and Kurani, K. S. (2007). Car buyers and fuel economy? *Energy Policy*, 35(2):1213 – 1223.

Tversky, A. and Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model. *The Quarterly Journal of Economics*, 106(4):1039–1061.

Viehmann, J. (2011). Risk premiums in the German day-ahead Electricity Market. *Energy Policy*, 39(1):386 – 394.

Weron, R., Bierbrauer, M., and Trueck, S. (2004). Modeling electricity prices: Jump diffusion and regime switching. *Physica A*, 336(1-2):39–48.

Xiao, Z. (2009). Functional-coefficient cointegration models. *Journal of Econometrics*, 152(2):81–92.

Yuan, Y. (2011). Attention and Trading. *SSRN eLibrary*.

Zachmann, G. (2012). A stochastic fuel switching model for electricity prices. *Energy Economics*, forthcoming.

Zachmann, G. and von Hirschhausen, C. (2008). First evidence of asymmetric cost pass-through of EU emissions allowances: Examining wholesale electricity prices in Germany. *Economics Letters*, 99(3):465–469.

Zellner, A. (1962). An efficient method of estimating seemingly unreleated regressions and tests for aggregation bias. *Journal of the American Statistical Association*, 57(298):348 – 368.

Curriculum Vitae

Stefan Thoenes

Personal Details

Date of birth: September 30th, 1987
Place of birth: Siegburg, Germany

Education

2009 - 2012 — **Cologne Graduate School**, University of Cologne, Germany
Doctoral student at the Institute of Energy Economics

2005 - 2009 — **University of Cologne**, Germany
Diplom in Business Administration

- Majors: Financial Markets, Corporate Finance, Statistics
- Thesis: Equilibrium prices of electricity forwards

2008 — **University of Sydney**, Australia
Exchange semester, postgraduate studies in finance

1997 - 2005 — Albert-Einstein-Gymnasium, Sankt Augustin, Germany
Higher education entrance qualification

Professional Experience

2010 — **Google**, Zurich, Switzerland
Internship: Industry Analyst in Sales

2007 — **Deloitte Corporate Finance**, Düsseldorf, Germany
Internship: Mergers & Acquisitions Advisory

2006 — **Eisenbahn-Bundesamt**, Bonn, Germany
(German Federal Railway Authority)
Internship: Financing of Railway Infrastructure

Conference Presentations

2012
Young Energy Economists and Engineers Seminar (Florence, Italy), 12th European Conference of the International Association for Energy Economics (Venice, Italy), 39th Annual Conference of the European Association for Research in Industrial Economics (Rome, Italy), International Ruhr Energy Conference, University of Duisburg-Essen (Essen, Germany)

2011
Energy & Finance Conference, Erasmus School of Economics (Rotterdam, Netherlands)

Summer Schools and Workshops

2010	German-Polish Economic Forum: "Energy Economics" University of Cologne and Warsaw School of Economics, Poland
2010	HEC Paris, France PhD Seminar: Interaction of Finance and Industrial Organization
2009	University of Seoul, South Korea Summer School, International Economics and East Asian History

Scholarships and Awards

2009 - 2012	Full scholarship for doctoral studies granted by Cologne Graduate School, University of Cologne
2007	Oliver Wyman - Köln Alumni - Vordiplomspreis Award for outstanding academic achievements