Not all Derivatives are alike:

Insights from the German Market

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Conferences and Seminars

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Chapter 1

Introduction

"…Derivatives are financial weapons of mass destruction, carrying dangers that, while now latent, are potentially lethal" (Berkshire Hathaway Inc., 2002, p.15). Even more strongly, Warrant Buffet and Charles Munger believed that derivatives and investment positions taken in derivatives are "time bombs, both for the parties that deal in them and the economic system." (Berkshire Hathaway Inc., 2002, p.13). For this reason, they did not at all invest in derivatives as they stated in the letter to the Berkshire Hathaway Inc. shareholders in 2002. And even in 2016, they partly reconfirmed their view on the role of derivatives. At the shareholders' meeting of Berkshire Hathaway in 2016, Warrant Buffett states that derivatives are complex and dangerous in times of discontinuity. Even though his viewpoint is more lenient than in 2002, he still believes that large derivative positions are dangerous (Gongol, 2016). Alan Greenspan, an American Economist and Chairman of the Federal Reserve of the United States from 1987, has had a similar view until 2006. However, he has changed his mind from a more positive to a more negative view. While in 2003, he believed that an unregulated market for derivatives is best, this point of view changed when the role of financial derivatives in the financial crisis became clear (The New York Times, October 9th 2008). The opinions of such prominent figures also explain the mostly negative public opinion which is supported by the presentation of the topic in the media. Denning (2013), writing for Forbes, states in his article that a new financial crisis is inevitable due to the strong derivative positions the financial institutions own.

This presentation of derivatives, however, only seems to be one part of the picture. The other part of the picture appears more positive and more differentiated. Earlier, Arthur Levitt (1995) believed that it is not about the derivative itself but about how they are used. He thus compared them to electricity: “Dangerous if mishandled, but also capable of doing enormous good,” which suggests that a more controversial discussion on derivatives would be necessary.

Especially after the financial crisis when financial derivatives were often named as a trigger for this crisis, discussions emerged that came to a more positive conclusion on derivatives even after addressing the risks. In this manner, Klieber (2012) emphasizes the qualities of derivatives to serve as market indicators and to redistribute risks. Stulz (2009) states the importance of derivatives contracts to shift risks and that they serve as a good signal for the health of the market. But he also points out that the derivative market would benefit from some regulations. Sharma (2013) similarly believes that an increase of market regulations for derivative contracts would lead to more transparency and hence, to an environment where the benefits of such products can be used, especially regarding risk management for companies. In sum, there are positive aspects of these products that cannot be denied, even if they need to be handled with caution. An indicator for the great role that derivatives play in the economies worldwide is their growth over the last years. Globally, the turnover of OTC derivatives has grown from around 1500 billion U.S. dollars in 1995 to 6514 billion U.S. dollars in 2016. During the same period, the turnover in Germany has grown from 79 billion to 116 billion U.S. dollars (BIS, 2017). Accordingly, Hull (2012, p.1) wrote that “whether you love derivatives or you hate them, you cannot ignore them.” The market size of derivatives, together with the controversial discussion going on over the years, make these products an interesting research subject. However, even though derivatives in general are often talked and written about, in their great extent, these products are not alike. This dissertation, therefore, analyzes two derivative products in particular: warrants and energy derivatives in Germany.

Derivatives are instruments whose value derives from the value of an underlying entity. This underlying is a more basic variable, which can be nearly everything, from a traded assets to the weather (Hull, 2012, p.1). Regarding a transaction that will be fulfilled at some point in time in the future, it is a contract between two parties, a buyer and a seller (Deutsche Börse AG, 2008, p.6). Derivatives have already been used by the Babylonians who lived around the 18th century B.C. Farmers used their products, which enable them to sell their crop at an agreed price to a wholesaler months before the crop was ready to harvest, similar to futures contracts we know today. The farmers could ensure a profit independent of the quality of the crop and survived by the profits across the following winter even having had a bad crop (Herrmann, 2015, pp.142-144). While the underlying in this time were only a few which were based on problems that may have decided about life or death of an individual, a great variety exists today, which aim to improve the situations of companies, insurances, and individuals by enabling them to transfer risks, especially future risk.

A price for the derivative must be available to transfer risks (Bouchaud and Potters, 2000, p.91). These prices should include available market information and should change with new information in the market. The connection between the prices of the derivative and the price of its underlying are visible since the value of the derivative is driven by the fluctuations of the underlying. Moreover, the risks that influence the value of the derivative also influence the derivative's price. The risk in general "may be defined as the potential variability of the outcomes from an investment. The less predictable the outcomes, the greater is the risk" (Block, Hirt and Danielsen, 2009, p.423). Investors might be willing to carry the risk, but they mostly want to be compensated. Hence, a risk premium should be added to the price of the derivative (Bouchaud and Potters, 2000, p. 138). Risks that influence the value of derivatives are, among others, price risks, counterparty risks, liquidity risks (Deutsche Börse AG, 2008, pp.24-26), and risks of external factors. However, not all derivative prices are affected by a particular risk in a similar vein. Often the impact depends on the marketplace where the product is traded and the product itself. Therefore, in the following, the derivative market in Germany with its marketplaces and their products is introduced (Figure 1.1).

The largest marketplace for derivatives in Germany is the EUREX. In 2015, around 2 billion contracts were traded at the EUREX which is No. 3 of all derivative marketplaces around the globe regarding traded contracts (Statista, 2017). The exchange, founded in 1998, offers a great variety of product underlying, including gold, real estate, and Euro-Swaps (Figure 1.1). The tradables are futures and options. While futures define an obligation between two parties to fulfill a transaction at some point in future, options are the right to do so. The buyer of an option is free to choose whether or not he will use the option to fulfill the transaction at a predetermined date in future. The EUREX only enables institutional investors to trade in this marketplace. Retail investors are excluded (EUREX Frankfurt AG, n.d.). The EUREX is a highly regulated market. EUREX lays down regulations such as the settling of contracts via a third party, the clearing house, and the daily balancing of the accounts until the maturity of the contracts, which each investor willing to participate in this market needs to adhere to. These regulations, also known as mark-to-market approach, reduce the counterparty risk. Since the accounts are balanced each day, the investor only loses the money from the change in position from yesterday to today. Therefore, any potential losses in case of an insolvency of the counterparty are kept to a minimum. The liquidity risk is also negligible in this marketplace. Due to the size of the market and the number of active participants, it seems highly unlikely that an investor will be unable to find a counterparty willing to take the counter position of the contract.

Figure 1.1: Overview derivative marketplaces in Germany

	EUREX	EEX (European Energy Exchange)	Börse Frankfurt Zertifikate AG	EUWAX (Börse Stuttgart)
Investors	- Institutional Investors	- Institutional Investors	- Retail Investors	- Retail Investors
Products	- Futures - Options	- Futures - Options	- Certificates - Warrants - Knock-outs	- Certificates - Warrants - Knock-outs
Underlying	- Interest Rates - Equity & Equity Index - Dividend - Foreign Exchange - Volatility Index - Exchange Traded Funds - Commodities - Property	- Power - Natural Gas - Coal - Fuel Oil - Environmental Markets - Freight - Metal - Agricultural Commodities	- Equity - Bonds - Fonds & Hedgefonds - Future - Property - Interest Rates - Commodities - Foreign Exchange - Indices	- Equity - Indices - Commodities - Foreign Exchanges

Note: Figure 1 characterizes underlying and products of the different marketplaces for derivatives in Germany: the EUREX, the markets for retail investors and the market for energy commodities.

The second marketplace for derivatives is the European Energy Exchange (EEX) founded in 2002 by a merger of the German power exchanges in Frankfurt and Leipzig. This exchange solely focuses on energy and commodity-related underlying, such as power and agriculture. The most important underlying in terms of trading volume is the derivative market for power. Products which are available on the different underlying are futures and options (EEX AG, 2017). One specialty about the future contracts on power are the different subcategories. Contracts are available that bundle specific hours of the day by the expected energy demand in those hours, which are so-called load profiles. All contracts traded at the EEX are only available to institutional investors. The EEX is a wholesale market where producers, transmission companies, and distributors are the main participants next to banks and other trading companies specialized on energy products. Financial companies not only trade on their behalf but also on behalf of small energy producers which are not able to carry the costs of trading on their own in terms of fees and personnel. The EEX is also a highly regulated market where contracts are settled via a clearing house and daily price settlements ensure the independence of the investor's position from the creditworthiness of the counterparty. Hence, similar to the EUREX, counterparty risk is negligible. Since the EEX is one of the major markets for energy and energy commodities in Europe, it seems to be reasonable to state that also the liquidity risk is close to none existent. However, one external risk that especially influences the market prices of the major product category, the power derivatives, is the weather. Over the last years, the share of renewable energy as part of the total energy production has increased. The production of renewable energy resources such as wind and solar energy depends on the weather. However, weather is unstable over time and difficult to forecast. Also, renewable energy is fed into the grid preferentially and hence, the effect of renewable energy production on the price is even greater. The focus on energy derivatives should consider this external risk factor.

Another marketplace for derivatives in Germany is the Börse Frankfurt Zertifikate AG, which was renamed in November 2013. The marketplace was previously known as Scoach. It is located in Frankfurt and is part of the Deutsche Börse AG. The Börse Frankfurt Zertifikate AG offers a wide variety of asset classes as underlying. Among others, they offer products on stocks, bonds, currencies, and indices. Different main product categories are available: warrants, certificates, and knock-outs (Deutsche Börse AG, 2017a). Warrants are similar to options. They offer a right without any obligation to buy (call) or sell (put) an underlying. Certificates are derivative instruments that enable an investor to participate in the price movements of a specific underlying. Each certificate has a defined redemption, which also depends on the price movement of the underlying. Knock-out products belong to the category of leverage products. The investor also participates in the price movement of the underlying, but the product includes a barrier which when not met before the product's maturity, will render the product worthless (Broadie, Galsserman and Kou, 1997, p.325; Hull, 2012, p. 579). This marketplace and its products are developed for retail investors. The entry barriers to the market are therefore lower than in the markets for institutional investors. Smaller contract sizes are available so that investors can buy only a fraction of one unit of the underlying asset. Banks offer these products which also often act as a market maker. For ensuring liquidity in the market, they are forced to offer bid and ask prices (Deutsche Börse AG, 2017b). Another major difference compared to the markets for institutional investors are the regulations concerning clearing and the mark-to-market approach. At the Börse Frankfurt Zertifikate AG, no clearing party exists, and hence, the contracts are settled directly between the bank and the investor. Moreover, no margin calls and no daily balancing of the accounts occur. Therefore, counterparty risk is present for an investor if he is active in this market. This creditworthiness of the issuer is an additional risk involved in the product and, therefore, should influence the value of the investment, which is the product's price. Liquidity risks seem to be negligible since the issuer of the products are obliged to buy back the products that they have offered.

Another marketplace where retail investors have the possibility to participate is the EUWAX which is part of the Börse Stuttgart. Already in 1999, the EUWAX started to take over responsibility for the derivative trading segment of the Börse Stuttgart (EUWAX AG, 2002-2017). The EUWAX offers similar products on comparable underlying as the Börse Frankfurt Zertifikate AG (Boerse Stuttgart GmbH, 2017) does. Since also the market regulations are similar to the one of the Börse Frankfurt Zertifikate AG, the product prices are influenced by similar risks. Especially, the counterparty risk is one to mention here again, since this is typical for the retail market where there is no mark-to-market approach nor any clearing party.

To analyze the effect of risks that influence prices in more detail, two products are chosen for this purpose of this dissertation: warrants and energy derivatives. One product of each category is chosen to account for the different target groups and the differences in the regulatory environment for retail and institutional investors. As already pointed out, the creditworthiness of the issuer influences most retail investor product prices. Therefore, the first part of the dissertation analyzes the credit risk and its influence on warrant prices. The underlying chosen for the analysis is the DAX performance index. Chapter Two analyzes the influence of the issuer’s credit risk on price-driving factors, and Chapter Three focuses on the relationship between a change in credit spreads and warrant prices. The second part of the dissertation analyzes the effect of weather on electricity futures prices.

Chapter 2. The second chapter investigates the importance of the issuer’s credit risk in the pricing of warrants during a period where credit spreads changes were at extraordinary levels. As the basis of this investigation, daily margins were used, meaning the difference between the warrants price and its theoretical value. The literature has shown that product-specific characteristics such as the moneyness and the time to maturity influences such margins. By using Fama-MacBeth estimations on a daily basis over a two-and-a-half-year period, we find that the factor sensitivities such as the time to maturity are not stable over time. We confirm this result for all six issuers in our sample, which were chosen due to their number of warrants outstanding. The influences of the factors for determining the warrant’s margin undergo change over time. We expected that the change in time to maturity sensitivities might correlate to the issuer's credit spread curve. Issuers may not capture their credit risk fully in the warrant prices since retail investors may have difficulties in evaluating the credit risk and hence, perhaps consider it only to some extent (Baule, et al., 2008). It is also imaginable that issuers use an average credit spread for pricing warrants with long and short times to maturity. Using a time-series test, we find evidence for the connection between the issuer's credit spread curve and time to maturity sensitivities. We know from the literature that the time to maturity has an influence on the pricing of warrants and hence, on its margin in such a way that the margins are reduced to the end of a product life when banks would buy back the product. However, our findings suggest that a steeper credit spread diminishes this pricing pattern. Hence, the issuer's credit spread also influences the warrant margins. Therefore, in times of major changes in the credit spreads, such as in a financial crisis, the pricing relationships changes, and retail investors should be aware of this change.

Chapter 3. Since Chapter 2 has already found a relationship between warrant prices and issuer's credit spreads, this article uses a new approach to analyze this relationship. It investigates how issuers adjust their warrant prices to a change in their credit risk. As Baule, et al. (2008) state, retail investors may have difficulties in evaluating the influence of the credit risk involved in warrants, which would lead to an opportunity for the issuers to navigate their prices actively. Taking as an assumption that they have this leeway, the issuer has no incentive to treat prices after a credit spread increases similar to a credit spread decrease. After the credit risk decrease, issuers would have an incentive to directly raise prices, which might be limited by the price sensitivity of the investors. But they have no incentives to lower prices after a credit risk increase since this will lower the issuer's profits. Therefore, an adverse pricing behavior is expected. To analyze these adverse pricing patterns, we not only consider the CDS spread of a specific day but also the spread changes of the previous days. For this analysis, we use the same data as in Chapter Two. Estimations were run again for each issuer separately to control for the fact that their price responses to changes in their credit risk may differ. We find support over the whole period that as a first reaction after a CDS spread increases, which means that the credit risk increases, and hence, lowering the prices should compensate investors and a price reduction indeed occurs. However, issuers will again increase their prices in the following days. Therefore, they at least partly neutralize the price reduction afterward. This price increase might be driven by a higher demand since new investors might be attracted to the warrant after the prices have decreased. In contrast, we are not able to find evidence across the whole period that after a CDS reduction, prices will increase in the days following. A price increase, however, would be justified since a reduction in CDS means less risk involved. The evidence is here only found for the period after the insolvency of Lehman Brothers, which we define as the period from July 2009 to June 2010. Comparing both effects to each other, we find that in the post-Lehman period, sample price changes after credit spread increases are absolutely smaller than after credit risk decreases. These results suggest that the issuers reduce their prices less after a CDS spread increase than they increase their prices after a CDS spread decrease. Based on these results, we conclude that issuers use their changes in credit risk to gain an additional profit.

Chapter 4. The last chapter of the dissertation focuses on the weather risk captured by weather parameters and its influence on the prices of energy products. The importance of renewable energy in Germany is the main reason why energy prices need to consider the weather risk. The weather is uncontrollable and difficult to predict, which means that it is difficult to predict the amount of energy generated by these resources and hence, the total amount of energy that will be available. The weather risk captured by the different weather parameters is analyzed over a 10-year period of German energy prices derived from the EEX. Since weather undergoes changes on a short-term notice, as expected, the results demonstrate that the weather risk affects spot market products stronger than derivative market products. However, not all weather parameters affect the products in the same way. Moreover, the prices of products with a longer time span are affected less by the majority of the weather parameters. Concerning the different load profiles, peak-load and base-load products are affected differently than off-peak load products are in the spot market. Over the 10-year period considered, the amount of renewable energy as a share of total energy production has steadily increased. With this increasing amount of energy fed into the grid in preference to energy from conventional resources, one would expect that also the influence of the weather parameter on the energy prices has changed. Subsamples were formulated to analyze the differences. One political change that took place during this time is the Nuclear Moratorium in March 2011. This event may serve as a good point in time to split the sample: a) the year 2011 is the middle of the 10-year period and hence, it split the subsamples into two periods with a comparable number of observations, b) this topic was raised to the media, which may have had an effect on the energy consumption of people, and c) Germany has decided to shut down all nuclear power plants and as direct consequence, it has already closed eight power plants because of their age. Even though a jump in the number of renewable energy resources installed and used cannot be expected to be achieved since Germany relies on a broad range of energy resources, this decision will lead to an increase in renewable energy over the next years to compensate the missing power from nuclear power plants. In sum, the Nuclear Moratorium seems to be a good choice for using this date for splitting the data set. The results of the comparison between the subsamples suggest that even though the influence of renewable energy is expected to increase, the influence of the weather parameter on the different products decreases in the second part of the sample. Especially, the influence on the derivative products loses in significance. In the last part of the analysis, the paper deals with the effect of unfavorable weather conditions on energy prices. For this purpose, the analysis includes different combinations of weather parameters of which one example leads to a low production of renewable energy, but the temperature would suggest that a large amount of energy is needed. This chapter shows that these different weather combinations increase the different energy prices. Hence, not only the weather parameters influence the energy prices but also the combinations of the weather parameters. This chapter, therefore, proves that an impact of the weather risk on product prices in the energy market is present and needs to be considered.

The different chapters demonstrate the differences of products and their risks affecting prices even though they are all called derivatives. But derivatives are not all alike. It is important to analyze the regulatory environment, the market, and product specialties to understand the nature of the risks that affect the prices of a specific derivative instrument. Moreover, these chapters demonstrate that changes in the environment are like the changes in the relationships between risks and price effects during a financial crisis and that also long-term developments such as the steady increase in renewable energy over the last years may have similar effects. Therefore, it is inadmissible to draw conclusions on derivatives in general. A more detailed analysis would be necessary in any case. One limitation of this dissertation is its scope. It serves as a beginning research to address the different products and the different risks in pricing. Future research may enhance this by focusing on other derivative products. Another interesting subject for future research would be a direct comparison between products more comparable to each other like warrants and certificates and a valuation of how a specific risk affects the prices of both products. Such results seem to be of relevance especially to the target group of the product, whether these are retail or institutional investors.

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Chapter 2

Issuers' Credit Risk and Pricing of Warrants in the Recent Financial Crisis[1]

We expect the factor sensitivities of margins of bank-issued warrants to depend on issuers' credit risk during the period of economic turmoil between January 2008 and June 2010. Therefore, we first apply Fama-MacBeth estimations and demonstrate that the sensitivities of margins in terms of time to maturity and moneyness vary substantially over time; the average outcomes are similar to the results of classical pooled estimations. Then we use time-series tests and find that the steepness of the issuers' CDS spread curves correlates negatively with the time-to-maturity sensitivities as well as with the explanatory power of Fama-MacBeth estimations. These findings indicate that the life-cycle hypothesis is weakened when the issuers' CDS spread curves become steeper.

Keywords: warrants, credit spread curve, crisis, Fama-MacBeth estimations
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2.1 Introduction

Recent empirical studies dealing with structured financial products (SFPs) analyze the price setting behavior of issuing banks (e.g., Baule, 2011; Baule and Blonski, 2014; Benet, et al., 2006; Chang, et al., 2012; Henderson and Pearson, 2011; Muck, 2006; Stoimenov and Wilkens, 2005; Wallmeier and Diethelm, 2009). These products allow retail investors to enter positions in securities that they could not otherwise build up, since market barriers and bottlenecks, for instance with respect to minimum investment amounts, hinder them in doing so. At the center of academic studies is a so-called margin defined as the difference between the market price of a product and its theoretical value determined by duplicating the product's cashflow stream. So far, studies addressing the pricing of SFPs have investigated either only a single calendar day (e.g. Stoimenov and Wilkens, 2005) or they have pooled daily data over various months in single estimations (e.g. Baule, 2011). For instance, Baule and Blonski (2014) pooled daily data over a 1-year horizon and investigated factors affecting margins. They find that the time to maturity of a warrant has a positive effect on margins, which is explained by the life-cycle hypothesis. This effect and other factor sensitivities measured in these studies, such as the ones on moneyness and product competition, are averages of the sample, of the products considered, as well as of the days that are pooled together. Pooling might imply a loss of information, which might be very strong in times of large changes in issuers' credit spread curves.

We expect instabilities in factor sensitivities, because the credit spread curves of issuing banks reached new levels during our sample period from January 2008 to June 2010. SFPs expose retail investors to issuers' credit risk, since there is no daily settlement of these products, although they are traded in an organized market. Issuers may not (totally) capture their credit risk in pricing, because retail investors may struggle to apply pricing models for risky securities, and therefore they may consider the issuers' credit risk only to some extent (Baule, et al., 2008). Moreover, issuers may use an average credit spread for pricing warrants with short as well as long times to maturity. We expect that issuers' credit spread curves affect the life-cycle hypothesis. Steeper credit spread curves may come along with higher time-to-maturity sensitivities, since issuers may then overprice warrants with long time to maturity much more than warrants with short time to maturity. Alternatively, however, steeper credit spread curves may dilute the relationship between the time to maturity and overpricing, since issuers have, with less informed retail investors, more leeway in pricing their products. Therefore, we examine a long period of time to be able to identify issuer-specific factors, such as the steepness of the issuers' credit spread curve, which may play a role in issuers' price setting.

To assess the influence of issuers' credit spread curves on factor sensitivities of the margins, we propose a two-step procedure, which sets our study apart from recent literature on SFPs. By running Fama-MacBeth estimations, a method originally invented for asset prices (Fama and MacBeth, 1973), we test how factor sensitivities behaved during our 2.5-year sample period, which is a much longer period than the ones used in many other studies. To the best of our knowledge, this is the first study that employs Fama-MacBeth estimations on SFPs. In these estimations, we primarily consider three prominent factors used in empirical margin studies, namely the time to maturity of a warrant, its moneyness, and the product competition the warrant faces. For all three factors, we find that sensitivities are not time constant. Such instabilities of factor sensitivities are expected for all SFPs. However, we use (naked) bank-issued warrants instead of other product types, for example bonus or express certificates, because the number of warrants was already substantial at the beginning of 2008, a condition that is necessary to implement Fama-MacBeth estimations in calendar time. These Fama-MacBeth estimations are not only useful to identify instabilities in factor sensitivities, but the outcomes of these estimations can also be used to analyze the factors that influence these outcomes over time. In other words, additional factors that influence issuers' pricing behavior *over time* can be identified. We put particular emphasis on issuers' credit spread curves, a variable so far not considered in the literature on SFPs, and investigate their impact on the time series of time-to-maturity sensitivities and coefficients of determination. We find that models considering traditional factors perform worse when issuers' credit spread curves are steeper, which is driven by a dilution of the life-cycle hypothesis in times of steep credit spread curves.

The remainder of this paper is organized as follows: Section 2 explains where the margins derive from and provides background information on warrants. Section 3 introduces the data and presents descriptive statistics as well as our model setup. The fourth section contains our empirical results, and the last section summarizes our findings.

2.2 Deriving Margins of Warrants

2.2.1 Theoretical Values

With a warrant, a retail investor purchases a right to buy (call) or sell (put) an underlying at a specified price and at a predetermined expiry date (European style) or each day until this point (American style). A retail investor can purchase warrants either over the counter or at an exchange. In Germany, SFPs are traded on two stock exchanges. The Certificate Stock Exchange run by Deutsche Börse is located in Frankfurt and was formerly known under the name Scoach, which was a joint venture between Deutsche Börse and SIX Swiss Exchange that ended in June 2013. The second exchange is the EUWAX, which belongs to Börse Stuttgart. Warrants are issued by well-known financial institutions, such as Commerzbank and Deutsche Bank.

Warrants have a structure that is similar to the one of options, but they differ in several important other aspects. Compared to EUREX options traded in an organized market with daily settlement, warrants are available in smaller volumes and therefore, retail investors can get also a fraction of one unit underlying. Another advantage of warrants is that they come along with fewer requirements in terms of daily margin calls and transaction costs than EUREX options. However, in the warrant market, short positions are not possible, and trading liquidity is lower than for EUREX options. The issuing entity is very often the market maker (Baule and Blonski, 2014) that is responsible to keep certain liquidity in the market. Therefore, they are obliged to ensure buying back a certain volume of each product outstanding.

The theoretical value of a warrant can be based on the model by Black and Scholes (1976). As the underlying we investigate is a performance index, no model adjustment for dividend payments is necessary. However, since warrants often do not refer to one unit of the underlying but a fraction, we have to adjust the value for the so-called ratio. In addition, we also have to adjust the theoretical value for the delay in repayment, because the valuation of a warrant takes place on the valuation date *T*, but the investor receives his repayment several days after this valuation date, which we call the payment date, τ. Every difference between the valuation and payment date means time the investor loses, since waiting for the money may imply missing a chance to profit from an alternative investment. Taking into account these two specificities, the Black-Scholes theoretical value of a European call warrant *i* at point in time *t* is given by:

$$TV_{it}^{BS} = \left[S_t N(d_{it}) - e^{-r_t(T_i - t)} \times X_i N\left(d_{it} - \sigma_{it}\sqrt{T_i - t}\right)\right] \times e^{-r_t^{FW}(\tau_i - T_i)} \times ratio_i \qquad (2.1)$$

with $$d_{it} = \frac{\ln\left(\frac{S_t}{X_i}\right) + (r_t + \frac{\sigma_{it}^2}{2}) \times (T_i - t)}{\sigma_{it}\sqrt{T_i - t}},$$

where TV denotes the theoretical value of the warrant, S denotes the price of the underlying, σ is the volatility of the underlying and X denotes the strike of the warrant. r is the risk-free rate used for the time between the day under focus, t, and the valuation date, T, which is the time to maturity of the warrant. r^{FW} is the forward rate applicable for the time between the valuation date, T, and the payment date, τ, which describes the time the investor is waiting for his money.

