The Dynamics of Overpricing in Structured Products

Thomas Ruf*

University of British Columbia

September 22, 2011

Abstract

Issuers of structured products have great power when setting the price of their securities. Each issuer is the sole liquidity provider in the secondary market for her products, and short-selling is not possible. Using a large, high-frequency data set, we investigate the pricing dynamics of a class of structured products, bank-issued warrants, and show that issuers use their monopoly powers to extract wealth from investors. First, we find that warrants are more overpriced the harder they are to evaluate, and the fewer substitutes are available. Second, issuers are able to anticipate demand in the short term and preemptively adjust prices for warrants upwards (downwards) on days when investors are net buyers (sellers). Third, issuers decrease the amount of overpricing over the lifetime of most warrants, lowering returns for investors further. Lastly, while we find a negative relationship between issuer credit risk and overpricing, the effect is generally too small, is absent prior to the Lehman Brothers bankruptcy and does not conform to models of vulnerable options. Thus, issuers gain access to cheap financing.

JEL classification: G11, G13, G21, G33

Keywords: Structured Products; Default risk; Retail investors; Overpricing

---

*Sauder School of Business, University of British Columbia, 2053 Main Mall, Vancouver BC, Canada V6T 1Z2 (e-mail: thomas.ruf@sauder.ubc.ca). Support for this project from the Social Sciences and Humanities Research Council of Canada is gratefully acknowledged. I would like to thank Thorsten Lüdecke (Universität Karlsruhe), Andreas Comtesse and Dietmar Grün (Börse Stuttgart AG) and the staff the Deutsche Börse AG web shop for providing the data at special rates and answering my questions. I appreciate helpful comments by Gordon Alexander (MFA discussant), Oliver Boguth, Siu-Kai Choy (NFA discussant), Lorenzo Garlappi, Maurice Levi, Mikhail Simutin and Tan Wang as well as seminar participants at the Midwest Finance Association 2011 meeting, the Northern Finance Assocation 2011 meeting and the University of British Columbia.

1 Introduction

The retail market for so-called structured products (SPs) has been growing rapidly around the globe over the last 20 years.[1] Although they come in many forms, structured products exhibit a number of key commonalities. Their payoffs are combinations of several primary securities that may include options, equities, equity indices and fixed income securities. The primary clientele for structured products are small investors who cannot replicate the payoff by themselves. In addition, SPs are issued by financial institutions that stand by to redeem the securities over their lifetimes. This is typically necessary, because the issuance volume of these instruments is too small to create a continuous market unless the issuer provides liquidity. Short-selling, however, is not possible. Lastly, because structured products are traded outside of derivatives exchanges with clearinghouse, they carry the credit risk of the issuing party.

The existing empirical literature commonly finds significant overpricing relative to the primary components (Bergstresser, 2009). This is sometimes attributed to a number of features beneficial to small investors, for instance small spreads (Bartram et al., 2008) and access to complex payoffs (Wilkens et al., 2003). More recently, however, a second strand of research has begun to focus on the negative aspects of SPs arguing that issuers market and sell complex products with low expected returns (Henderson and Pearson, 2010) to retail investors by exploiting their behavioral biases and lack of financial literacy (Bernard et al., 2009). Recent articles in the financial press provide ample evidence that some of the risks involved in structured products are ill understood by small investors[2]. In particular, the bankruptcy of Lehman Brothers caused unexpected losses to investors of Lehman structured products that were marketed as being safe[3].

In this paper, we present convincing evidence consistent with the more pessimistic view on SPs. We find that issuers dynamically exploit their position as monopolistic liquidity suppliers to extract gains from retail investors that go beyond the static overpricing previously documented.

Our analysis is based on a very large dataset of high-frequency trade and quote data of German bank-issued warrants. These warrants are the most basic SP because their

[1]In line with the existing literature, this study focuses on publicly available structured products designed and marketed to retail investors as opposed to products that banks tailor individually to the needs of large investors (e.g. over-the-counter swaps). Bergstresser (2009) refers to them as structured notes. They were developed in the U.S. in the late 1980s and early 1990s (Jarrow and O'Hara, 1989; Chen and Kensinger, 1990) and have spread to Europe, in particular Germany (Wilkens et al., 2003). More recently, they are experiencing rapid growth in Asian markets.