Because warrants are issued by banks and because they are not subject to a clearing system, an investment in a warrant exposes the retail investor to the credit risk of the issuer. Thus, the retail investor takes over the risk that the purchased financial product will lose its value in case of insolvency (Loudon and Nguyen, 2006). The credit risk can amount up to some dozens of basis points, although most of the issuers have high investment grade ratings (Baule, 2011). Therefore, we follow Hull and White (1995), who expanded the model provided by Black and Scholes to include the issuer's credit risk. The theoretical value of a European call warrant then is:

$$TV_{it}^{HW} = e^{-CS_{it}(\tau_i - t)} \times TV_{it}^{BS} \quad (2.2)$$

where CS is the credit spread of the bank that issued warrant i.

2.2.2 Margins and Input Parameters

The margin of a warrant *i* is defined as the difference between its observed market price P_{it} and its theoretical value, which we determine by using the model by Hull and White (1995):

$$Margin_{it} = (P_{it} - TV_{it}^{HW})/TV_{it}^{HW} \quad (2.3)$$

When issuers price warrants fairly with the model by Hull and White, the market price (P) minus the theoretical value (TV^{HW}) would be equal to zero. However, Stoimenov and Wilkens (2005) argue that issuers may face additional hedging costs, since they have to ensure liquidity in the market. In line with this argument, Deuskar, et al., (2011) find that illiquid over-the-counter interest rate caps and floors have higher prices than their liquid counterparts. In addition, administration costs and product structuring costs lead to a gap between the market price and the theoretical value. Besides this cost component, a profit component also plays a role, as issuers include an additional component in the price that they decrease over the lifetime of a structured financial product and that fluctuates systematically with retail investors' demand (Baule, 2011). Thus, this component is higher when issuers (mainly) sell than when they rebuy the product from retail investors. In addition, market makers of SFPs gain from differences between bid and ask prices, as all other market makers do.

These profit and cost components explain why various SFPs are overpriced as a wide range of literature has documented (e.g. Bartram, et al., 2008; Muck, 2006; Loudon and Nguyen, 2006; Baule, 2011; Fung and Zeng, 2012; Baule and Blonski, 2014). The literature also documents that a higher product complexity, in terms of multiple barriers or other characteristics influencing the payoff profile, comes along with higher overpricing (e.g. Entrop, et al., 2014; Baule and Tallau, 2011). For instance, discount certificates, which are less complex than other types of certificates, have lower overpricing than bonus certificates (Stoimenov and Wilkens, 2005) or turbo certificates (Muck, 2006). Several studies also deal with bank-issued warrants: Baule and Blonski (2014) find that retail investors compare the characteristics and prices of warrants not only of one but several issuers. Retail investors are price sensitive when it comes to many characteristics, and they are not bank loyal and therefore, choose the issuer offering the best price. Nevertheless, they are not absolutely price sensitive to the extent that high overpricing does not persuade them to leave the market. Despite high overpricing, they act in the warrant market, but search for the best prices.

Calculating the margins requires current market prices of the warrants and of the underlying as well as all characteristics of the warrants, such as strike price, time to maturity, ratio, and valuation and payment dates. This information is easily found, because it is stated for each product in the market. Calculating the margins also requires information on the risk-free rate, the forward rate, and the volatility of the underlying, none of which is directly observable in the market and therefore, has to be calculated from market data. To obtain the risk-free rate, r, and the implied forward rate, r^{FW}, for the time between payment and valuation date, the governmental spot-rate curve provided by the Deutsche Bundesbank is used; this method is based on the approach by Nelson and Siegel (1987) with the extension by Svensson (1994).

The volatility estimates, σ, are derived from daily settlement prices of EUREX call and put options on the DAX performance index retrieved from the Thomson Datastream. The implied volatility as an estimate of the underlying's future volatility captures the effect of the volatility smile described in the literature (e.g. Sircar and Papanicolaous, 1999; Baule and Tallau, 2011). Put and call options with identical strike and time to maturity are weighted to determine a hypothetical value of the underlying implied by put-call parity (Hentschel, 2003). Then, for each day under consideration, a multitude of implied volatility estimates is produced that differ according to their strikes and times to maturity. These implied volatility estimates are used to find an appropriate volatility estimate for valuating a warrant *i* at time *t*. Whenever we observe a pair of put-call options whose strike equals the warrant's strike and whose maturity date equals the warrant's payment date, we use the implied volatility of these options in our margin calculation.

However, the characteristics of the EUREX options often differ from those of the warrants. For all these warrants, we determine volatilities by using a two-dimensional interpolation of the options whose characteristics are closest to the ones of the warrant (e.g. Baule, et al., 2008). The concurrence in two relevant characteristics (strike and time to maturity) of warrants and EUREX options determines the number of required options for the interpolation. When the option and the warrant have either an identical strike or time to maturity, only the unequal characteristic has to be interpolated to derive an implied volatility for the warrant. Hence, when the warrant and the option have an identical strike, only an interpolation of the time dimension is necessary. Likewise, when a EUREX option is found with the same time to maturity as the warrant, only the strike dimension needs to be interpolated. In cases where no consistencies are found for both relevant characteristics, we first choose 2 pairs of put-call options that mature before the warrant (such that the strike of one pair is higher than the warrant's strike, while the other is lower); we then interpolate the implied volatilities of these. Then we choose 2 pairs of put-call options maturing after the warrant (again the strike of one pair is higher than the warrant's strike, the other one is lower). Finally, we interpolate in the time dimension by using the interpolated volatilities of selected options maturing before and after the warrant.

To calculate margins adjusted for the credit risk of the issuers, we also need a measure of market-perceived credit risk. Examining spreads from credit default swap (CDS) agreements, which are traded in over-the-counter markets, is one possible way to measure this risk. The buyer of a CDS pays a fee to the seller on a regular basis and receives compensation in the case of a pre-specified credit event. We use CDS spreads, since it has been argued that CDS spreads react faster than bond spreads (Norden and Weber, 2009). The smaller the value of a CDS spread, the smaller the credit risk and hence, the more creditworthy an issuer is. Since we need an issuer-specific time-variable measure of credit risk, spreads of senior CDS agreements with maturities of 0.5, 1, 2, 3, 4 and 5 years were collected from the Thomson Datastream and adjusted for coupon payments. Thus, CDS spreads are given with a predetermined time to maturity not fitting the characteristics of a structured financial product. To match the time to maturity of the CDS to the time to maturity of a warrant, we interpolated CDS spreads linearly in the time dimension.

2.3 Empirical Strategy and Variables Used

2.3.1 Sample

We consider outstanding call warrants in the German warrant market for the period from January 2008 to June 2010. Thus, our sample comprises warrants issued in this time frame, but also warrants issued before 2008 if they tended to expire after January 2008. The underlying of all warrants considered is the DAX performance index, which comprises the largest 30 German stocks in terms of market capitalization. The sample comes from 17 issuers. For the purpose of this paper, we focus on the six issuers with the highest number of warrants outstanding. These are BNP Paribas, Citigroup, Commerzbank, Deutsche Bank, Goldman Sachs, and HSBC.[2]

For warrants to be included in our sample, we require that the price data of the warrants and all other relevant information necessary to determine theoretical values of the warrants are available, such as the implied volatility of the underlying. Several warrants that are either deep out-of-the-money or deep in-the-money are not considered, because it was impossible to find EUREX options to determine the implied volatilities for these warrants. Furthermore, we follow the literature and drop observations when the warrants' time to maturity is less than six months (e.g. Baule, et al., 2008). After these adjustments, the final sample consists of 6,104 warrants corresponding to 885,573 observations. Deutsche Bank has much more warrants outstanding than all others issuers; HSBC is the least active issuer in terms of the number of warrants outstanding (see Table 1).

[2] We do not consider DZ Bank, Dresdner Bank, Landesbank Baden-Württemberg, Lang & Schwarz, Morgan Stanley, Sal. Oppenheim, Société Générale, Royal Bank of Scotland, UBS, Vontobel, and WGZ Bank because of missing credit risk information or an insufficient number of warrants outstanding.

Table 2.1: Variables Used

The table depicts descriptive statistics for our dependent and independent variables in the German warrant market for each day from January 2008 to June 2010. The margin is calculated using the Hull-White model adjusted for the delay in repayment and ratio. *TtM* denotes the time to maturity, *money* refers to moneyness, and *Comp* denotes an indicator of product competition, where higher values indicate stronger competition.

		BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC
No. of obs		45,076	201,378	207,047	285,385	83,375	63,323
No. of warrants		476	1,068	1,288	1,766	851	655
Margin	mean	0.032	0.107	0.022	0.029	0.051	0.007
	std dev	0.083	0.232	0.109	0.054	0.062	0.065
TtM	mean	1.210	1.625	1.476	1.697	1.248	1.359
	std dev	0.830	0.717	0.756	0.841	0.661	0.744
money	mean	0.007	0.080	-0.004	0.116	-0.057	-0.094
	std dev	0.194	0.361	0.318	0.379	0.149	0.165
Comp	mean	0.935	0.894	0.853	0.737	0.915	0.914
	std dev	0.093	0.089	0.198	0.316	0.156	0.136

2.3.2 Empirical Strategy

We use two estimation methods. Our first method is the one used in recent empirical studies on margins of SFPs (e.g. Baule, 2011; Baule and Blonski, 2014). This method pools all warrants issued by an issuer into one single estimation and controls for autocorrelation by using standard errors corrected according to Newey and West (1987). More specifically, to investigate the $Margin_{it}$ of warrant *i* at point in time *t* we run the following regression model for each issuer separately:

$$Margin_{it} = \alpha + \beta^{TtM} \times TtM_{it} + \beta^{money} \times money_{it} + \beta^{moneySQ} \times moneySQ_{it}$$
$$+\beta^{Comp} \times Comp_{it} + \varepsilon_{it}, \tag{2.4}$$

where TtM is the time to maturity, $money$ is the moneyness, $moneySQ$ is moneyness squared, and $Comp$ denotes a competition measure. These independent variables are borrowed from literature dealing with issuers' price-setting behavior (e.g. Muck, 2006; Baule, 2011; Baule and Blonski, 2014).

The literature has demonstrated a positive relationship between time to maturity and margins. Kassouf (1968) states that a warrant expiring two years from now has a higher value than a warrant expiring one year from now. Shelton (1967) describes the complete loss of the profit component in the warrant price when the warrant comes close to its expiration date. Thus, the literature argues that the overpricing of SFPs increases in the products' time to maturity. This effect is called the life-cycle hypothesis. Muck (2006), Baule and Tallau (2011), and Entrop, et al., (2014), among others, find strong empirical support for this hypothesis: SFPs with a longer time to maturity are more overpriced than the ones with shorter time to maturity. Thus, the profit and/or cost component declines over the lifetime of a structured financial product.

The moneyness of a warrant is expected to affect the profit and cost components determining the difference between market prices and theoretical values. Recent evidence indicates that the moneyness describes how intense the demand for warrants is: Baule and Blonski (2014) find that overpricing of warrants that are at-the-money is lower than the one of other warrants. Thus, the profit component of at-the-money warrants might be lower than the one of other warrants. As regards the cost component, it might be that issuers face higher hedging costs when they offer warrants deep out-of-the-money or deep in-the-money, which they then may consider in their price setting. In short, we expect that both the profit and cost components form a U-shaped effect with moneyness such that in- and out-of-the-money warrants have higher profit and cost components than at-the-money warrants. To model this nonlinear effect, we add a linear term as well as a squared term of moneyness in a similar way to Baule and Blonski (2014).

A product competition measure is used to control for the influence of product competition on margins. With higher competition, issuers may be forced to reduce the profit component. Baule (2011), for instance, finds evidence that discount certificates with strong product competition are less overpriced than discount certificates whose characteristics are uncommon in the market. Therefore, we expect to find prices closer to the theoretical values when product competition is high.

One drawback of the first estimation method is that it pools all observations, and coefficients are not allowed to vary over time. For instance, the effect of the warrants' time to maturity on margins is measured *on average* for all warrants as well as all days considered in the sample. This is a tremendous disadvantage especially when market conditions and issuers' price setting change over time. We expect parameters of the factors to fluctuate over time, because issuers' credit risk fluctuated substantially in our sample period. In order to address this problem, we use the Fama-MacBeth method to focus on and to detect factor instabilities. We do so by estimating the regression model given in Eq. (2.5) for each issuer and each day separately:

$$Margin_{it} = \alpha + \beta_t^{TtM} \times TtM_{it} + \beta_t^{money} \times money_{it} + \beta_t^{moneySQ} \times moneySQ_{it} + \beta_t^{Comp} \times Comp_{it} + \varepsilon_{it} \tag{2.5}$$

Depending on the number of warrants outstanding and the availability of issuers' CDS spreads, this approach leads to 420 estimations for Citigroup and as much as 604 estimations for BNP Paribas, Commerzbank, and Goldman Sachs for our 2.5-year sample period. For each single estimation, we test the significance of each single-day coefficient estimate by using t-tests with heteroscedasticity-consistent standard errors (White, 1980). Since we apply Fama-MacBeth estimations in calendar time, we also test whether the estimated coefficients are, on average, significantly positive or negative. Thus, we perform another type of t-tests on the coefficients (see, Cuthbertson and Nitzsche, 2004, p.193).

In general, are the coefficients on independent variables expected to differ? With respect to the time to maturity, we expect the life-cycle hypothesis to hold irrespective of the method chosen. Hence, the coefficients on time to maturity are expected to be positive. In contrast, the expected effects for moneyness are harder to determine, because a U-shaped effect is only expected when issuers have out-of-the-money, at-the-money, and in-the-money warrants outstanding. On a daily basis, however, it might well be that an issuer has no warrants outstanding that are either in-the-money or out-of-the-money, because their issuance behavior may change over time. Thus, coefficients on moneyness and moneyness squared may indicate either a positive, negative, or U-shaped relationship between margins and moneyness.

The question whether factor sensitivities are expected to differ when issuers' credit spread curves change substantially is even more important. They will change when issuers do not consider their actual time-to-maturity adjusted, market-perceived credit risk when pricing SFPs. We expect that the time-to-maturity sensitivity fluctuates systematically with the steepness of the issuer's credit spread curve. On the one hand, one may argue that issuers may overprice warrants with long time to maturity much more than warrants with short time to maturity when the credit spread curve becomes steeper and issuers use only an average credit spread (and not a spread that fits the time to maturity of a particular warrant) when pricing their products. Then we should see higher time-to-maturity sensitivities when issuers' credit spread curves are steeper. On the other hand, one can also argue that steeper credit spread curves dilute the relationship between the time to maturity and overpricing, since issuers have, with less informed retail investors, more leeway in pricing their products when their spread curves are steeper. Indeed, Baule, et al., (2008) argue that retail investors will have difficulties with pricing models for risky securities. Then we should see lower time-to-maturity sensitivities when issuers' credit spread curves are steeper.

2.3.3 Variables Used

Table 1 depicts descriptive statistics of margins calculated with Eq. (2.3). Citigroup has with 10.7% the highest average margin, followed by Goldman Sachs with 5.1%. These average margins as well as their standard deviations differ slightly from the ones presented by Baule and Blonski (2014) because of differences in the samples used. They consider warrants with a remaining lifetime shorter than 6 months, which we exclude from the analysis, and they do not consider warrants with a remaining lifetime longer than 12 months, which we include. Their average margins are expected to be lower than ours, because of the life-cycle hypothesis. Because of these differences in samples, we refrain from comparing results.

The three independent variables are measured as follows. The time to maturity of a warrant is the number of days between the day under focus and the valuation date measured in years: $TtM = (T - t)/252$. The average times to maturity vary between 1.21 years for BNP Paribas and 1.69 years for Deutsche Bank, while the standard deviations are quite similar for the issuers (see Table 1). Moneyness is the relative difference between the strike price and the current value of the underlying: $money = (S - X)/X$. According to this definition provided by Baule (2011), moneyness fluctuates around 0 and can take positive and negative values to infinity, while according to the traditional definition of S/X, also used in the literature (e.g. Muck, 2006, Loudon and Nguyen, 2006), it would fluctuate around 1 with a minimum value equal to zero. Our sample consists of in-the-money, at-the-money and out-of-the-money warrants. Three issuers (Deutsche Bank, Citigroup, and BNP Paribas) have a positive average moneyness (see Table 1). A look at the median values (not reported) shows that Deutsche Bank has more in-the-money than out-of-the-money warrants outstanding, while all other banks have negative median values of moneyness.

Finally, product competition among warrants is defined as $Comp_{i,t} = 1 - 1/(1 + No_{i,t})$, where $No_{i,t}$ denotes, for each warrant *i* and point in time *t*, the number of warrants whose strikes differ from the one under consideration by no more than 100 index points, whose times to maturity differ from the one under consideration by no more than 14 days, and that are supplied by another issuer. This competition measure, previously used by Baule (2011), equals 0 when the warrant *i* does not face any competitor, while it is close to 1 when it competes with many warrants with similar characteristics. The mean is lowest for Deutsche Bank with 0.737 followed by Commerzbank with 0.853 (see Table 1).

2.4 Empirical Results

2.4.1 Pooled Estimations

Panel a of Table 2 summarizes the results of the pooled estimations. In line with the life-cycle hypothesis, according to which the profit and cost components decline over the course of the lifetime of a warrant, coefficients on the time to maturity are significantly positive for all six issuers. We find the biggest economic effect for Commerzbank: A one-standard-deviation change in time to maturity accounts for 47.0% of the margins’ standard deviation. The ones for HSBC (36.5%), Deutsche Bank (31.0%), Goldman Sachs (20.3%), and BNP Paribas (19.1%) are also considerably large. Only Citigroup has a negligible effect.

The coefficients on the linear and squared terms of moneyness vary across the issuers considered. The results for four issuers suggest that moneyness may have a U-shaped effect on margins, since the coefficients on the squared term of moneyness are positive and significant. A U-shaped effect means that a change in moneyness in both directions starting from a minimum value of moneyness leads to an increase in the margin. For BNP Paribas, Citigroup, Deutsche Bank, and Goldman Sachs these minimum values are in-the-money, at 0.21, 0.49, 0.69, and 0.37, respectively. Since at-the-money equals zero, these minimum values indicate that a negative relationship to moneyness is not only relevant for out-of-the-money but also for in-the-money warrants. For two issuers, namely Deutsche Bank and Goldman Sachs the relationship between margins and moneyness, given the moneyness of warrants that these issuers have outstanding, is negative. The margins of Commerzbank and HSBC show an inverse U-shaped relationship. If one focuses on moneyness of the available warrants, the margins of Commerzbank show a positive relationship with moneyness.

Moneyness has sizeable economic effects for most issuers, which we state in the following in absolute terms: For Citigroup and Deutsche Bank, a one-standard-deviation change in moneyness accounts for 67.8% and 65.4% of the margins’ standard deviation, and a one-standard-deviation change in moneyness squared accounts for 46.5% and 40.7% of the margins’ standard deviation. BNP Paribas and Goldman Sachs have huge economic effects, as well, since a one-standard-deviation change in moneyness accounts for more than 45% of the margins’ standard deviation. For the other two issuers, the economic effects of moneyness are very moderate, since they account for less than 15% of the margins’ standard deviation.

Competition between warrants also affects the margins. For four issuers, we find a negative relationship, and for two issuers, namely BNP Paribas and Commerzbank, we find a positive one. Economic effects of product competition are, however, for all issuers negligible.

Table 2.2: Determinants of Margins

Panel a presents the results from margin regressions using daily data pooled for the period between January 2008 and June 2010. Newey-West standard errors (1987) are depicted below the coefficients. *Panel b* shows results from margin regressions performed for each calendar day between January 2008 and June 2010. It depicts coefficients averaged over all estimations and Fama-MacBeth standard errors. Moreover, the number of significantly positive and negative coefficients is reported, which are based on heteroscedasticity-consistent standard errors (White 1980). $Margin$ is calculated with the option valuation model by Hull and White (1995). *TtM* denotes the time to maturity, *money* is the moneyness, *moneySQ* is the moneyness squared, and *Comp* denotes an indicator of product competition. ***, ** and * indicate that the coefficient is significant at the 1%, 5%, or 10% levels, respectively.

Panel a: Pooled estimations

	BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC
TtM	0.019***	0.015***	0.068***	0.020***	0.019***	0.032***
	(0.001)	(0.002)	(0.001)	(0.000)	(0.000)	(0.001)
money	-0.218***	-0.437***	0.047***	-0.094***	-0.190***	-0.001
	(0.007)	(0.008)	(0.002)	(0.001)	(0.002)	(0.002)
moneySQ	0.531***	0.450***	-0.037***	0.068***	0.256***	-0.184***
	(0.023)	(0.011)	(0.002)	(0.001)	(0.011)	(0.014)
Comp	0.058***	-0.171***	0.022***	-0.011***	-0.024***	-0.011***
	(0.008)	(0.013)	(0.003)	(0.000)	(0.002)	(0.003)
No. of observations	45,076	201,378	207,036	285,385	83,375	63,323
Adjusted R^2	0.329	0.238	0.213	0.307	0.304	0.149

Panel b: Fama-MacBeth estimations

	BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC
TtM	0.007***	-0.026***	0.056***	0.023***	0.034***	0.040***
	(0.001)	(0.010)	(0.001)	(0.001)	(0.001)	(0.002)
	305/40	270/82	603/0	556/9	518/33	537/20
money	-0.242***	-0.086***	0.014***	-0.077***	-0.153***	0.119***
	(0.024)	(0.016)	(0.005)	(0.003)	(0.015)	(0.020)
	78/352	33/355	251/263	48/490	26/414	324/134
moneySQ	0.009	1.235***	0.006	0.171***	0.176***	0.117***
	(0.109)	(0.122)	(0.010)	(0.012)	(0.041)	(0.032)
	292/69	416/0	262/211	490/31	318/49	165/199
Comp	0.181**	-0.148***	0.027***	-0.009***	0.209***	0.047
	(0.090)	(0.032)	(0.006)	(0.001)	(0.033)	(0.037)
	100/62	55/247	140/137	110/250	106/168	136/136
No. of estimations	604	420	604	572	604	601
Avg. adjusted R^2	0.617	0.590	0.452	0.683	0.637	0.582

2.4.2 Fama-MacBeth Estimations

Panel b of Table 2 summarizes the results of Fama-MacBeth estimations by depicting coefficients averaged over all estimations for each of the issuers considered. Moreover, we depict Fama-MacBeth standard errors of the coefficients and the number of significantly positive and significantly negative coefficients. A coefficient counts as significantly positive (negative) when its individual t-value based on heteroscedasticity-consistent standard errors (White, 1980) is higher (lower) than (-)1.64.

On average, coefficients on the time to maturity are significantly positive for five of the six issuers. Only Citigroup's average coefficient on the time to maturity is significantly negative, which is caused by few large negative values that occur mainly in February 2009. We observe the biggest economic effect[3] for HSBC, for which a one-standard-deviation change in time to maturity accounts for 45.6% of its margins' standard deviation. The ones for Deutsche Bank (35.6%), Goldman Sachs (36.2%) and Commerzbank (38.7%) are also considerably large, while the ones of BNP Paribas and Citigroup are only moderate (7.0% and 8%, respectively). For five issuers, Fama-MacBeth estimates on time to maturity are, *on average*, similar to the outcomes of pooled estimations.

For five issuers, except Commerzbank, we find a negative time-to-maturity sensitivity on selected days. On these days, overpricing of warrants with short time to maturity was higher than the one of warrants with long time to maturity. Thus the life-cycle hypothesis does not hold on each and every day in our sample period. Such negative time-to-maturity sensitivities may show up, when the issuers use only an average credit spread for pricing

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[3] Economic effects are calculated as the average coefficient estimate times the standard deviation of the respective independent variable divided by the margins' standard deviation of the issuer under consideration.

warrants with different times to maturity and when their CDS spread curve is inverted, that is when the credit spread for few months is higher than the one for a longer period of time. Based on the Fama-MacBeth estimates for the warrants investigated here, we conclude that our sample period is characterized by extreme changes in terms of the time-to-maturity sensitivity, which might be caused by the tremendous changes with regard to issuers' credit spread curves. We will return to this issue in the next section of our paper.

Further, the results for Citigroup, Deutsche Bank, Goldman Sachs and HSBC suggest that moneyness may have a U-shaped effect on margins, since the coefficients on the squared term of moneyness are positive and significant. For Citigroup and Deutsche Bank, the minimum values are both in-the-money, at 0.035 and 0.033, respectively. Economic effects are tremendous for Deutsche Bank, but negligible for Citigroup. For Deutsche Bank, a one-standard-deviation change in moneyness accounts for 53.6% of the margins' standard deviation, and a one-standard-deviation change in moneyness squared accounts for 102.4% of the margins' standard deviation. For Goldman Sachs and HSBC, which have sizeable economic effects of more than 30% of the margins standard deviation, the minimum values are more extreme, namely 0.44 and -0.51, respectively. It is important to note that both of these minimum values are almost outside the range of observable moneyness in the data. Therefore, we can conclude that moneyness has a positive effect on the margins of HSBC warrants and a negative effect on the margins of warrants issued by Goldman Sachs. The margins of BNP Paribas show a negative relationship, which is sizeable in economic terms, while the ones of Commerzbank show a positive relationship in moneyness, which is, in economic terms, negligible. To sum up, for Citigroup, Commerzbank, and Goldman Sachs, we find that the *average* moneyness sensitivities in Fama-MacBeth estimations are similar to the ones in the pooled estimations.

Competition delivers as in the pooled regression mixed effects. For two issuers, we find, on average, a negative relationship, and for three issuers, namely BNP Paribas, Commerzbank and Goldman Sachs, we find a positive one. We need to emphasize here that the statistical significance of Fama-MacBeth estimates falls apart from the number of significantly positive and negative coefficients. For instance, for Goldman Sachs, we find that the average Fama-MacBeth effect of product competition is positive and highly significant. However, we find a significantly negative effect of competition on the margins in 168 of the 604 estimations, while we find a significantly positive effect in only 106 estimations.