[2]Wall Street Journal, May 28th, 2009, 'Twice Shy On Structured Products?'

[3]Wall Street Journal, October 27th, 2009, 'FSA to Clean Up Structured-Products Market'

payoff is simply that of an option[4]. We think that the insights that we gain from looking at warrants apply equally to more complex structured products, because they share most, and perhaps even all institutional features with bank-issued warrants in countries where both exist. In fact, they typically trade in the same segment of exchanges and many issuers of one type of instrument are active participants in the issuance of the other type of instrument as well. In addition, results based on warrants are not confounded by effects that arise from bundling several securities into one. A further advantage is the ease with which we can compare and match them to options on regular derivatives exchanges.

First, we investigate which types of warrants retail investors trade and how their preference affects overpricing. We document that retail investors, compared with professional investors, have a preference for far out-of-the-money (OTM) warrants offering high leverage as well as some far in-the-money (ITM) warrants. We argue that far OTM warrants are the most overpriced because unsophisticated investors find them difficult to evaluate, and no alternative instrument is available to them. Among the far ITM warrants, only puts are significantly overpriced because investors have few substitutes for short positions.

Second, we explore how issuers adjust prices facing demand in the secondary market. In particular, can issuers anticipate demand and exploit the liquidity needs of investors? Or do prices increase only after a positive demand shock consistent with a demand pressure explanation in the spirit of Garleanu et al. (2009)? Our results suggest prices for warrants are systematically higher (lower) on days when investors are net buyers (sellers). We show that it is not realized demand by investors which subsequently drives prices higher; rather, issuers are able to anticipate future net demand and opportunistically adjust prices in advance. Thus, the quoted bid/ask spread is not representative of the round-trip transaction costs that most investors face and returns are systematically lower, benefitting the issuer.

Third, we explore the 'life cycle hypothesis' (Wilkens et al., 2003) which suggests a declining pattern of overpricing over the lifetime of SPs. Previous studies use relatively small datasets and the methodologies of computing premiums are relatively crude due to lack of data. We revisit this question with our expansive dataset by applying a number of more refined matching techniques. We do find some evidence of a declining premium, but

[4]It is important to clarify that bank-issued warrants are not warrants in the usual sense, i.e. warrants issued by firms on their own stock that dilute existing shares upon exercise. Rather they are option-like instruments issued by banks on equity, equity indices or any other underlying and settled in cash only. They are virtually unknown in the U.S. because options exchanges have a long history there and are readily accessible by retail investors. In many other countries, however, centralized derivatives exchanges are a relatively recent development or have been out of reach for small investors. In those countries, bank-issued warrants can fill part of this gap.

the decline depends on the warrant's moneyness and time to expiration. In particular, close-to-expiry OTM puts do not conform to the hypothesis and display an increasing premium. We argue that in both cases, the issuer acts rationally and exploits investors' demand, albeit in different ways. Further, we suggest that the large decline in premium over the lifetime of warrants that was found in some previous studies may be due to improper matching along the maturity dimension between warrants and similar options on derivatives exchanges. We suggest several ways in which to adjust this mismatch.

Last, we investigate if an increase (decrease) in issuer credit risk leads to a decrease (increase) in the price of the structured product. Since SPs are unsecured debt obligations to the issuer, in an efficient market, their prices ought to rise and fall with the credit quality of the issuer. To the best of our knowledge, we are the first to measure this effect empirically.[5] We do find a negative effect of issuer credit risk on prices in our sample, but only in the aftermath of the bankruptcy of Lehman Brothers. However, the sensitivity seems generally too small and more specific predictions of vulnerable options models (Klein, 1996) are not borne out in the data. We would for instance expect that put warrant prices should be more sensitive to credit risk than calls. If anything, we find the opposite. These results suggest that investors are essentially providing issuers with cheap financing that goes beyond the notion of credit enhancement (Chidambaran et al., 2001; Benet et al., 2006).

The remainder of the paper is organized as follows. Section 2 discusses the existing literature. Section 3 details the data used and the methodology employed. Section 4 contains the empirical analysis. Section 5 concludes.

2 Literature review and institutional background

2.1 Structured Products

While structured products (SP) may differ in many ways across borders they share a number of similarities. Common to all of them is that their payoff is a combination of several primary securities that may include options, equities, equity indices and fixed income securities. Since large, sophisticated investors can build these combinations easily by themselves, most structured products can be thought of as being exclusively designed and marketed to the wants of smaller retail investors.