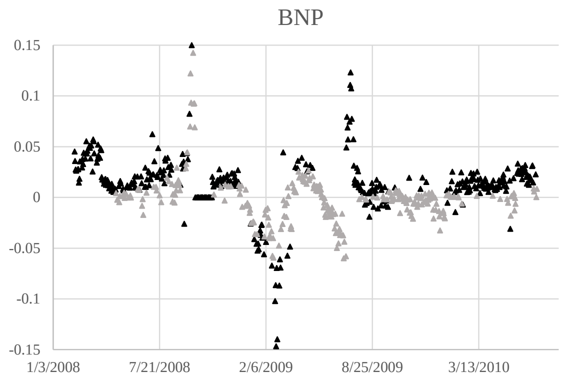
On average, the Fama-MacBeth estimations produce adjusted coefficients of determination between 45.2% for Commerzbank and more than 68.3% for Deutsche Bank, while the pooled estimations produce adjusted coefficients of determination between 14.9% for HSBC and 32.9% for BNP Paribas. Thus, our approach is, in terms of explanatory power, more useful than the pooled approach for the period under consideration. Since the Fama-MacBeth estimations are pure cross-sectional analyses, their explanatory power can be regarded as good to very good. Moreover, the estimations do not suffer from multicollinearity problems. We ensure that the independent variables considered can be jointly included in the estimations by checking variance inflation factors. Almost all estimations show factors below 10, which is often seen as a critical value but not commonly applied (Kumari, 2008)

2.4.3 The Role of Credit Spread Curves

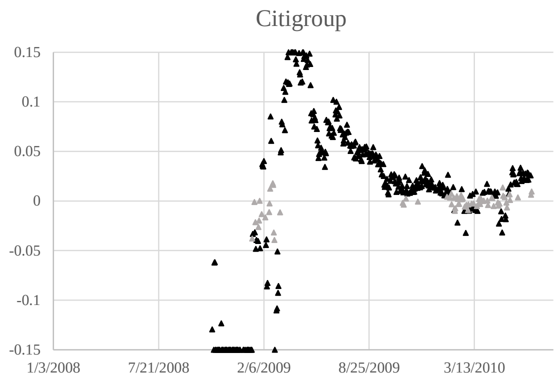
Next, we use the results of the Fama-MacBeth estimations to investigate whether fluctuations in the model outcomes can be attributed to issuers' credit spread curves. In Figure 1, we plot the time-to-maturity sensitivities in order to see how they behave over our sample period. Significant coefficients are depicted as black triangles, while insignificant ones are depicted as grey triangles. We depict coefficients only in the range between -0.15 and 0.15 to emphasize the important results in the middle of our graphs; coefficients whose values are lower or higher are clustered on the lower or upper boundaries. The time-to-maturity sensitivities show a clustering over time, which is most pronounced for Citigroup. The time-to-maturity sensitivities of Commerzbank fluctuate intensely, while the ones of Deutsche Bank are almost constant during our sample period.

In order to see whether the issuers' credit spread curves are responsible for changes in the time-to-maturity sensitivities of margins, we run a time-series regression for each issuer, where the dependent variable is the time-to-maturity sensitivity and the independent variables are the issuer's CDS spread curve (2-year CDS spread minus 6-month CDS spread) and the spot rate curve (2-year risk-free rate minus 6-month rate), which might be an alternative source of fluctuation for the sensitivity under focus. The results of these estimations are reported below the graphs in Figure 1. For four issuers, we find that the CDS spread curve correlates significantly negatively with the time-to-maturity sensitivity. Thus, for these issuers, we can conclude that steeper CDS spread curves dilute the relationship between the time to maturity and overpricing. Only for BNP we find that a steeper CDS spread curve comes along with higher time-to-maturity sensitivities, indicating that this issuer overprices warrants with long time to maturity much more than warrants with short time to maturity.

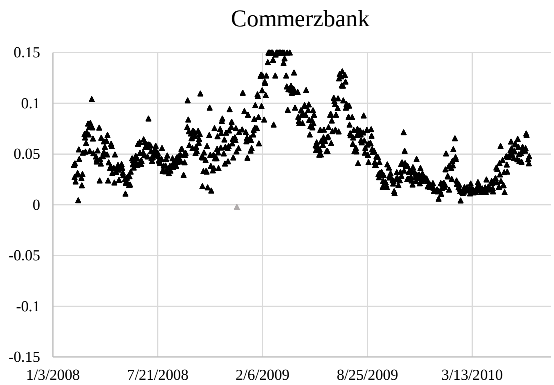
Figure 2.1: Time-to-maturity Sensitivity of Margins



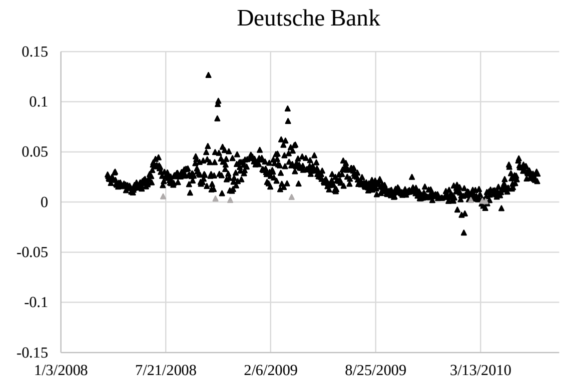
$$\widehat{\beta^{TtM}} = \underset{(0.048)}{0.206} \times CDSS^{2yrs-0.5yrs} - \underset{(0.723)}{1.933} \times r^{2yrs-0.5yrs}$$



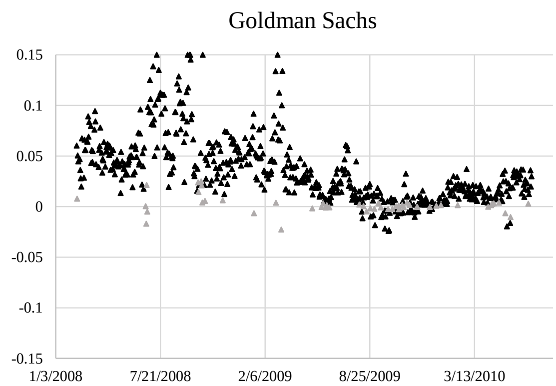
$$\widehat{\beta^{TtM}} = -\underset{(0.058)}{0.422} \times CDSS^{2yrs-0.5yrs} + \underset{(9.391)}{61.188} \times r^{2yrs-0.5yrs}$$



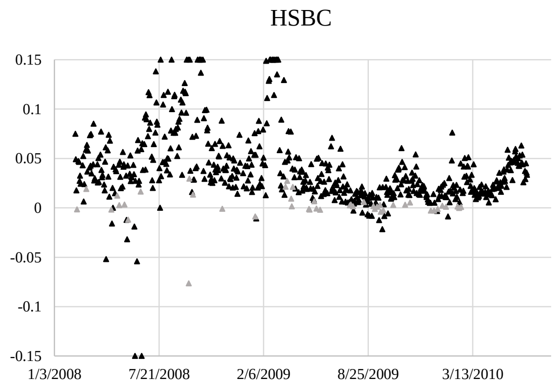
$$\widehat{\beta^{TtM}} = -\underset{(0.021)}{0.052} \times CDSS^{2yrs-0.5yrs} - \underset{(0.579)}{1.412} \times r^{2yrs-0.5yrs}$$



$$\widehat{\beta^{TtM}} = -\underset{(0.010)}{0.102} \times CDSS^{2yrs-0.5yrs} - \underset{(0.395)}{1.768} \times r^{2yrs-0.5yrs}$$



$$\widehat{\beta^{TtM}} = -\underset{(0.008)}{0.064} \times CDSS^{2yrs-0.5yrs} - \underset{(0.720)}{3.263} \times r^{2yrs-0.5yrs}$$



$$\widehat{\beta^{TtM}} = -\underset{(0.083)}{0.023} \times CDSS^{2yrs-0.5yrs} - \underset{(1.584)}{3.584} \times r^{2yrs-0.5yrs}$$

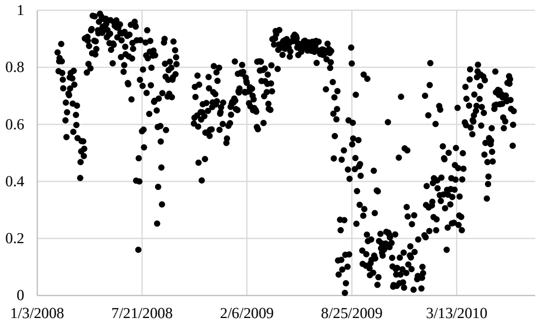
Notes: The diagrams show the time-to-maturity coefficients (β_t^{TtM}) of the following model: $Margin_{it} = \alpha + \beta_t^{TtM} \times TtM_{it} + \beta_t^{money} \times money_{it} + \beta_t^{moneySQ} \times moneySQ_{it} + \beta_t^{Comp} \times Comp_{it} + \varepsilon_{it}$, which was estimated for each day from January 2008 to June 2010 and for each issuer. Significant coefficients are depicted as a black triangle, while insignificant ones are depicted as a grey triangle. Afterwards, a regression was performed to estimate the dependence of β_t^{TtM} on the steepness of the issuers' CDS spread curve, $CDSS^{2yrs-0.5yrs}$ (2-year CDS spread minus 0.5-year CDS spread), and the term structure of spot rates $r^{2yrs-0.5yrs}$ (2-year rate minus 0.5-year rate). The regression outcomes are stated below the graphs, with Newey and West (1987) standard errors depicted below the coefficients.

Of particular relevance is also the coefficient of determination, since it captures how much of the margins' variation is explained by the time to maturity, moneyness and product competition. When steeper credit spread curves dilute the life-cycle hypothesis, we may see that the characteristics of warrants are useful in explaining variations in credit-risk adjusted margins in times of flat credit spread curves but less so in times of steep credit spread curves. In Figure 2, we present the adjusted coefficients of determination by depicting them for each issuer over the sample period. Coefficients of determination of Citigroup and Deutsche Bank are most stable, while HSBC has the least stable ones.

We run a time-series regression for each issuer, where the dependent variable is the adjusted R^2 and the independent variables are the issuer's CDS spread curve and the spot rate curve. The results of these estimations are reported below the graphs in Figure 2. For four of the six issuers, we find that the adjusted R^2 correlates significantly negatively with the CDS spread curve. Only for Goldman Sachs, we find a significantly positive relationship. The economic effects of the CDS spread curve are noteworthy: For Citigroup, a one-standard-deviation increase in the daily CDS spread curve accounts for a reduction of about 36.5% of the standard deviation of the adjusted R^2. This is the largest economic effect. The smallest economic effect is for HSBC, which is, however, not statistically significant. The spot rate curve correlates significantly negatively with the adjusted R^2 for six issuers; only the effect for Citigroup lacks statistical significance. The economic effects of the sport rate curve are also large: They vary from 16% for Deutsche Bank to 53.4% for Commerzbank. Thus, the variation in margins not explained by the warrant characteristics increases when the CDS spread curve and spot rate curve are steeper. These findings indicate that not only characteristics of warrants are relevant, but that issuer- and market-specific factors are also relevant for issuers' price setting.

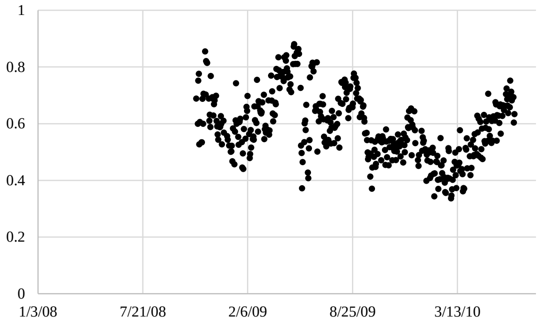
Figure 2.2: Coefficients of Determination

BNP



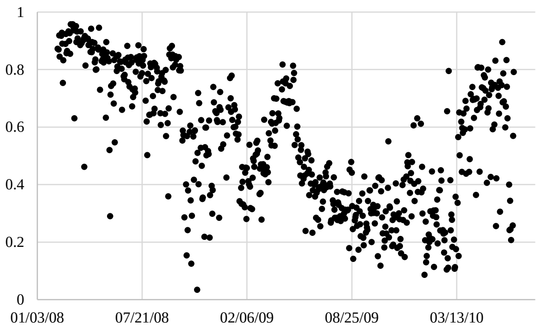
$R^2 = -1.288 \times CDSS^{2yrs-0.5yrs} - 21.248 \times r^{2yrs-0.5yrs}$
(0.292) (5.235)

Citigroup



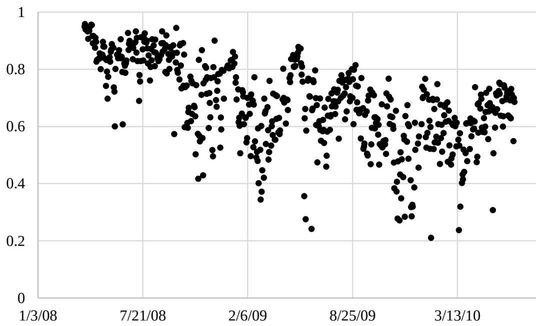
$R^2 = -0.183 \times CDSS^{2yrs-0.5yrs} - 1.341 \times r^{2yrs-0.5yrs}$
(0.042) (4.077)

Commerzbank



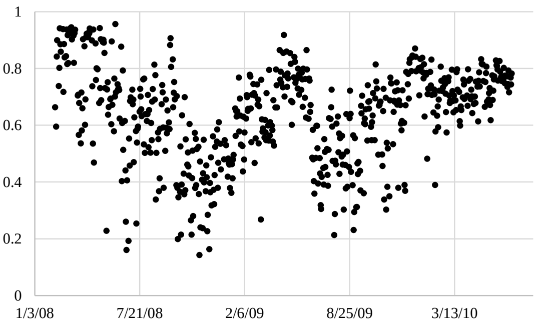
$R^2 = -0.177 \times CDSS^{2yrs-0.5yrs} - 27.661 \times r^{2yrs-0.5yrs}$
(0.052) (3.282)

Deutsche Bank



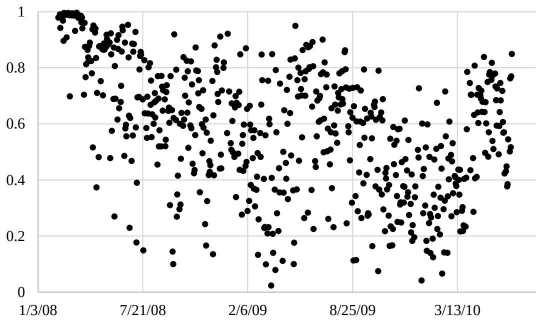
$R^2 = -0.345 \times CDSS^{2yrs-0.5yrs} - 6.006 \times r^{2yrs-0.5yrs}$
(0.124) (2.708)

Goldman Sachs



$R^2 = 0.256 \times CDSS^{2yrs-0.5yrs} - 10.493 \times r^{2yrs-0.5yrs}$
(0.047) (3.513)

HSBC



$R^2 = -0.182 \times CDSS^{2yrs-0.5yrs} - 12.869 \times r^{2yrs-0.5yrs}$
(0.240) (4.169)

Notes: The diagrams show the adjusted R^2 of the following model:
$Margin_{it} = \alpha + \beta_t^{TtM} \times TtM_{it} + \beta_t^{money} \times money_{it} + \beta_t^{moneySQ} \times moneySQ_{it} + \beta_t^{Comp} \times Comp_{it} + \varepsilon_{it}$,
which was estimated for each day from January 2008 to June 2010 and for each issuer. Afterwards, a regression was performed to estimate the dependence of R^2 on the steepness of the issuers' CDS spread curve, $CDSS^{2yrs-0.5yrs}$ (2-year CDS spread minus the 0.5-year CDS spread), and the term structure of spot rates $r^{2yrs-0.5yrs}$ (2-year rate minus the 0.5-year rate). The regression outcomes are stated below the graphs, with Newey and West (1987) standard errors depicted below the coefficients.

2.5 Summary

We investigated margins of warrants during a very turbulent phase, namely from January 2008 to June 2010, a time period characterized by tremendous changes in the term structure of issuers' credit spreads. Traditionally, margins of structured financial products have been investigated using pooled regressions employed for each issuer. In our case, however, the long and turbulent time period casted doubts on the suitability of such a method. Therefore, we used Fama-MacBeth estimations in calendar time in addition to the pooled method. The advantage of the Fama-MacBeth method in our setting is that it determines the sensitivities of margins with respect to the time to maturity and moneyness on a daily basis thus factor sensitivities can fluctuate freely over time. Hence, this method is useful to detect factor instabilities, which may show up when CDS spread curves or other issuer-related or market-related factors (such as volatility of the underlying and interest rate) relevant for pricing these products fluctuate over the time period under study.

We put particular emphasis on the time-to-maturity sensitivities. A comparison of the classical pooled results and the *average* Fama-MacBeth estimates showed that the outcomes are quite similar. New insights were then gained from inspecting Fama-MacBeth estimates over the sample period. We hypothesized that issuers' credit spread curve may play a role for the time-to-maturity sensitivity of margins, because retail investors may fail to apply valuation models for risky securities and issuers may not use credit risk measures that fit the time to maturity when pricing warrants. Our results indicate that the life-cycle hypothesis was for some days considered stronger than on other days. We also found several negative time-to-maturity sensitivities, which may show up when credit spread curves are inverted. Time-series tests on the time-to-maturity sensitivities indicate that higher credit spread curves dilute the relationship between the time to maturity and margins. This result receives further support when we investigated the coefficients of determination of the Fama-MacBeth estimations. Thus, this study identified new factors that are relevant to understand overpricing of warrants. In times of crisis, when issuers' credit spread curves change substantially, retail investors have to be aware of potential and substantial changes in pricing relationships.

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Chapter 3

Warrants Price Responses to Credit Spread Changes: Fact or Fiction?[4]

We use a new approach to analyze the relationship between warrant prices and issuers' credit spreads. This approach allows us to gain insights into whether issuers use their credit risk systematically to increase their profits. In a post-Lehman sample, we find strong support for a systematic use since issuers decrease prices less after credit spread increases than they increase prices after credit spread decreases. Credit spread decreases are accompanied by price increases on several successive days. This sluggish adjustment in prices can be explained by the fact that retail investors' purchase decisions depend on product prices.

Keywords: warrants, overshooting, sluggish adjustment, price changes, credit spreads
JEL Classification: D40, G13, G15

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3.1 Introduction

Retail investors face several limitations when investing in capital markets, since they cannot combine securities available to institutional investors due to market barriers and other bottlenecks. Therefore, several investment banks and large universal banks offer structured financial products (SFPs) to provide retail investors with products that have payoff structures similar to the ones institutional investors can buy or create by bundling securities traded at various exchanges to which retail investors have limited access. These SFPs are unsecured securities of the issuing institutions, and for this reason, retail investors purchasing these products are exposed to the issuers' credit risk. Recent studies argue that the credit risk of issuers gives them leeway when it comes to pricing these products because retail investors likely have difficulties determining the full implications of issuers' credit risk on products' values (e.g. Baule, et al., 2008). This study proposes a new approach to gain insights concerning the relationship between product prices and issuers' credit risk by determining how sensitive price changes of these products respond to contemporaneous and lagged changes in credit spreads (CS) of issuing institutions.

Our study differs from the recent literature, since we use price changes to examine issuers' pricing patterns, whereas recent studies investigate margins of SFPs to examine the price setting behavior (e.g. Baule, 2011; Baule and Blonski, 2015; Benet, et al., 2006; Chang, et al., 2012; Henderson and Pearson, 2011; Schertler and Stoerch, 2015; Stoimenov and Wilkens, 2005; Wallmeier and Diethelm, 2009). Margin is the relative difference between a product's market price and its theoretical value. Theoretical values are often determined by applying the model by Black and Scholes (1973), which does not consider issuers' credit risk, or the one by Hull and White (1995), which takes it into account. Using price changes instead of margins has two main advantages. First, information on price changes can be readily obtained, and do, therefore, not depend on assumptions of a theoretical valuation model and the assumptions made when generating input parameters required to calculate products' theoretical values. Since changes in prices of SFPs may result from price changes of underlying securities, we also use various adjusted price changes calculated with the help of the valuation models mentioned above, which we find to be highly correlated with pure price changes. By using both pure and adjusted price changes, we rule out that a particular valuation model drives our results. Second, price changes allow us to study two facets of dynamic responses of SFP prices, namely *adverse pricing* and *timely pricing*; both are new to the literature on SFPs.

Adverse pricing may come into play, because issuers have incentives to keep prices at a high level as long as retail investors purchase more products than they re-purchase. Therefore, we expect them to respond to an increase in an issuer- or underlying-specific factor that influences the product's value (such as issuers' credit risk and underlying's volatility) absolutely differently than to a decrease in this factor. We study adverse pricing with respect to changes in issuers' credit risk to test whether issuers use their credit risk systematically to increase their profits. More specifically, issuers that want to generate additional profits have an incentive to increase prices immediately after credit risk decreases, and only retail investors' price sensitivity (e.g. Baule and Blonski, 2015; Entrop, et al., 2016) may soften this incentive. Conversely, when their credit risk increases, they may keep prices of SFPs constant as long as possible to increase their profits. Thus, we expect the price response to depend on whether the CS change is positive or negative: prices are adjusted less after CS increases than after decreases. Such adverse pricing can only be identified when studying price changes, but not when investigating normalized prices, such as margins as used in the recent literature.

Timely pricing—the second facet of dynamic responses of SFP prices—comes into play since we also look at the relationship between price changes and lagged CS changes. So far, studies addressing the pricing of these products only investigate the contemporaneous relationship between credit risk and margins but not lagged effects. For instance, Baule (2011) finds that issuers' credit risk correlates positively with credit risk–adjusted margins. We argue that the joint effect of lagged CS changes may follow two pricing patterns, which we call *sluggish adjustment* and *overshooting*. Sluggish adjustment refers to a pricing path where issuers decrease (increase) prices both on the day of as well as on the days after the CS increase (decrease). Issuers are likely to adjust prices sluggishly, because retail investors are price sensitive. By doing so, they would reduce the price volatility of SFPs. Overshooting refers to a pricing path where issuers neutralize a part of the negative (positive) contemporaneous effect that an increase (decrease) in credit risk has on the product price on the following days. A CS increase first reduces product prices, but afterwards they are increased again. We contribute to the literature by introducing a new empirical approach that allows researchers and practitioners to gain valuable insights concerning the relationship between changes in issuer- and underlying-specific factors, such as issuers' credit risk, and the pricing of SFPs.

Our findings come from one particular product type, (naked) warrants, over a two-and-a-half-year period from January 2008 to June 2010. Warrants have the same payoff structure as options. In Germany, both warrants and options offer a right but not an obligation to purchase (call) or sell (put) an underlying. Also, both warrants and options are traded on exchanges: Warrants are traded at Certificate Stock Exchange run by Deutsche Börse and/or EUWAX belonging to Börse Stuttgart, whereas options are traded at EUREX, an organized market applying mark-to-market approach, which minimize the bankruptcy risk investors are exposed to. In contrast, no margin calls exist for warrants. Issuers of warrants in the German market often act as market makers. They are obliged to offer bid and ask prices and to ensure market liquidity of products by buying back a specific number of outstanding warrants. If an issuer of a warrant files for bankruptcy, retail investors may not get any compensation. Hence, the value of the investors' position depends on the creditworthiness of the issuer. Compared to EUREX options, warrants have smaller contract sizes, that is, investors can purchase a fraction of one unit underlying; short positions are, however, prohibited.

The term *warrant* is commonly used in different markets worldwide, for instance in the US and Asia, but it sometimes refers to different types of securities. Warrants in the German market are, in contrast to warrants in the US, stand-alone securities of the issuing institutions. For example, when an investor buys warrants issued by Deutsche Bank with the stock of Commerzbank as underlying, the investor can only sell it back to Deutsche Bank. In the US, warrants refer to equity options bundled with other securities. For instance, equity options are issued together with a bond, a combination that allows investors to execute the option at the end of the bond's maturity and to receive shares instead of bond redemption. The various parts of US warrants can also be traded separately (Bartram and Fehle, 2007).

Dynamic responses of warrant prices are interesting to study, because retail investors likely fail to detect the total value implication of issuers' credit risk changes on warrants' values, which may give issuers leeway in pricing these products substantially above theoretical values plus transaction costs for hedging their liabilities, marketing costs, and exchange listing fees (Henderson and Pearson, 2011). Our findings demonstrate that credit risk changes are considered in pricing but not always immediately; instead, we observe complex lag structures. For all issuers, increases in spreads of credit default swaps (CDS) immediately lead to price reductions. Thus, the contemporaneous effect of CDS spread changes on prices is, as expected, significantly negative. When we model adverse pricing, we find, especially in the post-Lehman period, that CDS spread increases come with lower absolute price changes, which we measure in Euros, than CDS spread decreases. Thus, after a CDS spread increase, issuers reduce their prices less than they increase them after a CDS spread decrease. This finding is in line with our argument that issuers may generate additional profit due to the fact that retail investors may struggle with the value implications of issuers' credit risk. For CDS spread increases, prices almost always overshoot; in contrast prices are adjusted sluggishly for CDS spread decreases in the post-Lehman period. These adverse adjustments may reflect the impact of investors' price sensitivities: For CDS spread decreases prices are not increased immediately to reflect the new credit risk level, most likely because this kind of price increase might drive retail investors either out of the market or they may purchase products offered by other issuers. Since several issuers in our sample received financial assistance from government rescue programs, we also test whether warrant price sensitivities differ between bailout and non-bailout periods. It is only during non-bailout periods that warrant prices are not increased immediately when the issuers' CDS spread decreases.

The remainder of the study is organized as follows: Section 2 develops hypotheses on the pricing of warrants after CS changes and explains where the adjusted price changes derive from. Section 3 describes the data and presents descriptive statistics on adjusted price changes and independent variables. The fourth section discusses the empirical results regarding timely pricing and adverse pricing for changes in issuers' CS. The last section summarizes and concludes.

3.2 Hypotheses on Price Changes of Warrants

The approach we propose here focuses on price changes instead of margins, the measure used in recent studies (e.g. Baule, 2011; Baule and Blonski, 2015; Benet, et al., 2006; Chang, et al., 2012; Henderson and Pearson, 2011; Schertler and Stoerch, 2015; Stoimenov and Wilkens, 2005; Wallmeier and Diethelm, 2009). An exception is the study by Schertler (2016), who uses difference-in-differences estimations on margins of discount certificates. To analyze when and how issuers change their warrants' prices in response to changes in their CS, we use the following linear regression model:

$$\Delta P_{it} = \alpha_0 + \sum_{j=0}^{4} \beta_j \times \Delta CS_{it-j} + \varepsilon_{it}, \tag{3.1}$$

where $\Delta P_{it} = P_{it} - P_{it-1}$ is the daily amount change measured in Euro in the market price of warrant *i* on day *t*. *ΔCS* denotes the daily basis-point change in the issuer's CS. We take into account the contemporaneous change in issuers' credit spread, ΔCS_{it}, and four lags of daily changes in issuers' credit spread captured by *j=1,…4*, ΔCS_{it-1} up to ΔCS_{it-4}. β_j is the coefficient on the *j*-days lagged change in issuers' credit spread. ε denotes an error term.

We expect that an increase in credit risk, which implies that a given issuer's creditworthiness becomes worse, reduces today's price of the warrant. Thus, we expect the contemporaneous effect to be negative, $\beta_0 < 0$. Evidence that retail investors have difficulties in understanding the implications of issuers' credit risk on the values of SFPs does not necessarily counteract a negative contemporaneous effect. This negative effect will prevail when retail investors recognize that increases (decreases) in credit risk reduce (increase) expected payoffs of SFPs.

If prices are fully and immediately adjusted to changes in products' value drivers, then yesterday's CS change and the one from the day before yesterday cannot explain today's change in warrant price. Thus, we should find $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 0$. This kind of pricing pattern is, however, unlikely, because the recent literature finds evidence that issuers increase margins to greater extent when retail investors purchase SFPs than when they re-purchase them (Baule, 2011) and that retail investors are price sensitive (e.g. Baule and Blonski, 2015; Entrop, et al., 2016). Because retail investors are price sensitive, issuers may adjust prices smoothly by considering only a part of the value implication caused by a CS change on the day of occurrence. Then, a decrease in issuers' CS would lead to an increase in prices not only on the day of the CS decrease but also on subsequent days. In a similar vein, an increase in CS may lead to a price reduction on the same but also on the following day(s). This is the case of sluggish adjustment, where we expect to find a negative contemporaneous effect and a negative joint effect of all lagged CS changes, $\sum_{j=1}^{4} \beta_j < 0$.

We expect issuers to adjust their prices adversely, since their incentives to change prices depend on whether their credit spread increased or decreased. As long as they sell more products than they re-purchase from investors, they have an incentive to keep prices of warrants at a high level. Hence, they will not be eager to pass on price reductions resulting from CS increases to retail investors. To the contrary, they will be happy to pass on each and every reduction in their CS in form of higher prices, which might, however, be limited because retail investors are price sensitive. To investigate such adverse pricing with respect to positive and negative changes in issuers' CS, we use the following model:

$$\Delta P_{it} = \alpha_0 + \sum_{j=0}^{4} \beta_j^{CS+} \times \Delta CS_{it-j}^{+} + \sum_{j=0}^{4} \beta_j^{CS-} \times \Delta CS_{it-j}^{-} + \varepsilon_{it}, \tag{3.2}$$

where ΔCS^{+} (ΔCS^{-}) denotes positive (negative) CS changes.

We refer to adverse pricing when we find $0 > \sum_{j=0}^{4} \beta_j^{CS+} > \sum_{j=0}^{4} \beta_j^{CS-}$. Moreover, when issuers consider retail investors' price sensitivity in their price setting, then one would also expect to observe that a CS decrease, but not necessarily an increase, comes with sluggish adjustment. Sluggish adjustment in prices after a CS decrease is very likely to ensure that retail investors stay with the issuer and do not begin to consider buying products from another issuer. Therefore, we expect that sluggish adjustment will more often and more intensely show up for credit risk decreases than for increases. Thus, when issuers price adversely, we should find $\sum_{j=1}^{4} \beta_j^{CS+} > \sum_{j=1}^{4} \beta_j^{CS-}$ and $\sum_{j=1}^{4} \beta_j^{CS-} < 0$.

One could even argue that sluggish adjustment is unlikely to be observed for a CS increase, because retail investors' price sensitivity is not a reason to decrease the warrant price step-by-step. Rather, a CS increase could come with price overshooting. The price reduction that follows from incorporating a part of the CS increase may trigger instantly additional purchases. Indeed, the recent literature finds evidence that the price level of SFPs, as described by default-free margins but not issuers' CS, affects retail investors' demand (Entrop, et al., 2016). Another study shows that issuers increase their prices when retail investors start purchasing a product intensely, which is known as the order-flow hypothesis (Baule, 2011). Thus, price overshooting may arise when retail investors fail to see the full value implications of issuers' credit risk and when issuers act as described by the order-flow hypothesis. When issuers neutralize a part of the initial price reduction caused by a CS increase after a few days, we may see $\sum_{j=1}^{4} \beta_j^{CS+} > 0$.

When testing these hypotheses, one important specificity found for warrants and other SFPs has to be taken into account: prices of SFPs with a long time to maturity deviate more from their theoretical values than the ones with short time to maturity. This is called the life-cycle hypothesis. Muck (2006), Baule and Tallau (2011), and Entrop, et al., (2014), among others, find strong empirical support for this hypothesis. Using Fama-MacBeth estimations, Schertler and Stoerch (2015) demonstrate that the time-to-maturity sensitivity in margin regressions depends on the issuers' CS. Therefore, investigating pure price changes might lead to wrong inferences, since the price change might be driven by the fact that time has gone by. Also, price changes may come from changes of other relevant value drivers, such as prices of the underlying securities. In order to rule out other drivers, we do not only look at pure changes of warrant prices, but also at adjusted price changes. These adjusted price changes result from the actual change in warrant prices plus the value change implied by a theoretical model valuing the worth of the warrant. We define adjusted price changes as follows:

$$\Delta P_{it}^{j} = P_{it} - P_{it-1} + \Delta TV_{it}^{j}, \tag{3.3}$$

with $\Delta TV_{it}^{j} = TV_{it}^{j} - \widetilde{TV}_{it-1}^{j}$, where TV_{it}^{j} denotes the theoretical value that is calculated by applying the option pricing model j, and $\widetilde{TV}_{it-1}^{j}$ is calculated with the input parameters of day *t-1* but with the time to maturity of day *t*. This adjustment eliminates two important factors in daily price changes: First, it acknowledges that a price change is due to a change in an input parameter determining the theoretical value. Second, it also controls for declining differences between market and theoretical prices over the life-time of warrants.

We determine the theoretical value of a warrant by using the models by Black and Scholes (1973) and Hull and White (1995), who adjust the theoretical value implied by the Black-Scholes model to the issuer's credit risk. Since the underlying of the warrants we study is a performance index, no adjustment for dividend payments is required. We adjust theoretical values to account for the fact that most warrants refer to a fraction of the underlying, the *ratio*. Then, theoretical values of a European call warrant *i* on day *t* are given by:

$$TV_{it}^{BS} = \left[S_t N(d_{it}) - e^{-r_t(T_i-t)} \times X_i N\left(d_{it} - \sigma_{it}\sqrt{T_i - t}\right)\right] \times ratio_i, \quad (3.4)$$

$$TV_{it}^{HW} = e^{-CS_{it}(T_i-t)} \times TV_{it}^{BS}, \quad (3.5)$$

with $$d_{it} = \frac{\ln\left(\frac{S_t}{X_i}\right) + (r_t + \frac{\sigma_{it}^2}{2}) \times (T_i - t)}{\sigma_{it}\sqrt{T_i - t}},$$

where *BS* denotes the model by Black and Scholes (1973), *HW* denotes the model by Hull and White (1995), S denotes the price of the underlying, σ is the volatility of the underlying, and X denotes the strike of the warrant. r is the risk-free rate used for the time between today, t, and the valuation date, T, and CS is the credit spread of the bank that issued warrant i.

We use an example to illustrate how much the theoretical value changes when the CS increases. We consider an at-the-money call warrant with a ratio of 0.01 that matures in exactly one year when the current price of the underlying equals € 5000, the volatility of the underlying is 20%, and the risk-free rate equals 1%. The model by Black and Scholes delivers a theoretical value of € 4.22. Assuming a CS of 100 basis points (bps), the theoretical value of the call warrant drops slightly to a value of € 4.17. Thus, an increase in

CS by 100 bps comes along with a price decrease of € 0.05. What happens when a dramatic increase in CS takes place? Suppose the CS increases to 600 bps. Then, the value drops to € 3.97, which is a price reduction of more than € 0.20. The changes in CS we observe in our sample are much smaller, and hence, price changes comprise only some cents.

3.3 Data and Descriptive Statistics

3.3.1 Sample

Our sample is comprised of call warrants in the German market with the DAX performance index as underlying. We consider outstanding warrants from January 2008 to June 2010. We focus on the following six issuers: BNP Paribas, Citigroup, Commerzbank, Deutsche Bank, Goldman Sachs, and HSBC, because these are the ones with the highest number of warrants outstanding in the period investigated.

Following the recent literature (e.g. Baule and Blonski, 2015), we restrict the sample in terms of time to maturity and moneyness. We include only warrants with a time to maturity between 0.5 and 2 years, because a high number of speculators is expected for warrants maturing in less than 6 months and only few warrants have a time to maturity longer than 2 years. We consider only warrants with a moneyness between +/–15%, this is defined here as the relative difference between the current value of the underlying (S) and strike price (X), $money = (S - X)/X$. Applying this restriction would remove, however, all warrants of particular issuers for entire weeks in 2008 from the sample, when the DAX performance index dropped from around 7000 index points in May 2008 to 3700 index points in March 2009. At that time, not many warrants deep in the money were outstanding, that met the moneyness restriction when the value of the index dropped. We avoid losing all observations for these weeks in 2008 by using a dynamic version of the moneyness restriction: Warrants are included in the sample if they meet the narrow moneyness restriction on several days, but, on others, stay within the double of the moneyness restriction mentioned above (-30% and +30%). After these adjustments, the final sample consists of 3531 warrants, which corresponds to 402,159 daily observations (see Table 1).

Table 3.1: Descriptive Statistics

This table provides descriptive statistics for daily price changes adjusted by using either the model by Black and Scholes (1973), ΔP^{BS}, or Hull and White (1995), ΔP^{HW}, in the German warrant market for the period from January 2008 to June 2010. To allow for comparisons, simple price changes, ΔP, are also shown. All price changes are given in Euros. In addition, the table depicts time-to-maturity adjusted CDS spreads, CS, the time-to-maturity adjusted CDS spread change in percentage points, ΔCS, the time to maturity, TtM, and moneyness, $money$, of warrants.

		BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC	Total
No. of obs		31,418	74,960	90,524	107,437	60,337	37,483	402,159
No. of warrants		347	519	739	881	606	439	3,531
ΔP^{BS}	mean	0.010	0.020	-0.005	-0.008	0.000	0.002	0.002
	median	0.029	0.046	0.017	0.030	0.016	0.017	0.026
	std dev	0.818	0.814	0.868	0.876	0.715	0.752	0.824
ΔP^{HW}	mean	0.010	0.020	-0.006	-0.008	0.000	0.002	0.001
	median	0.029	0.047	0.015	0.030	0.016	0.017	0.026
	std dev	0.817	0.803	0.863	0.874	0.712	0.750	0.820
ΔP	mean	0.000	0.005	-0.008	-0.008	-0.006	-0.004	-0.004
	median	0.010	0.020	0.010	0.020	0.010	0.000	0.010
	std dev	0.418	0.408	0.443	0.446	0.363	0.383	0.419
CS	mean	0.512	2.742	1.674	0.805	1.087	0.611	1.362
	median	0.415	1.791	1.298	0.748	0.811	0.518	1.066
	std dev	0.243	1.898	0.955	0.394	0.709	0.326	1.262
ΔCS	mean	0.001	-0.005	0.001	0.002	0.004	0.001	0.001
	median	0.000	0.000	0.000	0.000	0.001	0.000	0.000
	std dev	0.051	0.219	0.171	0.066	0.120	0.046	0.139
TtM	mean	0.905	1.180	1.065	1.168	0.969	1.049	1.086
	median	0.766	1.147	0.996	1.123	0.841	0.944	1.000
	std dev	0.382	0.411	0.405	0.434	0.388	0.421	0.421
$money$	mean	-0.004	0.003	-0.009	0.000	-0.043	-0.031	-0.011
	median	-0.017	-0.010	-0.021	-0.011	-0.054	-0.042	-0.024
	std dev	0.124	0.133	0.130	0.132	0.108	0.116	0.127

3.3.2 Adjusted Price Changes of Warrants

Most of the information needed to calculate adjusted price changes given in Eq. (3.3) is directly available. Only the risk-free rate and volatility of the underlying have to be calculated from market data. We use spot rates provided by Deutsche Bundesbank as risk-free rates, r, for the time to maturity of the respective warrant. The spot rates are based on the approach by Svensson (1994), an extension of the one by Nelson and Siegel (1987).

The volatility estimates, σ, are deduced from daily settlement prices of EUREX call and put options on the DAX performance index retrieved from Thomson Datastream. Since the approach taken here follows the one by Baule, et al., (2008) and Baule (2011), we state only the main steps in the following. By applying the put-call parity on a pair of call and put options with the same strike and time to maturity, a hypothetical price of the underlying is determined at which the implied volatilities of these call and put options are equal. These hypothetical prices of the underlying are then used to calculate implied volatilities with different strikes and times to maturity for each day in the sample period. Afterwards, we determine a volatility estimate for a warrant i at time t by using an interpolation in the dimensions strike and time to maturity, when the characteristics of the warrant differ from the ones of EUREX options. Then, two pairs of put-call options that mature before (after) the warrant are chosen. One pair has a strike higher than the one of the warrant; the strike of the other pair is lower. The implied volatilities of these options are interpolated in the strike dimension to receive an implied volatility for a hypothetical option maturing before (and one after) the warrant, which already has the same strike as the warrant. Then these implied volatilities are interpolated in the time dimension to fit the warrant's time to maturity. In summary, each warrant receives an implied volatility, which is unique in the strike and time dimensions.

Table 1 provides descriptive statistics of the three price changes. The daily price changes adjusted with the model by Black and Scholes (1973) are negative for Deutsche Bank and Commerzbank. For the other issuers there is, on average, a positive Black-Scholes adjusted price change. The highest average change in the sample belongs to Citigroup with € 0.020, followed by BNP Paribas with only € 0.010. The price changes adjusted with the model by Hull and White (1995) closely follow the ones adjusted with the Black-Scholes model. The small differences between the two adjusted price changes are in line with the example given in Section 2. Noteworthy, pure price changes are on average lower than adjusted price changes and they have a much lower standard deviation than adjusted price changes indicating that warrant prices are less volatile than the securities they are structured from.

The three price changes considered here are highly correlated. The two adjusted price changes have a Pearson correlation coefficient of 0.99, and the ones of pure price changes with the two adjusted changes are about 0.98. Therefore, we focus on only one of the changes. By using the price changes adjusted with the model by Hull and White (1995), one faces, however, endogeneity because, in this case, issuers' credit risk is considered in the dependent variable and it is used as an independent variable. Unadjusted price changes, as we discussed above, would emphasize the changes due to a loss in time value and other relevant market factors such as volatility changes of the underlying. Therefore, we present results from price changes adjusted with the model by Black and Scholes and use the other two price changes in unreported robustness tests, since they deliver the same results than the measure we use in the following.

3.3.3 Independent and Control Variables

We focus on a market-perceived measure of issuers' credit risk. One of the measures available for this purpose is dealt in over-the-counter markets, namely CDS agreements. On a regular basis, buyers of CDS agreements pay fees to sellers and in case of a pre-specified default event, they are compensated for their losses. Smaller values of CDS spreads are associated with lower credit risk and thus, with higher creditworthiness. Norden and Weber (2009) argue that CDS spreads react faster to changes in issuers' credit risk than bond spreads. Therefore, CDS spreads are especially useful for the purpose of this study. Spreads of senior CDS agreements with maturities of 0.5, 1, and 2 years are collected from Thomson Datastream and then adjusted for coupon payments. We interpolate CDS spreads linearly to fit it to the time to maturity (TtM) of the warrant. The average TtM-adjusted CDS spread in the sample is highest for Citigroup with around 274 bps, followed by Commerzbank with 167 bps. BNP Paribas has the smallest expected average risk of insolvency with only 51 bps (see Table 1). Since our approach focuses on changes and not on levels of issuers' credit risk, daily CDS spread changes are also depicted, which are, on average, close to zero bps. Goldman Sachs demonstrates the highest average daily increase in CDS spreads by 0.4 bps, while Citigroup has an average daily decrease by 0.5 bps. These average daily changes in CDS spreads are small and will create only small changes in theoretical values and consequently in prices of the products, as the example in Section 2 illustrates.

We use warrants' moneyness and times to maturity as control variables in addition to truncating the sample in terms of moneyness and time to maturity, since both measures are common in the literature on SFPs (e.g. Muck, 2006; Loudon and Nguyen, 2006; Baule, 2011; Baule and Blonski, 2015). For instance, Baule and Blonski (2015) find that margins of at-the-money warrants are lower than the ones of other warrants. One possible explanation could be that the number of at-the-money warrants is much higher, and for this reason, these warrants have to compete intensely with warrants of other issuers, a situation that is expected to reduce issuers' leeway in pricing warrants. Alternatively, it might be that issuers face higher hedging costs when they offer warrants deep out of the money or deep in the money, which they pass on to investors in the form of higher prices. The median moneyness is slightly negative for all issuers (see Table 1), showing that each issuer has more out-of-the-money warrants than other warrants in the market. The time to maturity, measured in years, TtM, captures effects of the life-cycle hypothesis, which was mentioned above. Its median value is smaller than one year for four issuers, namely BNP Paribas, Commerzbank, Goldman Sachs, and HSBC.

3.4 Results

3.4.1 Baseline model

Table 2 depicts the results concerning the relationship between daily price changes adjusted with the model by Black and Scholes and the TtM-adjusted CDS spread changes for each issuer considered.[5] We include the contemporaneous change of the TtM-adjusted CDS spread and four lags of these changes as stated in Eq. (3.1). Moreover, we use the warrants' time to maturity (TtM), moneyness ($money$) and a crisis dummy variable ($DumLehman$) as control variables. The dummy variable is equal to 1 on the day Lehman Bank declared insolvency (September 15, 2008) and for the 60 trading days after this event. A time trend is also included, since Baule, et al., (2008) find evidence that margins of discount certificates have declined over time. Newey and West (1987) standard errors considering 3 lags are

[5] Adjusted daily price changes are truncated by deleting observations smaller than the 1st percentile and greater than the 99th percentile to remove some heavy outliers.

presented. Since variance inflation factors are well below 10 for all estimations, the results do not suffer from multicollinearity.

In line with our expectation, the results show that the coefficients on the contemporaneous CDS spread change are significantly negative for all six issuers. This finding supports the view that increases in issuers' credit risk come, on average, with lower prices and vice versa. The economic effects of contemporaneous CDS spread changes on the price changes are considerable. For Deutsche Bank and BNP Paribas, a one-standard-deviation increase in the contemporaneous daily CDS spread change accounts for 35.3% and 31.9%, respectively, of the standard deviation of the issuers' adjusted daily price changes. The economic effects for Commerzbank, Goldman Sachs, and HSBC are, with more than 25%, also remarkable. Only for Citigroup, a one-standard-deviation increase in the contemporaneous daily CDS spread change accounts for as little as 16.7% of the daily price changes' standard deviation. While these results indicate that issuers adjust their prices to changes in their credit risk, they do not allow us to claim that the adjustment in warrant prices is sufficient or insufficient for the given change in the issuers' credit risk. Other approaches do, however, also not allow for this conclusion, since the true theoretical model is unknown and since the calculation of theoretical values is based on several assumptions and approximations.

For all issuers, we find positive and negative coefficients on lagged CDS spread changes. For three issuers, the first lag of the daily change in CDS spreads negatively affects daily price changes; thus, warrant prices are reduced on two successive days after issuers' CDS spreads increased. This may indicate that the contemporaneous price reduction is deemed as insufficient for the change in issuers' credit risk or, alternatively, that issuers adjust their internal CS used to price products sluggishly to market conditions. For all issuers, at least one of the lags has a significantly positive coefficient. This positive effect is found for the first or the second lag except for Commerzbank, for which the third lag is the first with a positive sign. Thus, price reductions due to CDS spread increases and price increases due to CDS spread decreases are partly offset on later days. The economic effects of lagged CDS spread changes are, however, only moderate. The highest economic effect of the first lag is observed for Commerzbank: A one-standard-deviation increase in the first lag of daily CDS spread changes accounts for 5.9% of the adjusted daily price changes' standard deviation. For Deutsche Bank, a one-standard-deviation increase in the third lag of daily CDS spread changes accounts for 8.8% of the daily price changes' standard deviation. For all other issuers, the economic effects vary between 1.6% and 6.8%.

Table 3.2: Price changes of warrants and credit risk changes

The results given below are based on the following regression model: $\Delta P_{it}^{BS} = \alpha_0 + \sum_{j=0}^{4} \beta_j \times \Delta CS_{it-j} + \alpha_1 \times TtM_{it} + \alpha_2 \times money_{it} + \alpha_3 \times Trend_t + \alpha_4 \times DumLehman_t + \varepsilon_{it}$, which was estimated for each issuer separately. The estimation period is from January 2008 to June 2010. ΔP_{it}^{BS} denotes the daily price change adjusted by adding the change in the theoretical value implied by the Black-Scholes model. Only coefficients on the contemporaneous and lagged CDS spread changes (ΔCS), time to maturity (TtM) and, moneyness ($money$) are reported. Below the coefficients, Newey-West standard errors are reported. ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

	BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC
β_0	-5.081***	-0.622***	-1.317***	-4.687***	-1.664***	-4.762***
	(0.107)	(0.020)	(0.023)	(0.056)	(0.070)	(0.152)
β_1	-0.712***	0.055***	-0.298***	-0.484***	0.305***	0.051
	(0.083)	(0.016)	(0.016)	(0.043)	(0.026)	(0.100)
β_2	0.257***	0.249***	0.004	1.163***	-0.132***	0.810***
	(0.081)	(0.013)	(0.020)	(0.059)	(0.028)	(0.084)
β_3	-0.219**	-0.167***	0.343***	-0.547***	-0.179***	-0.892***
	(0.087)	(0.011)	(0.018)	(0.056)	(0.031)	(0.105)
β_4	0.211**	0.179***	-0.033*	0.617***	0.026	1.286***
	(0.100)	(0.014)	(0.017)	(0.051)	(0.034)	(0.104)
α_1	-0.024*	-0.024***	-0.003	0.000	-0.015**	-0.010
	(0.012)	(0.007)	(0.007)	(0.006)	(0.007)	(0.009)
α_2	0.433***	0.454***	0.408***	0.378***	0.547***	0.521***
	(0.036)	(0.023)	(0.021)	(0.019)	(0.027)	(0.034)
$\sum_{j=1}^{4} \beta_j$	-0.463***	0.317***	0.016	0.749***	0.020	1.255***
	(0.176)	(0.032)	(0.034)	(0.091)	(0.047)	(0.177)
No. of obs	31,418	74,960	90,524	107,437	60,337	37,483
F-test	363.7***	324.0***	645.2***	1232.6***	150.5***	169.3***

In order to see whether prices are adjusted sluggishly, which we expect to find because retail investors are price sensitive, we sum up all lagged coefficients on CDS spread changes and test whether these joint effects are statistically different from zero. Thus, we test whether $\sum_{j=1}^{4} \beta_j = 0$. For Commerzbank and Goldman Sachs, these joint effects of lagged CDS spread changes are approximately equal to zero (0.2% and 0.16%, respectively), indicating that negative and positive coefficients on lagged CDS spread changes offset one another. For BNP Paribas, this joint effect is significantly negative, indicating sluggish adjustment in prices. Hence, the initial price reduction after an increase in this issuer's credit risk is followed by additional price reductions, or, conversely, the initial price increase after a decrease in credit risk is followed by additional increases in prices on the following days. Finally, for Citigroup, Deutsche Bank, and HSBC, we observe the opposite: The joint effects of all lagged CDS spread changes are significantly positive, indicating an overshooting effect, that is a part of the initial price reduction (increase) caused by a CDS spread increase (decrease) is partly offset after few trading days. Given these results, we cannot conclude that a particular pricing pattern can be observed; at best we can say that half of the issuers show overshooting prices after their CS changed, which is, however, not in line with pricing behavior that takes retail investors' price sensitivity into account.

As regards the control variables, moneyness has a significantly positive effect on price changes, implying that in-the-money warrants have higher average price changes measured in Euros than at-the-money and out-of-the-money warrants. This seems reasonable, since in the case of deep out-of-the-money warrants, possibilities to decrease prices further are limited. The economic effects of moneyness are between 5.7% for Deutsche Bank and 8.3% for Goldman Sachs. The coefficients on warrants' time to maturity are significantly negative for three issuers (BNP Paribas, Citigroup and Goldman Sachs). As the time to maturity shortens, the adjusted price changes increase. This effect might be explained by the order-flow hypothesis mentioned above, which stipulate that issuers increase prices when retail investors demand more products (Baule, 2011). The economic effects of this variable are negligible since they account for not more than 1.2% of the price changes' standard deviation.

3.4.2 Adverse Pricing

Next, we investigate whether price changes after CDS spread increases differ from the ones after CDS spread decreases. We expect to find different responses to increases and decreases when issuers use their credit risk to make additional profits and when retail investors are price sensitive. More specifically, as long as issuers expect to sell additional warrants, they have little interest to reduce prices immediately after CS increases, but they are likely to have a greater interest to raise prices after CS decreases. Therefore, we divide the contemporaneous CDS spread change and its four lags into two parts, as in Eq. (3.2), and expect that the joint effect including the contemporaneous effect for CDS spread increases ($\sum_{j=0}^{4} \beta_j^{CS+}$) is larger than the one for CDS spread decreases ($\sum_{j=0}^{4} \beta_j^{CS-}$). We present joint effects in Table 3.

Table 3.3: Positive and negative CDS spread changes

The results given below are based on the following regression model: $\Delta P_{it}^{BS} = \alpha_0 + \sum_{j=0}^{4} \beta_j^{CS+} \times \Delta CS_{it-j}^{+} + \sum_{j=0}^{4} \beta_j^{CS-} \times \Delta CS_{it-j}^{-} + \alpha_1 \times TtM_{it} + \alpha_2 \times money_{it} + \alpha_3 \times Trend_t + \alpha_4 \times DumLehman_t + \varepsilon_{it}$, which was estimated for the period between January 2008 and June 2010. Models were estimated for each issuer separately. ΔP_{it}^{BS} denotes the daily price change adjusted by adding the change in the theoretical value when applying the model by Black and Scholes. ΔCS^{+} (ΔCS^{-}) denotes the CDS spread change when it is positive (negative), and zero otherwise. Only joint β coefficients are reported. In parentheses below the coefficients, Newey-West standard errors are reported. The test statistics of difference tests on joint effects of all lagged positive CDS spread changes versus negative CDS spread changes are reported. ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

	BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC
			Full sample			
$\sum_{j=0}^{4} \beta_j^{CS+}$	-5.243***	-0.429***	-1.031***	-4.231***	-1.415***	-2.548***
	(0.306)	(0.053)	(0.053)	(0.139)	(0.103)	(0.253)
$\sum_{j=0}^{4} \beta_j^{CS-}$	-4.419***	-0.097*	-1.672***	-3.371***	-2.054***	-3.532***
	(0.251)	(0.049)	(0.055)	(0.134)	(0.163)	(0.318)
$\sum_{j=1}^{4} \beta_j^{CS+}$	1.733***	0.227***	0.112***	1.366***	-0.204***	3.000***
	(0.330)	(0.041)	(0.047)	(0.163)	(0.089)	(0.300)
$\sum_{j=1}^{4} \beta_j^{CS-}$	-1.195***	0.552***	-0.125***	0.385***	0.031	0.426**
	(0.198)	(0.039)	(0.045)	(0.116)	(0.059)	(0.217)
No. of obs	31,418	74,960	90,524	107,437	60,337	37,483
F-test	231.2***	236.5***	533.6***	825.0***	167.8***	109.0***
Difference tests						
$\sum_{j=0}^{4} \beta_j^{CS+}$ vs. $\sum_{j=0}^{4} \beta_j^{CS-}$	-2.082**	-4.600***	8.392***	-4.454***	3.314***	2.421***
$\sum_{j=1}^{4} \beta_j^{CS+}$ vs. $\sum_{j=1}^{4} \beta_j^{CS-}$	7.608***	-5.743***	3.642***	4.903***	-2.201***	6.952***

The two joint effects of positive and negative CDS spread changes are significantly negative for all six issuers, indicating that CDS spread increases lead to lower prices, whereas CDS spread decreases lead to higher prices. The next question to be answered is whether these joint effects differ from each other or, to put it differently, whether the sensitivity of the price changes depends on whether the CDS change is positive or negative. Difference tests indicate that the joint effects of CDS spread increases are greater than the joint effects of CDS spread decreases for Commerzbank, Goldman Sachs, and HSBC. This finding is in line with the argument that issuers use their own credit risk to generate additional gains: after credit risk increases, they reduce their warrant prices much less than they increase prices after credit risk decreases. For BNP Paribas, Citigroup and Deutsche Bank, we find the opposite, namely the joint effects of CDS spread increases are smaller than the joint effects of CDS spread decreases. Hence, we do not find a clear pricing pattern that holds for all issuers considered.

We also expect that positive and negative CDS spread changes matter for overshooting or sluggish price adjustment because issuers may increase prices only in a sluggish manner after CDS spread declines, since retail investors are price sensitive. In other words, overshooting the price after a decline in the CDS spread might frighten retail investors, whereas increasing prices in a sluggish manner after a CDS spread decrease might be less harmful. In contrast, an initial price reduction caused by an increase in CDS spread might create additional demand; to an extent that issuers (as predicted by the order-flow hypothesis) adjust their prices upward, creating price overshooting. As shown in Table 3, the joint effects of all lagged (without the contemporaneous) CDS spread increases are significantly positive for five issuers, a result that indicates price overshooting. The joint effects of lagged CDS spread decreases are significantly negative for two issuers and significantly positive for three issuers. Hence, there is strong evidence that lagged CDS spread increases create price overshooting, but we cannot identify a common pricing pattern for lagged CDS spread decreases and thus sluggish adjustment.

Price sensitivities and Government Rescue Packages

The mixed results on CDS spread decreases might be driven by the particular period we study here. So far, we pooled the data over the entire time period, but this approach might not be appropriate, since governments created rescue packages in 2008 that affected issuers' credit risk substantially. Therefore, we run additional analyses for issuers rescued by the government to see whether the lack of evidence for sluggish adjustments in warrant prices correlates with these programs.

We investigate government's rescue funds for BNP Paribas, Citigroup, and Commerzbank. Each bank received a bailout in 2008: On October 21, 2008, the French government announced that it would pump money into BNP Paribas by buying subordinated debt.[6] On November 24, 2008, the US government announced that it would rescue Citigroup by injecting new capital into the bank.[7] On November 3, 2008 Commerzbank indicated that it would ask for a bail out from the German rescue fund.[8] To determine if the warrant prices reflect differently to CDS spread increases than decreases, we consequently split the effects we measure for positive and negative CDS spread changes in those outside the bailout period and those within the bailout period. The bailout period covers four months after the announcement of using rescue funds (the results to come do not depend much on whether we consider a 4-month post-window or whether we use a 2-month pre- and post-window). We present the results in panel a of Table 4.

We find that the sensitivity between warrant price changes and CDS spread changes differs between bailout and non-bailout periods. We draw two important insights from the table.

[6] www.forbes.com/2008/10/21/bnp-banks-update-markets-equity-cx_ll_1021markets14.html
[7] www.reuters.com/article/us-citigroup-idUSTRE4AJ45G20081124
[8] https://www.bloomberg.com/news/articles/2008-11-03/commerzbank-taps-german-bailout-fundbusinessweek-business-news-stock-market-and-financial-advice

The first relates to the joint effect including the contemporaneous CDS spread change: The price response to CDS spread increases was significantly smaller than to CDS spread decreases for BNP Paribas and Citigroup in the full sample (see, Table 3), and in Table 4 we see that this difference is driven by the issuers' bailout period. Outside the bailout period, the price response to CDS increases and decreases does not differ for BNP Paribas, while for Citigroup the price response to CDS spread increases is larger than for decreases, which is in line with our adverse pricing argument. The second insight comes from timely pricing: Outside the bailout period, the lagged joint effect after CDS spread increases is significantly larger for all issuers than the one after CDS spread decreases, while it is significantly smaller in the bailout period. This may indicate that during the bailout period, internal credit spreads used to price SFPs poorly reflected market conditions of issuers' credit risk.

Table 3.4: Further tests

The results given below come from the following regression models:

Panel a: $\Delta P_{it}^{BS} = \alpha_0 + \sum_{j=0}^{4} \beta_j^{CS+} \times \Delta CS_{it-j}^{+} \times D\_Bail_{it} + \sum_{j=0}^{4} \beta_j^{CS-} \times \Delta CS_{it-j}^{-} \times D\_Bail_{it} + \alpha_1 \times TtM_{it} + \alpha_2 \times money_{it} + \alpha_3 \times Trend_t + \alpha_4 \times DumLehman_t + \varepsilon_{it}$ estimated for 01/2008-06/2010, and

Panel b: $\Delta P_{it}^{BS} = \alpha_0 + \sum_{j=0}^{4} \beta_j^{CS+} \times \Delta CS_{it-j}^{+} + \sum_{j=0}^{4} \beta_j^{CS-} \times \Delta CS_{it-j}^{-} + \alpha_1 \times TtM_{it} + \alpha_2 \times money_{it} + \alpha_3 \times Trend_t + \varepsilon_{it}$, estimated for 07/2009-06/2010.

Models were estimated for each issuer separately. ΔP_{it}^{BS} denotes the daily price change adjusted by adding the change in the theoretical value when applying the model by Black and Scholes. ΔCS^{+} (ΔCS^{-}) denotes the CDS spread change when it is positive (negative), and zero otherwise. D_Bail_{it} equals 1 for the first four months after the bailout was announced, and zero otherwise. Only joint β coefficients are reported. In parentheses below the coefficients, Newey-West standard errors are reported. The test statistics of difference tests on joint effects of all lagged positive CDS spread changes versus negative CDS spread changes are reported. In panel a, these difference tests are reported for bailout and non-bailout periods separately. ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

Panel a: Bailout

	BNP Paribas	Citigroup	Commerzbank
$\sum_{j=0}^{4} \beta_j^{CS+}$ $if\ D\_Bail = 1$	-0.046	-0.071	-0.085***
	(1.139)	(0.066)	(0.259)
$\sum_{j=0}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 1$	10.633***	0.896***	-0.984***
	(1.261)	(0.085)	(0.314)
$\sum_{j=0}^{4} \beta_j^{CS+}$ $if\ D\_Bail = 0$	-5.974***	-0.068	-1.134***
	(0.304)	(0.064)	(0.054)
$\sum_{j=0}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 0$	-5.388***	-0.439***	-1.688***
	(0.250)	(0.060)	(0.056)
$\sum_{j=1}^{4} \beta_j^{CS+}$ $if\ D\_Bail = 1$	-1.055	0.555***	-0.770***
	(1.147)	(0.047)	(0.244)
$\sum_{j=1}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 1$	12.861***	1.713***	0.881***
	(0.990)	(0.075)	(0.295)
$\sum_{j=1}^{4} \beta_j^{CS+}$ $if\ D\_Bail = 0$	2.202***	0.671***	0.147***
	(0.308)	(0.059)	(0.049)
$\sum_{j=1}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 0$	-2.427***	0.117***	-0.155***
	(0.190)	(0.081)	(0.051)
No. of obs	31,418	74,960	90,524
F-test	242.1***	216.6***	372.2***
Difference tests			
$\sum_{j=0}^{4} \beta_j^{CS+}$ vs. $\sum_{j=0}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 1$	-6.285***	-8.986***	2.209**
$\sum_{j=0}^{4} \beta_j^{CS+}$ vs. $\sum_{j=0}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 0$	-1.489	4.229***	7.121***
$\sum_{j=1}^{4} \beta_j^{CS+}$ vs. $\sum_{j=1}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 1$	-9.185***	-13.083***	-4.313***
$\sum_{j=1}^{4} \beta_j^{CS+}$ vs. $\sum_{j=1}^{4} \beta_j^{CS-}$ $if\ D\_Bail = 0$	12.754***	7.344***	4.539***

Panel b: Post-Lehman sample (July 2009 – June 2010)

	BNP Paribas	Citi-group	Commerz-bank	Deutsche Bank	Goldman Sachs	HSBC
$\sum_{j=0}^{4} \beta_j^{CS+}$	-7.296***	-1.844***	-1.007***	-6.074***	-2.078***	-5.677***
	(0.314)	(0.132)	(0.093)	(0.130)	(0.097)	(0.287)
$\sum_{j=0}^{4} \beta_j^{CS-}$	-6.511***	-1.845***	-2.055***	-6.780***	-5.162***	-10.560***
	(0.297)	(0.086)	(0.073)	(0.127)	(0.121)	(0.358)
$\sum_{j=1}^{4} \beta_j^{CS+}$	1.646***	0.865***	1.151***	0.492***	-0.709***	3.789***
	(0.328)	(0.114)	(0.079)	(0.137)	(0.101)	(0.303)
$\sum_{j=1}^{4} \beta_j^{CS-}$	-3.930***	-0.522***	-0.918***	-3.050***	0.146	-3.126***
	(0.190)	(0.081)	(0.051)	(0.092)	(0.103)	(0.277)
No. of obs	22,003	57,148	52,731	77,019	45,763	27,455
F-test	255.3***	459.0***	419.8***	1368.1***	504.7***	515.8***
Difference tests						
$\sum_{j=0}^{4} \beta_j^{CS+}$ vs. $\sum_{j=0}^{4} \beta_j^{CS-}$	-1.816*	0.006	8.864***	3.885***	19.886***	10.642***
$\sum_{j=1}^{4} \beta_j^{CS+}$ vs. $\sum_{j=1}^{4} \beta_j^{CS-}$	14.710***	9.918***	22.003***	21.464***	-5.927***	16.844***

The use of rescue funds is not only relevant for issuers' credit risk and thus warrant pricing, but many other government and central bank policies might have had an effect, too. In addition, for the globally operating institutions under focus, government and monetary policies in their headquarter countries are relevant, but also policies in their main foreign markets, especially in the US. Unfortunately, due to the large number of policy interventions, it is impossible to claim that particular effects are driven by particular policies as many of these are clustered in time. Nevertheless, we run another test to determine warrant price sensitivities for a 4-month post-announcement period of rescue funds from the government where the issuer has its headquarters. For BNP Paribas, Citigroup and Commerzbank, these estimations confirm the results in panel a of Table 4, while for the other three, they do not deliver additional insights. Therefore, we do not present them here.

Our next test minimizes the effects of government rescue plans by determining the warrant price sensitivity to issuers' CDS spread changes at the end of our sample period. More specifically, we conduct an analysis using only warrant data from July 2009 to June 2010. With this subsample, we still have enough observations to perform the analysis, and, at the same time, we exclude effects around Lehman's insolvency and the announcement of rescue packages from the analysis. We present the results in panel b of Table 4. The differences in the joint effects, including the contemporaneous effects, are noteworthy. For five issuers, the joint effects of CDS spread increases are larger than those of CDS spread decreases, albeit one issuer lacks statistical significance. These results from the post-Lehman sample are in line with the argument that issuers use their own credit risk to change warrant prices in their favor. We further find significant price overshooting after CDS spread increases for five issuers, and significant sluggish price adjustment after CDS spread decreases for five issuers, Goldman Sachs being the exception. These results support the argument that issuers use changes in their credit risk to price warrants in their favor.

In unreported regressions (results are available upon request), we modify the CDS spread changes. We re-estimated the models by using issuers' 1-year CDS spreads. The results do not change. The results also do not change when we include additionally squared terms of time to maturity and moneyness. Thus, the pricing patterns with respect to changes in CDS spreads are not overly dependent on warrant's moneyness and times to maturity.

3.4.3 The Role of Retail Investors' Demand

One critical aspect discussed in many studies dealing with the pricing of SFPs is retail investors' demand, since it influences issuers' price setting. Baule and Blonski (2015) find evidence that retail investors purchase warrants with round strikes more often than warrants with non-round strikes. Their line of argument follows Barber and Odean (2008), who argue that investors are more interested in attention-grabbing firms, which are regularly in the news and that therefore, the securities of these firms are more demanded than those of others. Round strikes might generate greater interest by investors than non-round strikes. To capture potential differences in retail investors' demand, we test whether the relationship between price changes and CDS spread changes for warrants with round strikes differs from the one for warrants with non-round strikes. Therefore, we employ subsamples. The first subsample includes warrants with round hundreds, that is, strikes ending with 200, 400, 600, and 800.[9] The second subsample contains the non-round hundreds, that is, strikes ending with 100, 300, 700, and 900. In case demand influences how issuers price their products, we expect to see that the relationship between price changes and CDS spread changes differs between the subsamples.

In the two subsamples (results are not reported but available upon request), we find the joint effects including the contemporaneous effect to be significantly negative for both positive and negative CDS changes for all six issuers considered. Hence, the relationship that a CDS spread increase comes along with a reduction in prices holds, on average, also for warrants with different demand intensities. For four issuers, we find, in the post-Lehman period of both subsamples, significant adverse pricing effects. Thus, with respect to adverse pricing, we do not find differences between subsamples of warrants with different demand intensities. Our results on timely pricing are, for both subsamples, also similar to the ones on all warrants in the post-Lehman sample: For five issuers, we see significant price overshooting after CDS spread increases, and significant sluggish price adjustment after CDS spread decreases. All in all, the findings suggest that there are little differences in the joint effects of increases and decreases in CDS spreads across subsamples.

[9] Because the number of warrants outstanding with a strike ending on 1000 and 500 is low and because these warrants might draw greater attention by investors than other round or non-round warrants, they are excluded from the subsample formation.

3.5 Conclusions

Our approach of investigating price changes measured in Euros instead of margins is ideally suited to examine whether issuers price their products adversely after issuer-specific or underlying-specific factors changed. Here, we examine whether CDS spread changes create adverse pricing patterns. Issuers likely have incentives to increase prices immediately after credit risk decreases. This incentive may be limited by retail investors' price sensitivity, but they do not have similar incentives to reduce prices after credit risk increases. We were unable to identify a clear pricing pattern for the entire sample from January 2008 to June 2010, possibly because of the high uncertainty during this period. However, in the post-Lehman period, price changes after CDS spread increases are absolutely smaller than after CDS spread decreases. Thus, we conclude that issuers reduce their prices to a lesser extent after a CDS spread increase than they increase their prices after a CDS spread decrease. This result is in line with the argument that issuers can generate additional profits due to the fact that retail investors struggle with the value implications of issuers' credit risk.

Our approach of investigating price changes and their relationship to contemporaneous and lagged credit risk changes is ideally suited to examine timely pricing patterns that reflect how issuers adjust their prices on subsequent days. We argue that CDS spread decreases have a high potential for creating sluggish adjustments in prices, because issuers that are aware of retail investors' price sensitivity will not immediately increase product prices after a credit risk decrease to keep their customers but may spread the required price increase over several trading days. We find sluggish price adjustment only in the post-Lehman sample. For CDS spread increases, the data tell a different story: In both the entire set and the post-Lehman sample, we find strong evidence for price overshooting after CDS spread increases. When prices overshoot, a part of the price reduction stemming from a CDS spread increase is neutralized on the following days. Investors' demand might explain this kind of overshooting. An increase in CDS spreads and a reduction in warrant prices might encourage retail investors to buy these warrants; thus, issuers have incentives to increase their prices (a phenomenon that is explained by the order-flow hypothesis). This argument is especially valid, since retail investors' demand does not depend on issuers' credit risk. We also analyze subsamples of round and non-round strikes in order to see whether this feature, which significantly affects retail investors' purchase decisions, comes along with different pricing patterns. We find that this is not the case.

We propose an approach that has several advantages, since it allows researchers to study two facets of dynamic pricing and can be applied to many other price-influencing factors, such as interest rates and volatilities. However, the results of our empirical analysis are also subject to some limitations. One limitation is that the warrant prices we use come from a period during which the volatility of the underlying and issuers' credit risk reached high levels. We tackled this limitation to some extent by using a post-Lehman subsample. Nevertheless, future research may test whether adverse pricing can also be observed in times of moderate credit risk levels. Another limitation is that we tackle demand effects only in one particular form, namely, by using subsamples of warrants with round and non-round strikes. While warrants with round strikes are significantly in greater demand, we are not able to control for warrants' order flow, because we lack the data. Despite these limitations, this study contributes by proposing a new approach which not only helps to gain valuable insights on credit risk but also for other issuer- and underlying-specific factors and hence, opens a new form of analysis.

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Chapter 4

Energy Prices in Flux – The Influence of Weather Parameters on Electricity Prices at the EEX

Energy produced from resources such as wind and sun are mainly defined by the weather which is far beyond human control. Energy prices depend on the production of energy in general and of renewable energy in particular. Hence, also several weather parameters affect energy prices. This paper examines three aspects: First, the influence of weather parameters on different spot and derivative energy products; second, the influence of weather parameters on the different energy prices in two subsamples; and third, the influence of weather parameter combinations. The results show that weather parameters affect spot market prices stronger than derivative market prices and that the effect on different load profiles is only present in the spot market. In the second half of the observation period, the influence of weather parameters decreased, but weather parameter combinations became important. These results are relevant for risk management to assess weather parameter risk on energy product prices.

Keywords: weather, energy prices, derivatives, energy exchange, EEX
JEL Classification: C33, G10, P18, P28

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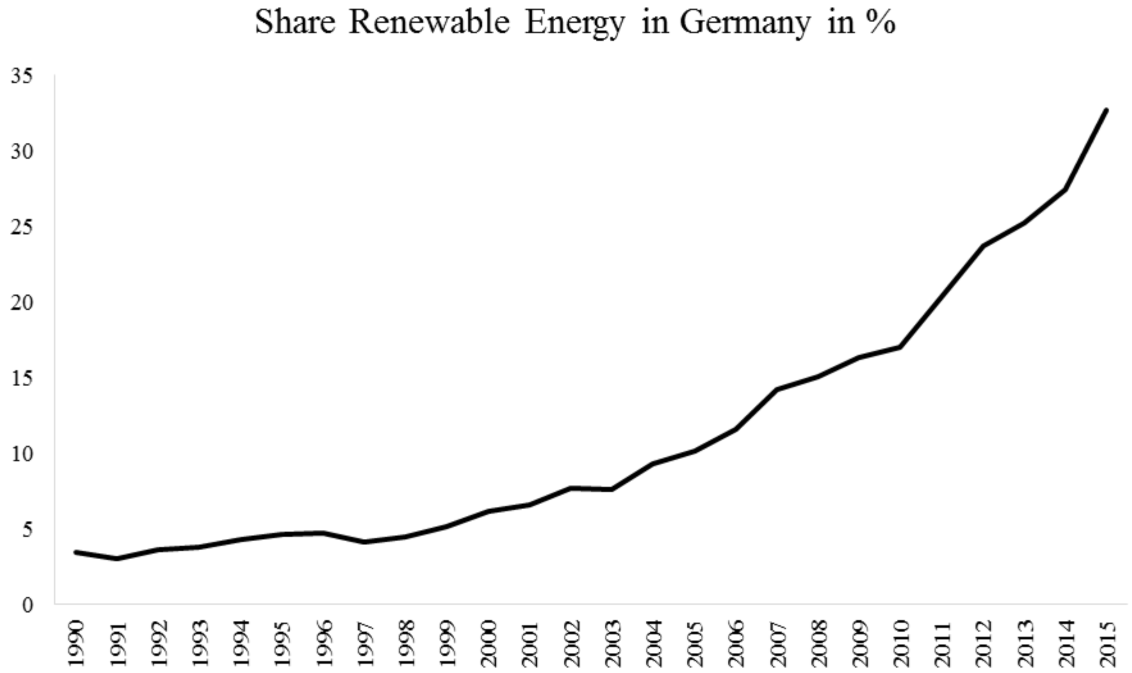
4.1 Introduction

In the German electricity market, the share of renewable energy has increased in recent years as Figure 1 shows (Figure 1). There are two main reasons for this development: the European Union's objective to increase the share of renewable energy in Europe and Germany's even more ambitious plan to exceed Europe's targets. In 2015, already 32.65% of the energy consumed in Germany was generated from renewable resources (German Federal Ministry of Economic Affairs and Energy, 2016a). However, the target is to increase the share of renewables in the gross final energy consumption to 45% by 2030 and even to 60% by 2050 (German Federal Ministry of Economic Affairs and Energy, 2016b, p.6).

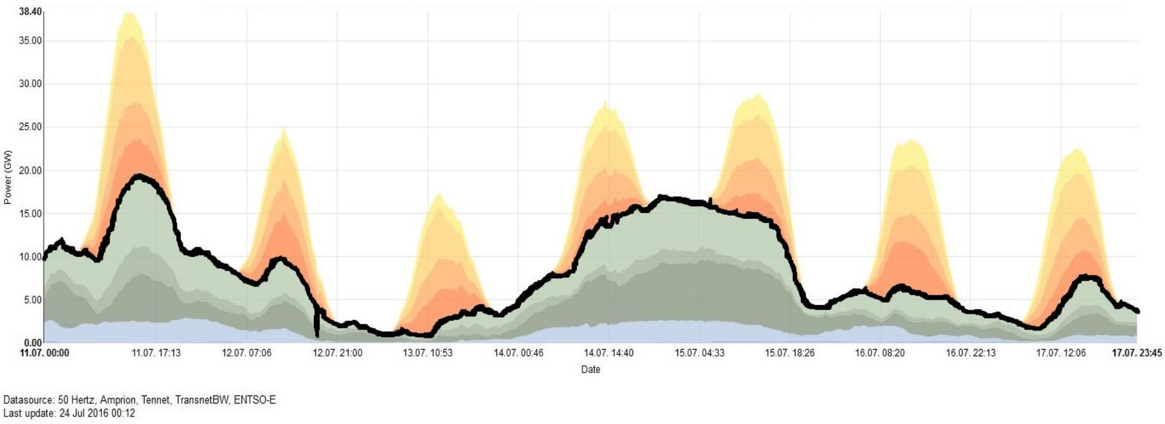
Figure 4.1: Development of Renewable Energy in Germany



Notes: The graph shows the increasing share of renewable energy of renewable energy of gross final energy consumption in Germany between 1990 and 2015.

Renewable energies have in means of production, especially in contrast to coal-fired or gas-fired plants, several advantages: They produce less emissions and depend on resources that are free and infinitely available compared to finite and increasingly limited resources such as coal. Moreover, the burning of, for example, coal always produces harmful substances such as fine dust, nitrogen oxide, and sulphur dioxide, which pose a threat to the environment and human health (German Federal Environmental Agency, 2016). However, the nearly exponential increase of renewable energy also has a major drawback: Daily operations of solar parks and wind farms are affected by the weather, which humans have no influence on. In addition, weather parameters like wind and sun not only vary by day and night but also within one day. As a result, also the amount of renewable energy produced is subject to volatility (e.g. Nicolosi and Fürsch, 2009; Claudius, et al., 2013). Figure 2 presents the wind and solar production in Germany during the 28th week of 2016.

Figure 4.2: Renewable Energy Production in Germany, 28th week 2006



Source: Frauenhofer ISE (https://www.energy-charts.de/power_de.htm?source=solar-wind&week=28&year=2016)

Notes: The figure shows the production of wind and solar energy in Germany for the 28th week of 2016 and the changes in renewable energy production over time. The black line marks the difference in the production of solar and wind energy. The area below the black line represents the production of wind energy and the one above the production of solar energy.

The black line marks the difference between the productions of solar and wind energy. The area below the black line presents the production of wind energy and the area above presents the production of solar energy. Data are taken from the transmission companies. The figure shows that there are times when only a small amount of renewable energy is produced. Since this figure represents a week during summer, the differences in the production of renewable energy between day and night are much more pronounced for the production of solar energy. This might be different on winter days, when over the day less sun is shining. In the case of wind energy, the production is not affected by the time of day and unstable over the week. While only a small amount of wind energy is produced in the evening of July12 and in the morning of July13, a high amount of wind energy is produced on July14 and July15. Hence, the production of wind and solar energy depend on the weather conditions and is unstable over time. The German government requires that operator feed renewable energy into the grid preferentially. This regulation, called "Renewable Energy Sources Act (EEG)," was enacted in its first version in 2000. The regulation has two main components: First, operators are forced to take renewable energy even from small producers and to transfer this renewable energy preferred into the grid. Second, producers will receive a guaranteed amount of money per unit of produced energy (German Federal Ministry of Economic Affairs and Energy, 2016c). In the five amendments since 2000, the rates for a producer have changed, but the preferable energy infeed remained untouched. For this reason, renewable energy is used first to meet the demand. If too little renewable energy is available, the rest of the demand needs to be satisfied using energy from conventional power resources. Therefore, conventional power plants are mostly required in times of high demand (peak load). Since the costs of producing renewable energy after the first installing investments is very low, electricity prices have dropped (Nicolosi and Fürsch, 2009). Since conventional power plants are mostly needed in times of energy demand peaks, they contribute less to the load in times of moderate demand. However, due to the instability associated with renewables, only a fraction of the base load (6%) can be insured, since the production is not stable over time. Therefore, the prices have become more volatile in recent years. For this and other reasons, renewable energy cannot, at this point, replace fossil fuels and nuclear power (Schaber, et al., 2012).

A part of the energy produced is traded at exchanges for energy products, such as the European Energy Exchange (EEX). Energy producers, distributors, and financial investors are active at this wholesaler market. The EEX offers a wide range of energy-related products, but the main product field are power products in the spot and derivative market (EEX AG, 2017a). Since these power products also contain power from renewable energy resources, their prices traded at this energy exchange should be affected by the weather, too. However, it seem unreasonable to believe that the spot and the derivative markets are influenced to the same extent by the weather. Therefore, the impact of weather parameters on product prices in both markets have to be analyzed and compared. Products cannot only be differentiated by their time span, but also by their load profile. The load profile is defined by a combination of hours across the day which are expected to have a similar demand. So, for example, one important load profile is the peak load, which is defined by the hours between 8 a.m. and 8 p.m. (Madlener and Kaufmann, 2002, p.16), a period of time during which the demand is high. It can be assumed that products with different load profiles will be influenced to a different degree by the weather. For this reason, this study analyzes not only the differences between the spot and the derivative market but also the influence of weather on products with different load profiles.

In a second step, the impact of weather on the electricity prices is analyzed by splitting the sample into two subsamples. This approach is necessary because the share of renewable energy has increased considerably in the last decade. By splitting the sample, one can analyze whether an increase in the share of renewable energy has increased the impact of weather parameters. Therefore, a point in time needs to be found that may serve as splitting point. In March 2011, after an accident at the Fukushima Daiichi nuclear power plant in Japan, the German government decided to shut down all nuclear power plants until 2022. Nuclear power plants contribute to the base load to a considerable extend. Eight power plants were shut down immediately in 2011 (Haunss, et al., 2013), accelerating the shift to renewable energy. While the actual impact of the Nuclear Moratorium is difficult to assess, this landmark political decision for Germany is likely to have had an influence on energy markets. In addition, it is suited to create two comparable samples.

The results show that weather parameters tend to affect the prices of spot market products to a greater extent than those of derivative products. The longer the time to maturity of the contracts in the derivative markets, the lower the impact of weather parameters. One potential reason may be that it is impossible to infer what the weather will be later, for example, six months. Peak loads are influenced to a greater extent by weather parameters than off-peak loads, since the availability in peak load hours, when demand is higher, is of greater importance. The comparison of the two sample periods does not confirm the expectation of an increasing influence of weather parameters, since the influence decreases for most of the weather parameters.

The influence of individual weather parameters may decrease over time, but the combinations of weather parameters might have an effect on energy prices. Nicolosi (2010) states that so called tight market situations can lead to extreme prices in the energy market. These situations occur either in times when energy demand is low and the amount of renewable energy produced is high or in times when energy demand is high and the amount of renewable energy produced is low. Such situations can destabilize the power grid. This paper combines different weather parameters to model such situations. Six variables of different combinations are built to test whether combinations of weather parameters can affect energy prices in the second half of the sample. The results show that all different weather combinations increase prices and significantly affect most energy prices in the spot and derivative markets.

With these results, this study contributes to the literature on energy finance and the pricing of commodities in three ways: First, it provides evidence for the influence of weather parameters on the pricing of energy products. Second, it shows how the prices of different energy products are affected by the weather. This findings can be used by risk managers to better assess the risk involved in energy products used for hedging. Third, it offers a new perspective on tight market situations by using weather parameter combinations. This approach contributes to the literature by offering an alternative to the one used by Nicolosi (2010), which focused on the definition by price levels. The approach taken here considers that combinations of weather parameters affect different energy product prices to different degrees in tight market situations.

The remainder of the paper is structured as follows: Section 2 introduces the weather parameters, related renewable energy resources, the German energy market, and products traded in exchanges such as the EEX. It also develops the hypotheses and presents the model. Section 3 describes the data and the modification of these and shows the descriptive statistics. Section 4 presents the results and Section 5 concludes.

4.2 Weather Parameters, the EEX and Its Electricity Prices

This chapter describes the renewable energy resources and the influence that weather parameters have on them. It moreover presents the electricity market in Germany, with a particular focus on the electricity marketplace: the European Energy Exchange (EEX) and the different products available in the spot and derivative markets. Based on the presented weather parameter and then the marketplace, the hypotheses are formulated and the models used are presented.

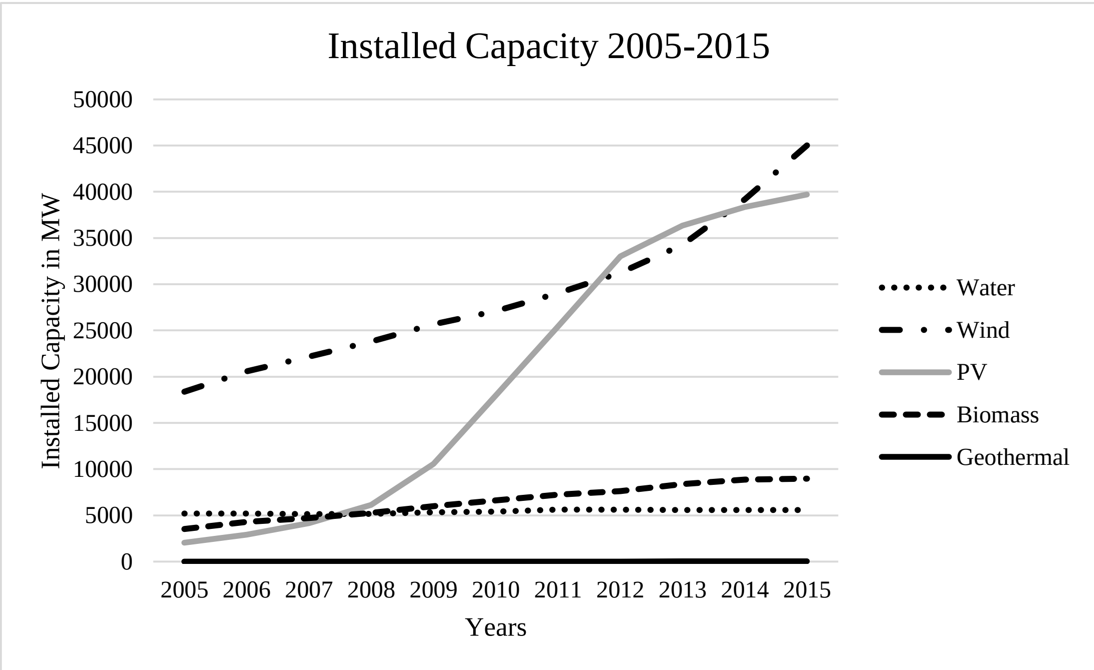
4.2.1. Renewable Energy Resources and the Influence of Weather

Five sources of renewable energy exist: wind energy, solar energy, biomass, hydro energy and geothermal. They can be differentiated by the way they are generated. Wind energy combines energy generated by off-shore (in the sea) and on-shore (on the land) wind turbines (Quaschning, 2011, p.264). Solar energy is produced by large installation parks as well as by comparatively small installations on the roofs of houses. In Germany, this includes company buildings as well as private households that use solar energy primarily for their purposes but also feed additional energy into the grid and hence, into the market (Bundesnetzagentur, 2017; Quaschning, 2011, p.165). Energy from biomass defines everything produced by waste, which are remnants of biological and organic substances, regardless of whether these substances come from agriculture, fishing, households or production. Depending on the source, biomass can be solid, liquid, or gas and is burned to obtain energy out of the substance (Quaschning, 2011, pp.331-341). Hydroelectric energy can be classified into two main groups: a) storage power stations which use the falling of water at dams or lakes to generate electricity or b) running water pipes which use the current of rivers or canals (Quaschning, 2011, p.299). Moreover, small hydropower plants exist functioning similar to the big ones but having a smaller installed capacity and hence, producing less electricity. While the production from hydro energy is high in other European countries such as Austria, Switzerland, Norway, and Sweden, this energy resource is only used to a small amount in Germany (Eurostat, 2017). Geothermal power plants use the heat of the earth to produce energy. In Germany, this is only a negligible part of renewable energy production until now. Reasons are the high costs due to the difficulty of installation and expensive deep boreholes (Quaschning, 2011, p.35).

The main renewable energy resources in Germany according to the amount of megawattage (MV) installed are wind and solar energies, respectively (Figure 3). The installed capacity of wind energy has increased steadily from 2005 onward. Since 2014, the installed capacity for wind energy is again higher than that of solar energy following a short period (2012 to

2014) when the installed capacity of solar energy was higher. One reason is the slower increase in installed capacity of solar power, which might be due to a reduction of money that the operator receives for feeding the solar energy into the grid (German Federal Ministry of Economic Affairs and Energy, 2012). Compared to the wind and solar power, the money received for the other renewable resources remained mostly constant over the years. The possibilities to produce water energy are the most used, which explains the stable amount of installed capacity over the years. The amount of geothermal power is close to zero, which is due to the high cost of generation. In contrast, the installed capacity of biomass has increased over time.

Figure 4.3: Installed Capacity of Renewable Energy from 2005 to 2015



Notes: The diagram shows the development of installed capacity for different renewable energy resources in Germany over a 10-year period, from 2005 to 2015.

However, not all of the renewable energy resources presented are influenced similarly by the weather. Hence, to analyze the influences of weather parameter on energy prices, the renewable energy resources that largely depend on the weather condition and those that do so only marginally must first be differentiated. Wind and solar power are highly affected by the weather. Wind energy can be generated only when the wind is blowing. A similar relationship is valid for solar energy: Solar panels can produce energy only when the sun is shining. Such an analogous relationship between the production of energy and the weather cannot be found for the other renewable energy resources. Biomass, for example, can be generated throughout the whole day. One reason is the different sources which contribute to the biomass production. Sources like sludge and landfill gas are produced on a regular basis and are mostly independent of weather conditions. The same is true for water and geothermal energy. Energy from the earth heat uses the warmth that is saved in the depths of the earth's crust. In contrast, water energy is partly influenced by the weather. Water energy is affected marginally by climate changes and seasons. However, it is not affected by the daily weather. Since the focus of this paper is the influence of weather on the energy prices, it will focus on renewable energy resources which are highly affected by the daily weather: wind and solar energy. This influence of daily weather on wind and solar energy will affect the amount of energy produced and hence, how much energy will be available to the energy market.

Weather parameters which influence the wind and solar energy production are the wind speed, the available amount of sun, and the precipitation in the form of rain or snow. The wind speed is the main driver for the energy production on wind farms. The most electricity can be produced during a moderate to high level of wind speed. In situations of low wind speed, often the amount of energy is needed to operate the wind farm is higher than that which can be gained by running the turbines, which is unfavorable. Moreover, high wind speeds are unfavorable too, since in this case, wind farms need to be shut down to avoid damage to the rotor blades, for example, due to strong winds (BWE, 2017). The availability of sun and the strength of the sun is relevant for the production of solar energy; the longer the sun shines, the more energy can be produced. Additionally, the sun around noon favors solar energy production more than the sun in the morning or evening, and the sun in summer will favor the production more than the sun in the winter, due to its intensity. The intensity of the sun is mostly influenced by the position of the sun (Institute for Medical Climatology at Christian-Albrechts-University Kiel, 2015). Notably, the production of solar energy depends only on daytime since, at night, no solar energy can be produced. Since in the summer, the days are longer than in the winter, the production of solar energy also depends on the seasons. Therefore, driven only by the daylight available, the amount of potential solar energy in summer is higher than in winter. Moreover, in the winter time, precipitation is more likely. When it rains or snows, the probability is high that the sky is cloudy, which will lead to either no or a negligible amount of solar energy produced. Therefore, precipitation interacts mostly with sun hours and wind speed. Often rain and snow are accompanied by the wind and hence, this is a favorable state for wind production.

Temperature is another important parameter. Not only are there temperature differences over the days as within one day as also with the other weather parameters, but the temperature also shows seasonal effects like higher temperatures in summer and lower temperatures in winter. Temperature, on the one hand, interacts with the other weather parameters in that, for example, the temperature is higher when the sun is shining and lower when it is colder or when it is raining or snowing. On the other hand, temperatures influence the amount of energy we need over the day, especially the heating in households and commercial enterprises such as stores. The lower the temperature, the higher is the number of people willing to use heating either for themselves or to satisfy their customers. The higher the temperature, the more people and commercial enterprises might be willing to use air conditioning, and hence, this also causes a higher energy consumption.

Since the weather parameters presented is important for the generation of wind and solar energy and also influences our energy-using behavior, these should also have an influence on the energy prices at the energy exchange.

4.2.2. The Energy Market and Hypotheses

The largest exchange for electricity products in Europe is the EEX, which is located in Germany. The EEX was founded in 2002 by merging the German power exchanges in Frankfurt and Leipzig. The head office of the group, which is comprised of different commodity exchanges across Europe, is in Leipzig. The electricity products examined in this study are traded directly at the EEX. The greatest shareholder is *Deutsche Börse AG* (EEX AG, 2017b).

The EEX, which is mainly a market for wholesalers, is used by its participants on a regular basis. Hence, the market and its products can be considered liquid. Operators in Germany are required by national state regulations to buy renewable energy from the energy producers for pre-specified prices regardless of the market price at any given moment after §1 AusglMechAV (Bundesanzeiger, 2015). Due to the increasing market share of renewable energy over the last years, the total amount of energy is less controllable, leading to market situations of electricity oversupply. In the past, energy was offered free of charge at the energy exchanges in such a situation. However, this price still did not appropriately reflect the situation (Nicolosi, 2010). The EEX adapted to this situation by allowing negative prices since October 2008, so the prices can float freely. Since then, high price fluctuations have been observed (e.g. Kettler, 2014; Nicolosi and Fürsch 2009).

At the EEX, spot and derivative products for electricity are available. Spot and derivative products and their prices are normally connected to each other but have different time spans. Spot market products focus on energy delivery intra-day or the day after. Derivatives are contracts settled today for some point in the future. A price will be determined by the contract parties which seem to be reasonable all available information considered as well as including assumptions about the future. Assumptions which might be of interest for the price development might be about climate change, about the consumption development, and about the seasons. Derivatives enable the market participants to hedge their risk. On the one hand, there are those who buy energy to hedge against price risk and, on the other hand, there are the producers and transmission companies that seek to balance their production, and thus stabilize their gains. Such future contracts are available with different time spans, like monthly, quarterly, or year contracts, depending on the time span in which the contract will be delivered. At the EEX, one can buy or sell several months, quarters, and years in advance. Hence, buyers for energy in the wholesale market, such as distribution companies, can settle a quarterly contract with a producer where a specific quantity of energy will be delivered at a specific price (EEX AG, 2011). Independent of the price fluctuations in the spot market, the distributor receives the energy for a known price, which makes it easier to calculate the energy prices for the end consumer without being afraid to operate at a loss. He needs to interact with the spot market only when the distributor needs additional energy on short notice, and hence, it depends on the price. From the viewpoint of an energy producer, this arrangement also has its advantages. The future contract specifies the amount of energy that the distributor will buy and so guarantees the producers a known income. Only the amount of energy that will be additionally produced needs to be sold on the spot market, which always carries the risk that the energy needs to be sold at negative prices, leading to a high loss for the producer.

Expecting that the weather affects the energy prices in several ways, it seems to be questionable whether the influence is the same for spot and derivative products. One may expect that the weather today has a significant impact today's or tomorrow's energy prices. One important reason here is that energy until now, especially in Germany, cannot be stored well. Hence, if it is a sunny and windy day and a high amount of renewable energy is produced, and there is only a negligible option to store it, it needs to be used immediately. If the energy demand at such moment is low, the spot price will drop. However, the directly observable weather might not be a good indicator of the weather after some months and also not necessary for the weather after some years. This assumption is supported by the German government and lead to a change in regulation so that transmission companies are forced to forecast the amount of energy produced only one day ahead. Before this change, they were forced to forecast one month in advance which proofed to be inefficient (Kettler, 2014). This situation means that the forecast for the weather after some months is not reliable and thus may contain no reliable information on the weather at the time of the contract's delivery period. For this reason, this information should not be considered and does not influence the price. The longer into the distant future the delivery periods of the future contract are, the lower should be the impact. As a result, the first hypothesis is formulated as follows:

Hypothesis 1: The prices of derivative products with a longer time span are less affected by weather parameter than the prices of derivative products with shorter time spans. The prices of all spot products are expected to be affected more strongly than those of the derivatives.

Next to the differentiation between the spot and derivative markets and different time periods, the products available at the EEX can be differentiated by their load profile. Three different load profiles are currently offered: base load, peak load, and off-peak load. While the base load covers the entire day, peak load contracts only capture the working hours from 8 a.m. to 8 p.m. During this period, mainly the secondary factor is at work, for example, producing goods, and, hence, a greater amount of electricity is needed. The off-peak period covers the other 12 hours, i.e. from 8 p.m. to 8 a.m. the next day (Madlener and Kaufmann, 2002). It is expected that at night, less energy is consumed than during the day. The differentiation in load profiles also influences the prices. Since the off-peak load covers the hours where less energy is consumed by producing and commercial companies, and even private persons, during the time they are sleeping, the price is comparably lower to that during the peak load period. The base load covers the other two load profiles and hence, the prices lay in between the two on average. But not only does the energy demand play a role, but so does the energy supply. If the energy supply is high during the peak load time, the price can be comparably low, nonetheless. However, if the production is relatively low, then the prices may run to an extraordinary level since the demand is high, but the supply might be relatively low. Since the supply side depends on the amount of energy produced and hence also on the amount of renewable energy produced, weather parameters are expected to influence the prices of load profiles differently. Due to the higher demand in peak load periods, the production of renewable energy may have a stronger impact, particularly because renewable energy is preferred in Germany, and the part of more reliable energy resources have decreased over the last years. Because the production of renewable energy is unpredictable, weather parameters may more strongly affect the peak loads than the base and off-peak loads. Following this assumption, the second hypothesis is formulated:

Hypothesis 2: Due to the higher demand in peak-load times, peak load products are more strongly affected by the weather than base loads and off-peak loads.

The steady increase of renewable energies over the last years also has another effect which especially affects operators of conventional power plants. Since renewable energy is fed into the grid preferentially, conventional power plants are not needed the whole time. When the production from renewables is high, conventional power plants might not even be needed to meet the demand. In contrast, when the production from renewables is low, then energy from other resources is necessary to satisfy the demand. This means that conventional power plants are needed in some instances and are superfluous in others (Kettler, 2014; Nicolosi and Fürsch, 2009). As a result of the reduction in running time, some conventional power plants are no longer profitable, but they are required to ensure a stable energy supply and save the grid from outages. This phenomenon, known as the merit order effect, already forces Germany to sell electricity to neighboring countries at a loss in times of high production and buy it back at a premium when the market is tight, i.e. when the demand is high and renewable production is low. Because this phenomenon is related to the amount of renewable energy on the grid, the strong and steady increase in renewable energy may have deteriorated this effect. Hence, one might expect that over time that also the influence of the weather parameter on electricity prices has increased. Two subsamples will test the hypothesis of an increasing influence of weather parameter over time. Good for the sample to split would be a) splitting the sample into two subsamples of similar size and b) marking a point in time that is expected to influence the share of renewable energy further. One event that fulfills the criteria is the Nuclear Moratorium. The Nuclear Moratorium was enacted in March 2011 by the German Government. The trigger for enacting this regulation was the accident at the nuclear power plant in Fukushima, which raised a strong debate about the safety of nuclear power plants throughout Europe (Haunss, et al., 2013). The German government first tested the safety of all German nuclear power plants and second, had decided to decommission all of them by 2022. Already in August 2011, eight German nuclear power plants were forced to cease operations. The reaction of the German government was one of the strongest in Europe. Other European countries either stayed with their nuclear power plants or decided not to build the ones already planned but stay with the ones already existing (Haunss, et al., 2013). Due to this political decision, it became necessary to accelerate the energy production from renewables in Germany. This decision also affected the energy supply and hence, the price. Since generating capacities associated with low marginal costs such as nuclear power plants are removed from the system, the Nuclear Moratorium shifts the supply curve to the left. As a result, prices will rise (Thoenes, 2011). This date, therefore, seems to serve as a good event for splitting the sample and for controlling the single periods. The author's hypothesis for these different time periods is as follows:

Hypothesis 3: In the period after the Nuclear Moratorium, the influence of weather parameters on energy prices have increased.

4.2.3. The Model

In the first part of the analysis, the influence of weather parameters on the prices of different energy products at the EEX is analyzed. For this purpose, the model is defined as follows:

$$P_t = \beta_0 + \beta_1 \times Temp_t + \beta_2 \times Temp2_t + \beta_3 \times Speed_t + \beta_4 \times Rain_t$$
$$+ \beta_5 \times Sunhours_t + \beta_6 \times Snow_{t-1} + Control\,Variables_t + \varepsilon_t \quad (4.1)$$

where P_t denotes an electricity price at the EEX for each individual product. The products considered for the spot market are the base load, peak load, off-peak load, and month peak load. The products of the derivative market comprise the month base and peak load, the quarterly base and peak load, and the yearly base and peak load. $Temp_t$ and $temp2_t$ describe the temperature and the squared term of temperature on day t. The temperature was included in squared terms since the literature has found evidence for such a non-linearity (Mansanet-Bataller, et al., 2007; Boudoukh, et al., 2007). Bessec and Fouquau (2007) emphasize the non-linear effect that temperature has on demand. When temperatures are low, heat has to be generated, and for this reason, consumption increases. As temperatures rise, the necessity to heat one's home, for example, decreases. In the summer months, the necessity for cooling (air conditioner or other cooling devices) increases with the rising temperatures. In the northern hemisphere, cooling has played only a moderate role until today. However, due to the climate change over the last years, this importance increases steadily. The impact of higher average temperatures and very hot and dry summers, as well as the difficulties arising therefrom, are well documented for Germany. For example, Schaeffer, et al., (2012) identify that higher temperatures will increase the need for cooling. Rübbelke and Vögele (2010) show that climate change and increasing average temperatures already have an impact on the infrastructure of the energy sector. While the literature often uses heating and cooling days to capture the nonlinearity of temperature, this approach has some drawbacks (Bessec and Fouquau, 2007). For example, the definition of heating and cooling days is not necessarily supported by the empirical evidence. First, to the best of the author's knowledge, there is no data available on the heating behavior of German inhabitants, and second, it would still only capture an average effect. For this reason, this study includes the squared term of temperature for analyzing whether the nonlinear effect can also be observed in Germany in recent years.

Speed describes the daily wind speed. The variable is adjusted to extreme high and low wind speed levels, which makes the operation of the wind farm impossible. The wind speed is set to zero if the wind speed is below 1.6 m/s. No adaption needs to be made for values above 24.5 m/s since no such an observation was available. No further variable for energy production from the wind is necessary since Mulder and Scholtens (2013) find that wind speed and wind energy production are closely related in the case of Germany.

Rain indicates the amount of precipitation on a given day and $snow_{t-1}$ the amount of yesterday's snowfall.

Sunhours is defined as follows:

$$Sunhours = \frac{Hours\ of\ Sunshine}{Daylight} \tag{4.2}$$

This definition is chosen to distinguish between similar hours of sunshine during different seasons. For example, the sun may shine for two hours on either a winter or a summer day. In the former case, two hours is a relatively long time, considering that in winter, a day in terms of the difference between sunrise and sunset is shorter compared to a day in summer. For this reason, the available hours of sunshine per day are weighted with the hours between sunrise and sunset. During this time, the sun is up, and solar energy can be potentially produced. The real time when energy is produced, however, depends on the time the sun is shining, measured by the hours of sunshine. The hours of sunshine already incorporate the level of cloud cover and hence, don't need to be considered separately as an additional variable. Mulder and Scholtens (2013) find when using the same measure that this variable is a good proxy for solar energy produced since they are closely related to each other. Hence, for this study, no explicit measure of solar energy production was included.

The study also controls for seasonal effects and time trends. The literature often mentions the seasonal effects on electricity prices. Mulder and Scholtens (2013) define the different periods using a daylight variable controlling for shorter days in winter and longer days in summer. Other authors, for example, Pietz (2009) or Kettler (2014), define different seasons to control for these effects. This paper follows a similar approach by defining dummy variables for three out of four seasons. Winter consists of the months December, January, and February. March, April, and May are titled Spring. And Summer consists of the three months following that. Moreover, the literature mentions evidence that energy prices tend to decrease over the course of time due to the increase of and the preference for renewable energy in the system, which is produced almost at no costs (e.g. Schaber, et al., 2012; Claudius, et al., 2013). In accounting for the decrease in the prices, it is important to model this effect by including a time trend.

4.3 Samples, Modification of Weather Data, and Descriptive Statistics

This chapter first introduces the data used for the analysis and then explains the empirical strategy for how the data were used, and afterward, presents descriptive statistics.

4.3.1 Data

This study uses daily electricity prices and weather data over a ten-year period from December 2005 to December 2015. The electricity prices were taken from the EEX and were retrieved from Thomson Reuters Datastream. Ten different products from the spot and derivative market are covered. The derivative products involve year, monthly, and quarterly contracts. The sample consists of baseload, peak-load, and off-peak load products. Data for each product are available for the entire sample period.

The weather data were taken from the German *Wetterdienst* for all active weather stations available for the period examined in this study. In total, data from 78 stations were collected. As the EEX has participants from across Europe, it may be questionable whether the German weather is appropriate for analysis. However, it still makes sense to focus on the impact of weather in Germany for several reasons: First, Germany is the largest electricity market in Europe; second, the EEX is located in Germany, and hence, the German weather might be relevant due to the proximity of the market and its connection to the German weather; and third, a great number of participants are from Germany.

In line with the literature, unit-root tests were performed to test the stationarity of the electricity spot prices and to check whether it is necessary to use the first differences, including the Augmented Dickey-Fuller test and the Phillips-Perron test. The results of these three tests indicated that the electricity spot prices are stationary, and hence, no further adjustments were made to the energy prices.

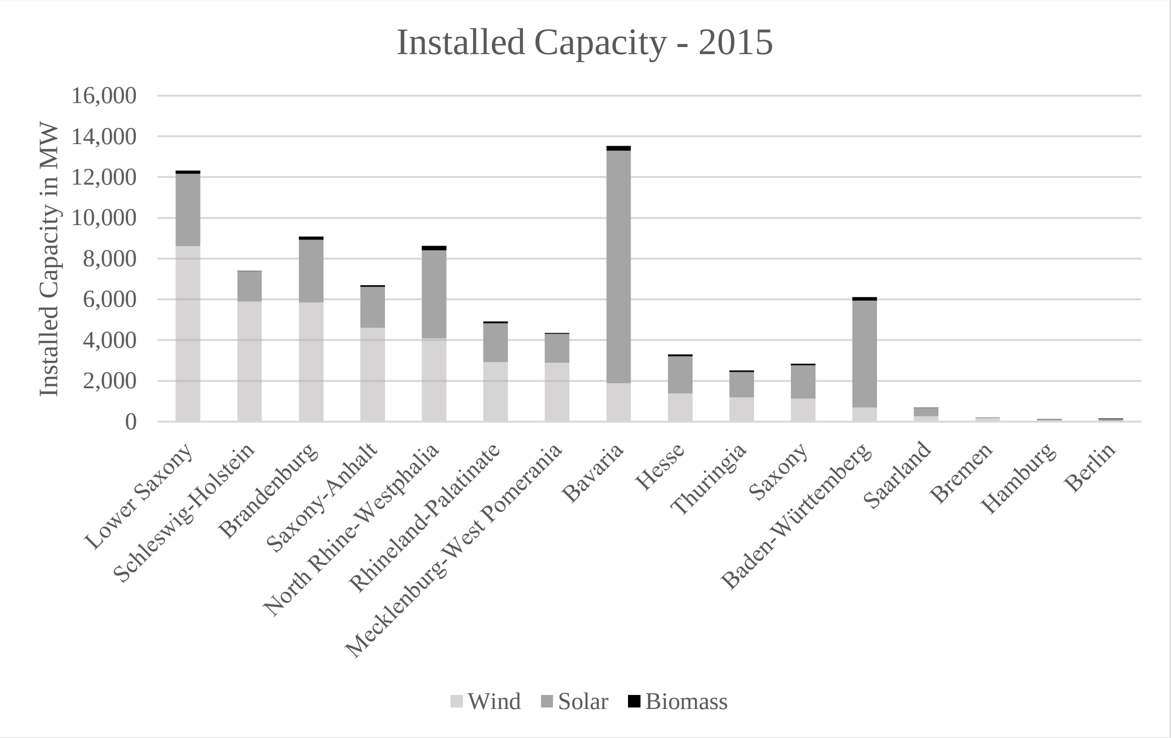
4.3.2 Modification of Weather Data

In the literature which analyzes the influence of weather parameter on prices, different approaches are known how to modify the weather data observed for analysis. One approach is to use an average of the weather data gathered from different weather stations (e.g. Longstaff and Wang, 2004; Bessec and Fouquau, 2007), and others like Mansanet-Bataller, et al., (2007) in using the weather parameter to build an index. Mansanet-Bataller, et al., (2007) weighted the weather variables for a specific weather station by the population living in the city or region. Using this approach, they received a daily index value per weather parameter like wind speed for Germany. This study combines different approaches of weather data modification. The variables are differentiated by their contribution to the energy production of wind and solar energy and the energy usage.

Mansanet-Bataller, et al., (2007) claim that temperature is expected to have a stronger influence on the demand side than on the energy production, as temperatures will influence our heating and cooling behavior. Next, to their method of weighting the weather data of one weather station by the population around this station, Mansanet-Bataller, et al., (2007) exclude the weather stations in sparsely populated areas. While this seems a reasonable method to use, the author decided to include temperatures as averages not only to focus on households but also on companies and industrials which are often located in rural areas. Moreover, all weather stations are used for calculating the daily averages. This approach ensures that all areas are considered which may influence the energy demand.

While the usage of averages seems to fit well for temperatures, this is not the case for the other weather parameters. Wind speed and sun hours are strongly related to the production of solar- and wind energy (Mulder and Scholtens, 2013). However, the installed capacity for wind and solar energy production is not equally distributed across Germany. Weight (2009) demonstrates that large differences exist between the amount of MW installed for wind energy in the North and the MW installed in the South. Similar differences are visible for the installed capacity of solar energy in Germany. To analyze the difference in greater detail, Figure 4 shows the amount of installed MW for wind, solar energy, and biomass by federal states. Data on installed capacity in 2015 were retrieved from Statista.

Figure 4.4: Installed Capacity of Renewable Energy 2015 by Federal States



Notes: The diagram shows the installed capacity in the sixteen federal states of Germany. The light grey part of the bar depicts installed capacity of wind energy, the grey one solar energy, and the black one biomass. The diagram shows the data for 2015.

The figure demonstrates that the highest MW of wind energy installed is located in Lower Saxony, Brandenburg, and Schleswig-Holstein, respectively. Less capacity for wind energy is installed in the city-states as Hamburg and Berlin, which is because these federal states consist of predominantly urban areas where there is less space for the installation of wind turbines. The largest capacity of solar energy installed is located in the south of Germany (Bavaria and Baden-Württemberg) and the west of Germany (North Rhine-Westphalia). Only in Bremen, there is no capacity of solar energy installed at all.

The renewable energy production depends on the weather where the energy is produced, hence where capacities are installed. Therefore, the weather around areas which have a high installed capacity is more relevant than the ones with a low installed capacity. For example, the wind speed present in Lower Saxony on a specific day is more relevant than the wind speed in Baden-Württemberg. The reason is that due to a high installed capacity, Lower Saxony can produce relatively more than Baden-Württemberg, which is accounted for by the weather parameters measured at a specific weather station relative to the installed capacity of the relevant federal state. An index for each weather parameter is constructed as follows:

$$weather\ index_t = \sum_{i=1}^{16} w_i \times weather\ parameter_t \quad (4.3)$$

where *weather index* is the constructed index for each weather variable and each day, w_i is the weight that is given to each federal state, and $weather\ parameter_t$ is the value for the unweighted daily weather parameter. The weight w is constructed by calculating the percentage of each federal state's installed capacity in terms of the total installed capacity for Germany. In the case of wind energy, the total installed wind capacity was taken as 100% and distributed to the federal states based on how much wind energy capacity they have installed. The wind speed is weighted with the installed capacity for wind energy and the sun hours are weighted with the installed capacity for solar energy. While the modification of wind and solar energy seem intuitive, the modification of humidity such as rain and snow is more difficult since they affect wind and solar energy production. While rain and snow are often accompanied by wind, they do not have an influence on the amount of wind energy produced. In contrast, Schaeffer, et al., (2012) identify that humidity has a direct impact on solar energy since it affects solar panels. Imagine a winter day after it has snowed. Even though the sun will shine in this time, the snow lying on the solar panels prevent them from producing energy. For this reason, humidity seems to have a stronger impact on the production of solar energy, and the installed capacity of solar energy will serve as a weighting factor for the weather parameters wind and snow.

An argumentation against the approach of weighting weather parameters in terms of the installed capacity of wind and solar energy in the federal states would be that the capacity has changed over time. Therefore, taking the installed capacity of one point in time would not be appropriate. However, not the installed capacity is taken but the contribution of each federal state to the total installed power. Even though the amount of installed capacity has increased strongly over the last years; it is assumed that the distribution across the federal states has not dramatically changed over time. Capacities are installed where the climatic conditions are preferable compared to those in other areas. Despite the influence of climate change, it can be assumed that the differences regarding climate between north and south or east and west are similar to those some years ago. Thus, using the weights gained from the installed capacity of 2015 seem to be a reasonable approach for integrating the weather data.

4.3.3. Descriptive Statistics

Table 1 Panel A shows the descriptive statistics for the weather data. The temperature is shown as daily averages of all German weather stations in degrees Celsius. The average temperature, with 9 degrees Celsius over the ten-year period considered seems to be a reasonable average of the 78 different weather stations in the diverse landscape Germany. The variable wind speed is received by weighting the wind speed measured in meters per second (m/s) with the installed capacity of the federal state where the weather station is located. The average mean of wind speed over the last ten years was around 4.82 m/s. The sun hours are contained by first weighting the daily hours of sunshine of each weather station with the installed capacity for solar energy of the federal state where the station is located. Second, this daily value is used and divided by the total amount of hours between sunrise and sunset. On average, the sun was shining for 35% per day in Germany over the last ten years. The humidity factors, the rain and snow of each weather station, are weighted by the amount of installed capacity of the federal state where they are located for each day. The rain is measured in millimeters (mm) and snow is measured in centimeters (cm). The amount of rain in Germany averages out at 2.33 mm and snow averages out around 7.22 cm. One reason for the high average of snow might be that due to the weighting procedure per federal state, those with more mountainous areas are weighted higher. Bavaria, for example, has the highest weight due to the highest installed capacity for solar energy, but it is also the federal state where the Alps begin. Therefore, there are weather stations located which can be assumed to have a large amount of snow during much of the year.

Table 4.1: Descriptive Statistics

This table provides descriptive statistics of the weather parameter and different energy products. X_AV indicates that variable X was calculated using the average of all stations in Germany, while X_IC indicates that the variable X was weighted by a weighting factor for the different federal states. This weighting factor is based on the installed capacity of the relevant renewable energy. Panel B depicts the descriptive statistics for the different energy products. D_X mark the product X of the derivative market, which are future contracts.

Variable	No of obs	Mean	Std. Dev.	Minimum	Maximum
Panel A: Weather Parameter					
Temp_AV	2607	9.049	7.084	-13.388	25.282
Wind Speed_IC	2607	4.824	1.624	2.016	12.553
Rain_IC	2607	2.334	2.856	0.000	24.005
Sunhours_IC	2607	0.350	0.235	0.000	0.948
Snow_IC	2607	7.220	8.063	0.000	46.024
Panel B: Products					
Base	2607	47.651	17.562	-56.870	301.540
Peak	2607	57.146	25.312	4.160	543.720
OffPeak	2607	38.175	12.445	-124.683	85.313
MonthPeak	2607	56.117	19.438	6.760	141.050
D_MonthBase	2607	45.889	13.280	26.500	98.410
D_MonthPeak	2607	60.304	20.313	32.310	141.560
D_QuarterBase	2607	47.467	13.428	28.690	97.500
D_QuarterPeak	2607	62.939	20.440	35.250	136.400
D_YearBase	2607	49.224	11.364	28.580	90.150
D_YearPeak	2607	65.956	17.939	35.630	127.800

Table 1 Panel B shows the descriptive statistics for the different product prices in Euro. A comparison reveals that peak loads are, on average, sold at higher prices than base loads, which would be expected. During peak times, the demand is higher, and, consequently, the price should be higher as well. For the base and the off-peak load spot product, the minimum price over the ten-year period is negative. For the other products, the minimum price over the last ten years is positive. The peak-load products of the spot market are on average sold at lower prices than the peak-load products of the derivative markets. The longer the time spans of the derivative contracts, the higher the average price in the sample. The lowest prices are available for the off-peak products, which is expected since during this period, demand is low, and the market is already satisfied in times of high renewable energy production. The highest value can be found for the peak load prices, which can be explained as follows: During peak times, demand is high. If the energy supply is limited during such times, prices can increase dramatically. Notice that these daily weather parameters are similar independent of which product is under investigation since the daily weather parameter are regressed on each available product in the market.

4.4 Results

The results section first presents the results of the influence of weather parameters on the prices of different spot and derivative products. Second, it uses four products which are two spot market and two derivative market products, to compare the period before and after the Nuclear Moratorium and the influence that weather parameters have. This section concludes with presenting the influence of different weather parameter combinations and its effects in the two subsamples.

4.4.1. Weather Parameters and Different Products

The results of this study indicate that in general, all considered weather parameters affect at least some product prices significantly. Table 2 Part I shows the marginal results for the spot market products, whereas Part II of Table 2 depicts those for the derivative products.

Table 4.2: Product Differentiation

The results given below are based on the following regression model:
$P_t = \beta_0 + \beta_1 \times Temp_t + \beta_2 \times Temp2_t + \beta_3 \times Speed_t + \beta_4 \times Rain_t + \beta_5 \times Sunhours_t + \beta_6 \times Snow_{t-1} + Control\ Variables_t + \varepsilon_t$,
which was estimated for each product separately. Part I of the table reports the results of the effect of weather parameter on the spot market product prices, while Part II reports the results on the derivative market product prices. Below the coefficients heteroscedasticity-consistent standard errors are reported (White 1980). ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

Part I

	Spot Market Product Prices			
	Base Load	Peak Load	Off-Peak Load	Month Peak Load
Temp	-1.461***	-1.907***	-1.013***	-0.766***
	(0.153)	(0.249)	(0.097)	(0.131)
Temp2	0.066***	0.094***	0.038***	0.032***
	(0.011)	(0.019)	(0.005)	(0.007)
Speed	-2.742***	-3.263***	-2.222***	-0.580***
	(0.181)	(0.237)	(0.152)	(0.211)
Rain	-0.348***	-0.420***	-0.271***	-0.333***
	(0.115)	(0.153)	(0.092)	(0.124)
Sunhours	-8.662***	-14.071***	-3.057***	-7.410***
	(1.643)	(2.342)	(1.186)	(1.766)
Snow_{t-1}	0.085**	0.048	0.120***	0.327***
	(0.043)	(0.061)	(0.032)	(0.052)
Season_Winter	-10.564***	-12.619***	-8.470***	-9.097***
	(1.089)	(1.553)	(0.926)	(1.137)
Season_Spring	-10.478***	-15.424***	-5.451***	-16.436***
	(0.928)	(1.314)	(0.698)	(1.026)
Season_Summer	-8.755***	-13.090***	-4.411***	-9.215***
	(1.076)	(1.493)	(0.804)	(1.177)
Time	-0.009***	-0.014***	-0.004***	-0.013***
	(0.000)	(0.001)	(0.000)	(0.000)

No. of obs	2606	2606	2606	2606
F-test	92.083	84.963	71.166	164.475
Adj. R^2	0.308	0.307	0.228	0.375

Part II

	Derivative Market Product Prices					
	Month Base Load	Month Peak Load	Quarter Base Load	Quarter Peak Load	Year Base Load	Year Peak Load
Temp	-0.299***	-0.372***	-0.192***	-0.140	-0.087	0.005
	(0.073)	(0.106)	(0.071)	(0.094)	(0.056)	(0.070)
Temp2	0.014***	0.021***	0.014***	0.019***	0.004	0.003
	(0.004)	(0.006)	(0.004)	(0.005)	(0.003)	(0.004)
Speed	0.207	0.190	0.155	0.082	0.248***	0.299**
	(0.137)	(0.184)	(0.134)	(0.175)	(0.096)	(0.120)
Rain	-0.293***	-0.393***	-0.268***	-0.344***	-0.144**	-0.234***
	(0.090)	(0.119)	(0.091)	(0.117)	(0.063)	(0.081)
Sunhours	-2.762**	-5.241***	-3.288***	-5.159***	-0.959	-1.487
	(1.223)	(1.653)	(1.168)	(1.517)	(0.858)	(1.061)
$Snow_{t-1}$	-0.108***	-0.244***	-0.221***	-0.412***	-0.108***	-0.190***
	(0.029)	(0.039)	(0.028)	(0.035)	(0.020)	(0.022)
Season_Winter	-2.930***	-4.198***	-7.225***	-9.460***	-1.961***	-1.697***
	(0.664)	(0.972)	(0.635)	(0.875)	(0.436)	(0.531)
Season_Spring	-9.206***	-15.037***	-7.356***	-10.190***	0.153	0.529
	(0.719)	(0.967)	(0.653)	(0.841)	(0.465)	(0.550)
Season_Summer	-6.342***	-9.974***	-3.497***	-5.163***	1.328**	1.798**
	(0.864)	(1.143)	(0.865)	(1.128)	(0.625)	(0.812)
Time	-0.010***	-0.018***	-0.011***	-0.020***	-0.012***	-0.021***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
No. of obs	2606	2606	2606	2606	2606	2606
F-test	238.042	324.801	237.361	388.878	440.148	889.200
Adj. R^2	0.397	0.523	0.442	0.582	0.593	0.736

For all spot market products, the effect of temperature and the squared term are highly significant. The positive coefficients for the squared temperature suggest the form of a U-shaped parabola, which means that for low and high temperatures, the effect on the energy price is higher than for medium temperatures. This result is in line with the ones of Bessec and Fouquau (2007), which find evidence for a nonlinear relationship between energy consumption and temperature in Germany. Concerning the derivative product prices, a significant nonlinear effect can only be found in the monthly contracts and the quarterly base load contract. The prices of the quarterly peak load and the year contracts lack statistical significance. Wind speed, sun hours, and rain have a significant negative influence on all prices of the spot market products. The negative impact of wind energy on the electricity prices is in line with the findings of Mulder and Scholtens (2013) who found that the wind speed in Germany and the Netherlands negatively affected the electricity prices in the Netherlands. For the prices of the derivative products, only the effect on the year contracts is significant. However, the influence is now significantly positive, which means that while a one unit increase in wind speed will lead to a price reduction in the spot market, the prices of the future year contract will increase. An increase of rain and sun hours lead to a reduction in prices of all products in the spot and the derivative market. The significant negative effect of sun hours is not in line with the results of Mulder and Scholtens (2013) who find no significant impact of sun hours in Germany and the Netherlands on the electricity prices in the Netherlands. One potential reason might be the different countries on which the studies are focused. Snow has a significant positive impact on the different sports market prices except for the peak-load prices, where the statistical significance is missing. In contrast, the effect on prices in the derivative market is significantly negative. The positive effect in the spot market seems to be reasonable since snow yesterday means that a lower amount of solar energy could be produced.

The results only partially confirm that derivative contracts of a longer time span are less affected by weather parameters than derivatives contracts of a shorter time span. The hypothesis holds for temperature and sun hours. Both weather parameters still demonstrate a strong, significant effect on the quarterly contract prices, but they are insignificant for the year contract prices. When focusing on the economic effects, temperature has an economic effect of 57% on the base load product in the spot market, while it decreases to 16% for the monthly base load and 10% for the quarterly base load in the derivative market. For products with a longer duration, the effect is insignificant. Similar results are found for sun hours: While the peak load in the spot market demonstrates an economic effect of 13%, the derivative monthly peak load only demonstrates an economic effect of 6% and the quarterly contract also only an economic effect of 6%. Again, the effect on the year contract is insignificant. Focusing on the results for rain offers another important insight: In order to answer the hypothesis whether derivatives are less effective by weather parameter than derivatives with longer time spans, it is imperative to consider the different load profiles, too. Comparing the economic effects of the monthly peak load and the quarterly base load, the economic effect of the monthly peak load is slightly lower (5.5%) than the one of the quarterly base load (5.7%). However, if we consider the differences in the derivative contracts only between the products of similar load profiles, the hypothesis holds. When we consider the derivative contracts for the base load, we find a clear reduction of the economic effect of an increase in time. The economic effect of the weather parameter rain on the product prices is around 6.3% for the monthly contract, while it decreases to 5.7% for the quarterly contract and 3.6% for the year contract, respectively. Similar results are found when focusing on the peak load profiles in the derivative market.

In analyzing the difference between the products of the spot and the derivative market, the coefficients of the weather parameters on the spot product price are compared to the ones of the different derivative product prices. However, only similar loads are compared to each other. So, the base load is compared to the monthly base load, the quarterly base load, and the yearly base load. Table 3 Part I shows the differences in the marginal effects and the significance level indicated by the stars.

Table 4.3: Difference Tests

The table shows difference tests (t-tests) of the influence of weather parameters vis-a-vis the dimensions time span and load profile. Part I presents the absolute difference between the coefficients for different time spans. All coefficients of longer time spans of one load profile are compared to the coefficient of the spot market product. ***, **, and * indicate the significance of the difference test at the 1%, 5%, or 10% levels, respectively. X_S signals that the product prices X are prices in the spot market. Part II presents the absolute differences and significance levels of the coefficients between different load profiles either in the spot or derivative market. ***, **, and * indicate the significance of the difference test at the 1%, 5%, or 10% levels, respectively.

Part I: Differences in Time Span				
	Peak vs. Month Peak_S	Peak vs. Month Peak	Peak vs. Quarter Peak	Peak vs. Year Peak
Temp	1.141***	1.535***	1.767***	1.902***
Temp2	0.062***	0.073***	0.075***	0.091***
Speed	2.683***	3.453***	3.345***	3.562***
Rain	0.087	0.027	0.076	0.186
Sunhours	6.661**	8.830***	8.912***	12.584***
Snow_{t-1}	0.279***	0.292***	0.460***	0.238***
	Base vs. Month Base	Base vs. Quarter Base	Base vs. Year Base	
Temp	1.162***	1.269***	1.374***	
Temp2	0.052***	0.052***	0.062***	
Speed	2.949***	2.897***	2.990***	
Rain	0.055	0.08	0.204	
Sunhours	5.900***	5.374***	7.703***	
Snow_{t-1}	0.193***	0.306***	0.193***	
Part II: Differences in Load Profile				
	Base vs. Peak	Base vs. Off-Peak	Peak vs. Off-Peak	
Temp	0.446	0.448***	0.894***	
Temp2	0.028	0.028***	0.056***	
Speed	0.521*	0.520**	1.041***	
Rain	0.072	0.523	0.149	
Sunhours	5.409*	5.605***	11.014***	
Snow_{t-1}	0.037	0.035	0.072	

	Base vs. Peak Month Contract	Base vs. Peak Quarter Contract	Base vs. Peak Year Contract
Temp	0.073	0.052	0.092
Temp2	0.007	0.005	0.001
Speed	0.017	0.073	0.051
Rain	0.1	0.076	0.09
Sunhours	2.479	1.871	0.528
Snow_{t-1}	0.136***	0.200***	0.082***

The effects on the different electricity prices differ in their magnitude between the spot and the derivative market for all weather parameters except for rain. Focusing on the peak load products for temperature and sun hours, it holds that the longer the time span, the greater the difference between the marginal effects. All differences are highly significant. Also, the differences in wind speed are increasing with an increasing time span. Only the difference between the peak load and the quarterly peak load is slightly smaller than the one between the peak load and the derivative contract for monthly peak load. Snow also indicates an increase in differences the longer the time span between the spot and the derivative contract. However, the difference between the peak load and the peak load year contract show a smaller difference than the difference between the two spot market products (peak load and peak month load). The results from the comparison between different base load coefficients partially support the former results. Temperature and sun hours demonstrate an increase in difference the longer the time span between the compared products. So the difference between the base load and the month base load are clearly smaller than the ones between the base load and the quarterly base load. Snow and wind speed show a different pattern where the difference between the marginal effects of the spot market product and the quarterly contract of the derivative market is smallest. So for the majority of weather parameters, the influence on the different product prices not only vary significantly between the spot and the derivative market, but the difference becomes greater when the time span of the derivative contract is longer. A greater difference at this moment means that the marginal effect of the spot product is mostly larger than the one of the derivative contracts for the majority of weather parameters. Hence, the second part of Hypothesis 1 seems to hold.

Hypothesis 2 stated that even within the same time span, differences might occur due to the different load profiles of the products. For example, it could be that for the off-peak period, i.e. the hours between 12 a.m. to 8 a.m. and 8 p.m. to 12 a.m., the impact of sun hours is smaller than for the peak load period. Since the base loads always contain the peak and the off-peak load, a difference between the peak load and the base load should also be visible. Difference tests were used to test the different load profile for each time span (Table 3 Part II). The results indicate that against expectation, no differences between the base load and the peak load is visible for most weather parameters and time horizons. Only the prices for load profiles in the derivate market are differently affected by snow. Here, the marginal effects show that the snow has a stronger negative influence on the peak load than on the base load. The negative effect, however, remains unclear since it is counterintuitive that in times of higher energy demand, the price will be reduced by the additional amount of snow. The differences between the base and the peak load in the spot market are only shown for the weather parameter wind speed and sun hours. These differences are significant at a 10% level. One reason why only these two parameters are significant may be that these are the factors directly influencing the production of the relevant renewable energy resources, wind and solar, while the other weather parameters influence them only indirectly. Significant differences are found especially in the comparison between the base and off-peak load, and between peak and off-peak load. Regarding the significant differences, we find that the differences between the base and the off-peak load are smaller than the ones between the peak and the off-peak load. The underlying reason is again the times that the different load profiles comprise. Since the base load also contains the off-peak, the smaller differences seem reasonable. In comparing the marginal effects, the effects on the peak load are always larger than on the off-peak load, revealing a stronger impact on the peak load as expected. Hence, the evidence is that peak loads are affected more strongly by the weather than off-peak loads. However, a similar connection between the peak and the off-peak load is evident only for some parameters such as wind speed and sun hours in the spot market.

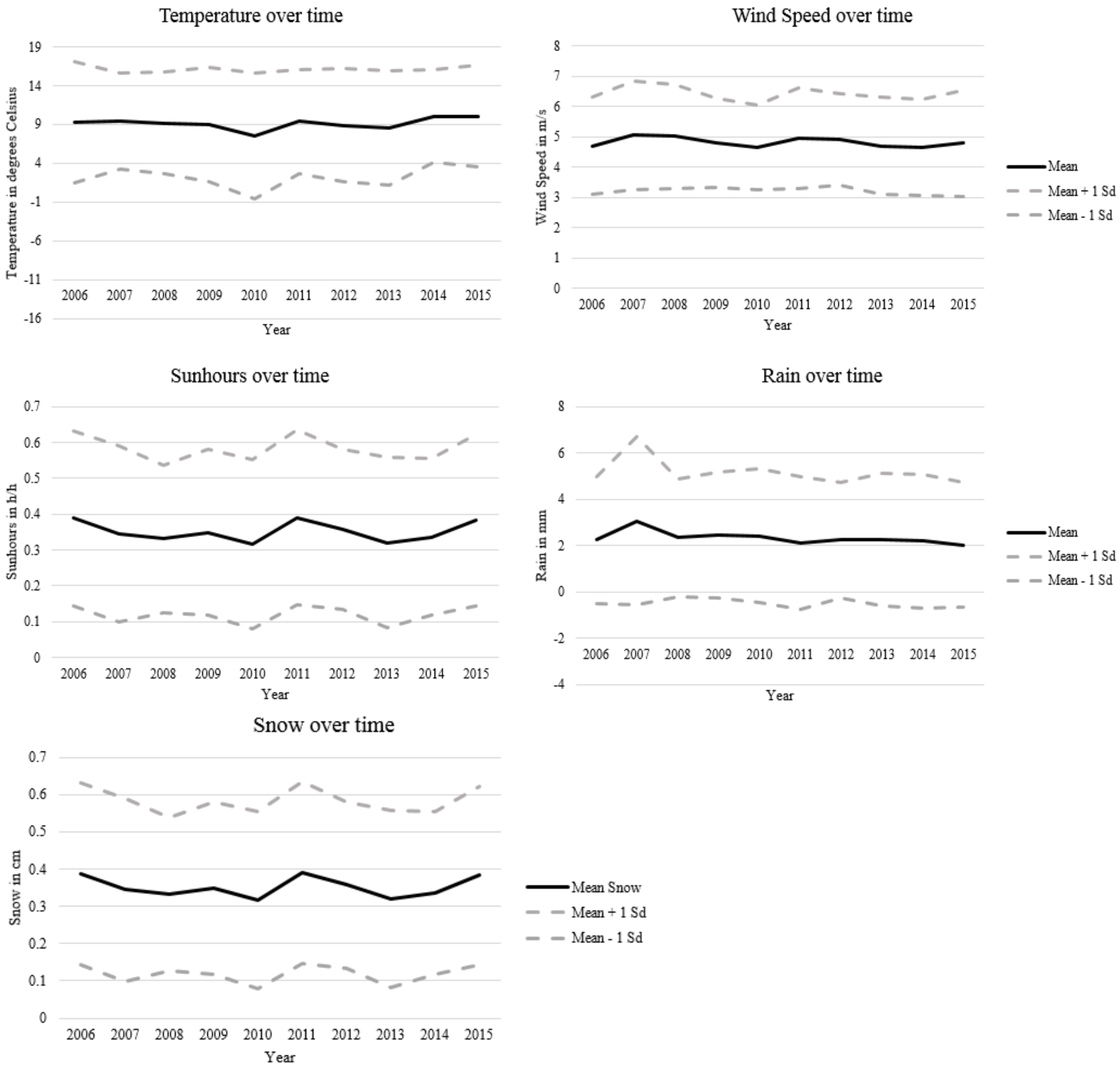
To summarize, different products are influenced differently by weather parameters. Two important factors determining the impact of the parameters on product prices are the time span and the load profile. The influence of weather parameter on both factors is stronger in the spot market than in the derivative market. For the majority of weather parameters, load factors are only relevant in the spot market. Since there are differences found between the markets and load profiles, it seems to be reasonable to consider them further in the analysis remaining. However, due to similar patterns across different load profiles, the number of products under consideration for further analysis will be reduced from ten to four. Therefore, the analysis can be more focused without losing essential information. The two products of the spot market and the two products of the derivative market are considered: the peak and the off-peak load and the quarterly base load and the quarterly peak load, respectively. The medium time span is chosen to avoid a greater closeness to the spot market. The peak and the off-peak loads are considered since the influence of weather conditions thus became clearer since the load profiles are strictly separated from each other. An off-peak load would also be preferable for the derivative market but is not available, and hence, the base load is taken for comparison.

Since the results found in this section might be driven by the method used to modify the weather data, two other methods were used, and the model was re-estimated. In the first re-estimation, all weather parameters were included in the model as averages of all weather stations across the different weather stations in Germany. In the second re-estimation, all weather parameters were weighted after the installed capacity of the federal states and then included in the model. Coefficients neither change in their sign nor their significance level in both re-estimations. Further explanations and the results tables are included in the Appendix.

4.4.2. The Influence of Weather Parameters over Time

It is considered to analyze two subsamples for whether the influence on weather parameters correspond with the steady increase in the share of renewables over a ten-year period. However, to ensure that the differences between the subsamples that might be observed are not driven by the weather, Figure 5 shows the development of the weather parameters over time. For each weather parameter, the average, as well as +/- 1 standard deviation, is presented. All weather parameters seem to be relatively stable over time so that changes seem to be driven directly by the influence of the amount of renewable energy in the system.

Figure 4.5: Development of Weather Parameter over Time



Notes: The graphs shows the yearly average and +/- one standard deviation of the weather parameters temperature, wind speed, rain, sun hours, and snow between 2006 and 2015.

For the first period which covers the time of December 2005 until March 2011, the temperature demonstrates, similar to the full sample, a U-shaped effect that is significant for all four products (Table 4). In contrast, in the second subsample, this effect is only found in the spot market. The influence of the temperature on the energy prices of the derivative market is insignificant. Difference Tests across the subsamples show that the effect in the spot market does not differ from each other. When focusing on the wind speed, the difference tests suggests that only the impact of wind speed on the off-peak load changes in the second half of the observation period. While a one-unit increase in wind speed leads to a price reduction of around 1.94 units, this reduction increases to 2.63 units in the second period. In the subsample after the Nuclear Moratorium, the impact of wind speed on the prices of derivative products is significantly positive. However, in the first subsample, the tests do not show a statistical difference from the insignificant negative marginal effects.

Table 4.4: Weather Parameter across Subsamples

The results given below were generated with the following regression model: $P_t = \beta_0 + \beta_1 \times Temp_t + \beta_2 \times Temp2_t + \beta_3 \times Speed_t + \beta_4 \times Rain_t + \beta_5 \times Sunhours_t + \beta_6 \times Snow_{t-1} + Control\ Variables_t + \varepsilon_{it}$, which was estimated before and after the Nuclear Moratorium (March 2011). Peak and off-peak are prices of spot market products, and the other two are prices of derivatives. Coefficients for seasons and the time trend are not reported. Below the coefficients, heteroscedasticity-consistent standard errors are reported (White 1980). ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

	Before			
	Peak Load	Off-Peak Load	Quarter Peak Load	Quarter Base Load
Temp	-2.204***	-0.845***	-0.257*	-0.213*
	(0.451)	(0.127)	(0.153)	(0.113)
Temp2	0.125***	0.034***	0.031***	0.020***
	(0.036)	(0.007)	(0.010)	(0.007)
Speed	-3.498***	-1.943***	-0.306	-0.119
	(0.426)	(0.231)	(0.311)	(0.224)
Rain	-0.674**	-0.371***	-0.539***	-0.426***
	(0.272)	(0.142)	(0.207)	(0.150)
Sunhours	-18.029***	-6.237***	-10.845***	-7.768***
	(4.424)	(1.926)	(2.757)	(1.953)
$Snow_{t-1}$	0.253***	0.252***	-0.380***	-0.147***
	(0.085)	(0.047)	(0.052)	(0.039)
No. of obs	1374	1374	1374	1374
F-test	29.575	40.442	134.055	64.981
Adj. R^2	0.186	0.185	0.323	0.219

	After			
	Peak Load	Off-Peak Load	Quarter Peak Load	Quarter Base Load
Temp	-1.587***	-0.979***	-0.011	0.001
	(0.145)	(0.150)	(0.059)	(0.045)
Temp2	0.061***	0.037***	0.008**	0.003
	(0.006)	(0.006)	(0.003)	(0.002)
Speed	-3.211***	-2.634***	0.218**	0.201***
	(0.155)	(0.146)	(0.093)	(0.072)
Rain	-0.036	-0.142*	-0.091	-0.062
	(0.078)	(0.079)	(0.057)	(0.047)
Sunhours	-10.666***	-0.022	-0.349	0.521
	(1.259)	(0.923)	(0.738)	(0.613)
$Snow_{t-1}$	-0.148***	-0.044	-0.364***	-0.228***
	(0.048)	(0.034)	(0.034)	(0.026)
No. of obs	1232	1232	1232	1232
F-test	304.577	212.622	641.570	723.419
Adj. R^2	0.664	0.490	0.866	0.867

Focusing on the weather parameters rain, sun hours, and snow, the majority of these lose their influence on the different product prices in the time after the Nuclear Moratorium, which is against expectations. Rain loses its influence on all product prices except for its effect on the off-peak load in the spot market where the effect remains the same since the t-test across subsamples does not show any significant differences. Similarly, only the influence of sun hours on the peak load in the spot market remains the same in the time before and after the Moratorium. Sun hours have no significant influence on any other product in the second half of the period, while it is highly significant in the earlier subsample. While snow demonstrated an unclear pattern with positive effects on the prices in the spot market and negative effects on the prices in the derivative markets, this result changed in the period after the Nuclear Moratorium. In the second half of the observation period, the effect of snow is negative on all four different products. The effect on the quarterly peak load is similar in both periods since the difference test is insignificant. Only for the quarterly base load, comparing the marginal effects, evidence was found that the effect of snow is stronger after the Nuclear Moratorium.

In sum, the assumption in Hypothesis 3 cannot be supported by the results. The contrary is true. In the second subsamples, the influence of weather seems to be lower than in the first subsample, which, however, raises the question if not the influence of the weather parameter itself has increased over time than what is responsible for the strong price influence of renewable energy on prices as discussed in the literature (e.g. Nicolosi, 2010). The answer might be that these effects are not driven by the weather parameter and the production of renewables but by a combination of these, such as tight market situations.

4.4.3. The Interaction of Weather Parameters

Tight market situations occur in two cases: a) the energy demand is low, and the energy supply is high (energy oversupply) and b) the energy demand is high, and the energy supply is low (energy undersupply). Nicolosi (2010) argues that tight market situations are mainly driven by renewable energy production, especially when there is an oversupply in energy. Moreover, he found that with the increasing share of renewable energy in the system, the likelihood of such tight market situations has increased. Therefore, one might expect that such tight market situations have an impact on the electricity prices. Nicolosi (2010) analyzes the load and wind power infeed in Germany in hours with extreme negative prices (prices of at least -100 Euro/MWh). He finds that in these hours, the wind power infeed is relatively high, while the demand is low. This study uses combinations of weather parameters to analyze unfavorable combinations of weather having a similar effect on the electricity prices such as the tight market situations. For each of the two cases where tight market situations can occur, weather conditions should proxy the given market situation.

Tight market situations are always defined by a combination of supply and demand. So, in order to build proxy variables, the weather parameters need to be split into those that can serve as rough indicators of the energy demand and those which can serve as indicators for the energy production from renewable energy resources. The temperature influencing our energy usage behavior thereby serves as a rough indicator of the energy consumption. The interaction of the other weather parameter models the production of renewables, especially of solar and wind energy. For each case, high energy demand combined with low renewable energy production, and low energy demand combined with high energy production, three proxies are built. Table 5 presents an overview of the definitions of the variables.

Table 4.5: Definition of Weather Combinations

This table summarizes the defining factors for the six variables defining weather combinations, which serve as proxy variables for tight market situations and the expectation how these weather combinations will affect energy prices. The last column lists the percentage of data that fit the definition of each variable.

Variable	Expectation about effect on prices	Temperature in °C	Wind speed AND/OR Sun hours	Rain AND/OR Snow	% of data point
WC_1	+	≤ 10 or ≥ 20	≤ 10th percentile		13.7
WC_2	?	≤ 10 or ≥ 20		≥ 90th percentile	12.9
WC_3	(+)	≤ 10 or ≥ 20		≤ 10th percentile	8.3
WC_4	-	> 10 and < 20	≥ 90th percentile		7.9
WC_5	-	> 10 and < 20		≤ 10th percentile	12.7
WC_6	+	> 10 and < 20		≥ 90th percentile	6.4

WC_1, WC_2, and WC_3 are based on the assumption of high demand. Since temperature has shown a significant squared effect on the energy prices in the regressions, also for the using behavior and hence the demand, this squared relationship is expected. Thus, a lower and an upper barrier are defined where the energy consumption is expected to change. One may argue that the lower barrier is less relevant since a lower temperature and hence an increase in heating would affect other fuel prices more than the energy price itself. However, the majority of days when the average temperature is as low that heating is needed can be expected in the autumn and winter when also the electricity usage is higher than in summer when daylight is available longer. In order to ensure that days are really included when demand is high, an attempt was made to set the barriers relatively low (high). For the winter months, the author chose an average temperature of 10 degrees Celsius as a barrier. This means that the temperature in Germany in some regions lay well below this number, which hence seems to ensure that people use the heating system. As an upper barrier, 20 degrees Celsius was used. Again, this is the daily average across the country, meaning that at midday, the temperature is well above this number. To identify the days with relevant high and low temperatures, a new variable is defined which is 1 if the daily average temperature across Germany is above or equal to 20 degrees Celsius or below or equal to 10 degrees Celsius. These values for temperature were combined with weather parameters suggesting a strong or low production of solar or wind energy. Situations where the production from both renewable energy resources is high, meaning the German average across one day exceeding the 90th percentile of all observations of wind speed and sun hours, have not been visible in the past 10 years. In contrast, some observations are visible for a wind and solar production below the 10th percentile. However, since this number is relatively low (n=50) and would lead to difficulties during the analysis, this paper focuses on situations where at least one weather parameter directly affecting the production of wind or solar energy is high (low).

In this manner, WC_1 describes a situation where the temperature is relatively high or low and the production of wind or solar energy is low, too (below or equal to the 10^{th} percentile of wind or sun hours). In this situation, the supply curve would shift to the left while the demand curve would shift to the right, which is expected to result in higher prices. WC_2 combines temperatures signifying a high need of energy with a great amount of rain and snow (above or equal to the 90^{th} percentile), which would lead to a lack of solar production but might be accompanied by a high production of wind energy. The increasing amount of demand would shift the demand curve to the right. However, it remains unclear whether the supply curve would shift, too. For this reason, the influence on the energy price remains open. WC_3 describes the case with similar temperatures, but with rain and snow values equal to or below the 10^{th} percentile, and in this case, solar production is more probable. The production of wind energy remains unclear. Again, the demand curve shifts to the right and the supply curve can be expected to shift to the right, too. If the increase in supply can capture the higher demand fully, then the prices will remain the same. If the shift in the supply curve is smaller than the one in the demand curve, then the prices may increase.

WC_4, WC_5, and WC_6 are based on the assumption of low demand, meaning medium average temperatures between 10 and 20 degrees Celsius. The scenario drawn in WC_4 refers to medium temperatures but with a wind speed and/or sun hours equal to or above the 90^{th} percentile. In this case, the demand curve will remain the same, but the supply curve will shift to the right, which should lead to lower prices. WC_5 defines medium temperatures and low values for rain or snow. In this case, again, the demand curve is not expected to shift, but the supply curve will shift to the right since no precipitation will at least increase the probability of solar production. WC_6 combines medium temperatures with high values for rain and snow. Again, no shift is expected in the demand curve, but in this case, no solar production is probable. The production wind energy remain unclear. Therefore, also the influence on the energy price remains unclear. The days describes by one of the weather parameter combinations amount to 62% of the whole data set. The six variables are added to the model used for the other parts of the analysis and presented for the time period after the Nuclear Moratorium in Table 6.

Table 4.6: Weather Parameters and Weather Combinations

The results given below were generated with the following regression model: $P_t = \beta_0 + \beta_1 \times Temp_t + \beta_2 \times Temp2_t + \beta_3 \times Speed_t + \beta_4 \times Rain_t + \beta_5 \times Sunhours_t + \beta_6 \times Snow_{t-1} + \beta_7 \times WC_{1_t} + \beta_8 \times WC_{2_t} + \beta_9 \times WC_{3_t} + \beta_{10} \times WC_{4_t} + \beta_{11} \times WC_{5_t} + \beta_{12} \times WC_{6_t} + Control\ Variables_t + \varepsilon_{it}$, which was estimated for four different products. Peak and off-peak are prices of spot market products, and the other two are prices of derivatives. The coefficients for the seasons and the time trend are not reported. Below the coefficients, heteroscedasticity-consistent standard errors are reported (White 1980). ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

	Peak Load	Off-Peak Load	Quarter Peak Load	Quarter Base Load
Temp	-1.578***	-0.973***	-0.034	-0.013
	(0.146)	(0.143)	(0.056)	(0.042)
Temp2	0.061***	0.036***	0.009***	0.004*
	(0.006)	(0.005)	(0.003)	(0.002)
Speed	-3.197***	-2.590***	0.300***	0.259***
	(0.165)	(0.147)	(0.095)	(0.075)
Rain	-0.218**	-0.376***	-0.274***	-0.206***
	(0.108)	(0.139)	(0.071)	(0.058)
Sunhours	-12.518***	-1.418	-2.225***	-1.073
	(1.434)	(1.047)	(0.810)	(0.667)
$Snow_{t-1}$	-0.197***	-0.112**	-0.383***	-0.246***
	(0.055)	(0.054)	(0.037)	(0.029)
WC_1	0.563	0.999	0.020	0.130
	(0.736)	(0.773)	(0.368)	(0.291)
WC_2	1.514	2.647**	0.900	0.812*
	(1.051)	(1.203)	(0.596)	(0.464)
WC_3	2.069***	1.038**	2.246***	1.909***
	(0.767)	(0.523)	(0.417)	(0.336)
WC_4	2.245***	1.399**	0.403	0.621
	(0.847)	(0.679)	(0.562)	(0.454)
WC_5	-0.296	1.392***	2.404***	1.706***
	(0.583)	(0.403)	(0.424)	(0.340)
WC_6	2.382**	2.606**	2.675***	2.037***
	(0.953)	(1.076)	(0.781)	(0.623)

No. of obs	1232	1232	1232	1232
F-test	200.290	139.178	442.018	485.727
Adj. R^2	0.667	0.495	0.873	0.873

The results for the weather parameter itself only slightly change compared to the results for the second subsample without the six variables of weather combinations. Temperature still demonstrates a significant U-shape in the spot market, and for the derivative market, only the squared terms are significant. However, the temperature variable is negative as usual but lacks statistical significance. While rain had previously only shown a slightly significant marginal effect on the off-peak load, now the rain has a highly significant influence on all products considered. For sun hours, not only does the peak load marginal effect remain significantly negative but also the marginal effect for the effect of rain on the quarterly peak contract prices gain in significance. Its impact is also not significant negative. Snow now shows a significantly negative impact on all the different product prices, while before this result was also found for three out of the four products.

Concerning the weather combination variables, the results are partly unexpected. WC_3 and WC_6 demonstrate significantly positive effects on all products. This means that in the case of the former, the energy produced of renewables is not enough to capture the shift in the demand curve to the right. For the latter, it suggest that while the demand does not shift, only the amount of wind energy can drive a renewable energy production, which is not present, and hence, the supply curve shifts to the left and prices do increase. No solar energy is expected since a high amount of rainfall and snowfall will block the sunshine. WC_2 only has significantly positive effects on the off-peak and the quarterly base contract prices, meaning that in this cases again, the amount of wind energy produced is not able to carry the right shift of the demand curve. What is unexpected here is that this effect is only present on the peak and base load products. The off-peak products already include a time where the demand should be lower. One potential reason might that during these hours and due to an expected lower demand, some conventional power plants also produce a lower amount of energy and hence, the dependence on the wind energy is even higher than throughout the day. The effect that is visible in the quarterly base load might, therefore, also be driven by situations during off-peak load hours. An unexpected result is also be found for the influence of WC_4 in the spot market. Against the expectation of decreasing prices, as also Nicolosi (2010) suggests, medium temperatures and an increased production of renewables still lead to higher prices in the spot market. The results suggest that during either peak load or off-peak load times, the amount of renewable energy is insufficient to capture the demand. While temperatures seem to have a squared effect on the electricity prices, this might be a hint that temperature does not serve as a good indicator for demand. The significantly positive effect of WC_5 on the off-peak load and the derivative products is also unexpected. One potential reason might be that due to the merit order effect and similar to the production from renewable energy resources, other conventional power plants are driven out of the market. This situation will first reduce the prices but may also lead to difficulties later in the day. However, since this study only focuses on daily data, this is only a speculation and a deeper analysis of the reasons need to be left for future research. The evidence which is important to remember from this analysis is that the combination of weather parameters indeed affect the electricity prices in the spot and derivate markets. Moreover, the energy prices are increased by the presence of weather combinations which may serve as an indicator for tight market situations.

4.5 Conclusion

This paper analyzes the influence of different weather parameters on prices in the electricity market over a 10-year period. It focuses on the main important renewable energy resources in terms of installed capacity, namely wind and solar energy. Not only considered are the parameters that directly influence the production of these resources such as wind speed and solar hours, but also the parameters with an indirect influence on renewable energy production such as precipitation in the form of rain and snow. A differentiation between prices of ten products with different load profiles, four from the spot market and six from the derivative market, ensures a deep analysis of how the weather parameters affect the different load profiles and the different markets. The results show that weather parameters over a ten-year period have an impact especially on the prices of spot market products. With a longer time span of products, this influence reduces. The influence of weather parameters on different load profiles in the derivative market does not show any significant differences. However, in the spot market, differences between the peak load and the off-peak load as well as between the off-peak load and the base load became visible.

Splitting the ten-year period into two subsamples demonstrates a more differentiated picture. Since the renewable share has increased steadily over the ten years, a political change was used to split the sample. In March 2011, the German government decided to focus on green energy and shut down nuclear power plants over the years following. Not only does this political change split the sample into similar subsamples but also the decision to shut down nuclear power plants may accelerate the impact of renewable energies. The results show that the impact of weather parameters on various energy prices has diminished compared to the first half. Therefore, in the third step of the analysis, a combination of weather parameters which proxy the presence of tight market situations are analyzed as well as their effects on the prices. These combinations mostly increase the energy prices and are hence unfavorable for energy users.

The results of the paper emphasize that in future research, it is necessary to differentiate between the different load profiles in the spot market. Accounting for the differences in the products in the spot market may enable future research to gain deeper insights into the reaction of energy prices to different events. Moreover, the combination of different weather parameters offers a new approach to analyze the influence that external factors may have on electricity prices. Future research may improve on this method and analyze the influence of external factors on different energy product prices from a new perspective. Also, the analysis of similar effects on hourly energy data may be of advantage. While this was beyond the scope of this paper, it is open to future research to analyze the effects of weather parameters also based on hourly data. Practitioners using large amounts of energy may gain from the insights of this study and consider the weather and weather combinations in their risk management and hedging strategies. Moreover, it may enable a more precise hedging by choosing the product that most fits their needs.

4.6 References

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4.A. APPENDIX

4.A1. Results of the stationarity tests

Table A1 shows the results of the unit-roots test per time series of spot market product prices. For example, the first line shows the unit root test over the 10-year period of the base load prices. Two stationarity tests of the time series were used: the Augmented Dickey-Fuller and the Phillips-Perron. The values given are the test statistic value. ***, **, and * indicate that the test statistics are significant at the 1%, 5%, or 10% levels, respectively.

Table 4.7: Stationarity Tests

The table shows the test statistics of the Augmented Dickey-Fuller Test and the Phillips-Perron Test for different spot market product prices. ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

Product Prices	Augmented Dickey-Fuller Test	Phillips-Perron Test
Base Load	- 17.352***	-17.196***
Peak Load	-20.667***	-21.807***
Off-Peak Load	-16.037***	-15.381***
Month Peak Load	-6.604***	-6.069***

4.A2. Comparison of results between different weather parameter specifications

This sections presents the results for the different methods of modifying the weather data and the results of model (1). Next to the mixed model explained in detail in the paper, two other methods were used, and the models were re-estimated. For the first re-estimation, all weather parameters were included in the model as averages of all weather stations across the different weather stations in Germany. In the second re-estimation, all weather parameters were weighted after the installed capacity by federal state and then included in the model. The majority of coefficients neither change in their sign nor in der significance level. Also in terms of the model fit, the three different approaches lead to similar results. Therefore, the author decided to use the model using averages and weighted parameters after installed capacity. Table A2 shows the results of the different modification methods for four different product prices. Panel A shows the results for the peak load product prices, Panel B the ones for the off-peak load, Panel C the ones for the quarter peak load, and Panel D the ones for the quarter base load. The product prices of panels A and B are spot market products and the ones of the other two panels are derivative products. Only the coefficients of the weather parameters are presented.

Table 4.8: Results of the Different Weather Modifications

The results given below were generated with the following regression model: $P_t = \beta_0 + \beta_1 \times Temp_t + \beta_2 \times Temp2_t + \beta_3 \times Speed_t + \beta_4 \times Rain_t + \beta_5 \times Sunhours_t + \beta_6 \times Snow_{t-1} + Control\ Variables_t + \varepsilon_{it}$, which was estimated for different weather data modifications. The label Average states that all weather parameters are averages of German weather stations. The label Weighted states that all weather parameters are weighted by the amount of installed capacity of the belonging federal state. The label Mixed states that temperature is included as average, while the other weather parameter are weighted. Below the coefficients, heteroscedasticity-consistent standard errors are reported (White 1980). ***, **, and * indicate that coefficients are significant at the 1%, 5%, or 10% levels, respectively.

	Panel A: Peak Load			Panel B: Off-Peak Load		
	Mixed	Average	Weighted	Mixed	Average	Weighted
Temp	-1.918***	-1.958***	-1.878***	-0.995***	-0.947***	-0.967***
	(0.253)	(0.266)	(0.241)	(0.097)	(0.099)	(0.095)
Temp2	0.094***	0.094***	0.094***	0.037***	0.035***	0.037***
	(0.019)	(0.019)	(0.018)	(0.005)	(0.005)	(0.004)
Speed	-3.258***	-3.830***	-3.267***	-2.222***	-2.817***	-2.226***
	(0.237)	(0.288)	(0.237)	(0.152)	(0.189)	(0.152)
Rain	-0.421***	-0.248	-0.415***	-0.273***	-0.133	-0.273***
	(0.153)	(0.172)	(0.153)	(0.092)	(0.100)	(0.091)
Sunhours	-13.978***	-13.940***	-14.192***	-2.938**	-3.233***	-3.044**
	(2.348)	(2.252)	(2.336)	(1.185)	(1.199)	(1.186)
$Snow_{t-1}$	0.036	0.016	0.031	0.125***	0.177***	0.127***
	(0.064)	(0.086)	(0.065)	(0.032)	(0.041)	(0.032)
No. of obs	2607	2607	2607	2607	2607	2607
F-test	85.051	85.740	85.029	70.524	71.097	70.287
Adj. R^2	0.308	0.305	0.308	0.229	0.234	0.228
	Panel C: Quarter Peak Load			Panel D: Quarter Off-Peak Load		
	Mixed	Average	Weighted	Mixed	Average	Weighted
Temp	-0.198**	-0.270***	-0.195**	-0.226***	-0.246***	-0.215***
	(0.095)	(0.097)	(0.093)	(0.072)	(0.075)	(0.071)
Temp2	0.021***	0.023***	0.021***	0.015***	0.016***	0.015***
	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)
Speed	0.089	-0.007	0.087	0.158	0.048	0.156
	(0.175)	(0.215)	(0.175)	(0.134)	(0.164)	(0.134)
Rain	-0.338***	-0.343***	-0.335***	-0.265***	-0.268***	-0.264***
	(0.117)	(0.128)	(0.117)	(0.091)	(0.100)	(0.091)
Sunhours	-5.443***	-5.754***	-5.483***	-3.443***	-3.765***	-3.474***
	(1.520)	(1.552)	(1.524)	(1.169)	(1.196)	(1.171)
$Snow_{t-1}$	-0.425***	-0.548***	-0.428***	-0.229***	-0.285***	-0.229***
	(0.036)	(0.047)	(0.036)	(0.028)	(0.038)	(0.028)
No. of obs	2607	2607	2607	2607	2607	2607
F-test	389.261	392.125	389.442	237.956	237.651	237.848
Adj. R^2	0.582	0.583	0.583	0.442	0.441	0.442