[5] Recently, there have been a number of studies that discuss credit risk in the context of structured products. However, their starting point is always a model of vulnerable options from which fair values are computed. See for instance, Baule et al. (2008).

SPs are most commonly issued by financial institutions such as large investment banks who typically also act as a market maker or liquidity provider in a secondary market. However, there is anecdotal evidence (see e.g. Pratt, 1995) that the early SPs issued in the U.S. were troubled by low volumes in the secondary market. On the other hand, SP issuers in German exchanges are obligated by the exchange to provide liquidity in narrowly defined terms (see e.g. (Stu, 2010a) p.11). Among other things, issuers have to continuously provide binding quotes and keep the bid/ask spread within tight bounds. In all other ways, issuers are essentially free to set ask and offer prices.

While there may not be enough liquidity to allow for investors to trade structured products among themselves, the issuers stands by to sell and redeem its products at all times. Further, short-selling is not permitted by the issuer or by the exchange (see e.g. (Stu, 2010b), Section 49). Because SPs are traded outside of regular derivatives exchanges there is no central clearing house guaranteeing both sides of each trade and as a consequence all SPs carry the credit risk of the issuing party.

By now there exists a sizeable literature on structured products from a number of international markets. Studies for the U.S. market have discussed Primes and Scores (Jarrow and O'Hara, 1989), S&P indexed notes or SPINs (Chen and Sears, 1990) and market-index certificates of deposits or MICDs (Chen and Kensinger, 1990), foreign currency exchange warrants (Rogalski and Seward, 1991) and more recently, reverse exchangeables (Benet, Giannetti, and Pissaris, 2006) and SPARQs (Henderson and Pearson, 2010). International studies have covered markets in Switzerland (Wasserfallen and Schenk, 1996; Burth et al., 2001; Grünbichler and Wohlwend, 2005), in Australia (Brown and Davis, 2004) and Germany (Wilkens et al., 2003; Stoimenov and Wilkens, 2005; Wilkens and Stoimenov, 2007). More or less all of them report that SPs contain a premium when compared to their individual components. The premium seems to be particularly large around issuance; e.g. Horst and Veld (2008) report premia of over 25% during the first week of trading.

The size of the premium is generally hard to justify but some studies suggest beneficial properties like guaranteed liquidity (Chan and Pinder, 2000) and smaller bid/ask spreads Bartram et al. (2008) as causes. In addition, trading frictions like access to derivative markets or scalability may prevent retail investors from building these payoffs by themselves. In that sense, structured products may offer value by bundling securities, or 'packaging' (Stoimenov and Wilkens, 2005), for which investors should be willing to pay a premium. These benefits are largely absent for retail investors in the U.S. though; in particular, they already enjoy easy access to options exchanges and even more sophisticated strategies like the writing of options or spread trading can be implemented with little difficulty.

It is therefore almost surprising that only recently the literature takes a more negative view of structured products. Henderson and Pearson (2010) call SPs the 'dark side of financial innovation' because investors would be better off in the money market than buying SPARQs, the particular SP they analyze. Bernard et al. (2009) argue that issuers emphasize outcomes with high payoffs and low probabilities in their marketing materials leading retail investors to overweigh those states in their expected return calculation. Bethel and Ferrell (2007) discuss legal and policy implications of the explicit targeting of unsophisticated investors with offers of complex financial securities. In the model of Carlin (2009) issuers faced with increasing competition increase the complexity of their products to make comparisons for investors more costly and maintain overpricing. Dorn (2010) documents that investors regularly fail to identify the cheapest security among in principle identical options. According to this view, issuers market and sell complex products to investors by exploiting their lack of financial literacy and behavioral biases (Shefrin and Statman, 1985, 1993).

2.2 Bank-issued Warrants

Bank issued-warrants can be thought of as simple structured products as their payoff structure is just that of a put or a call option. Their existence is mainly due to the difficulty with which retail investors can access derivatives markets in a number of countries. They are unknown in the U.S. precisely because well-regulated and easily accessible derivatives exchanges have developed as early as the 1970s. By stark contrast, Germany did not have a derivatives exchange until 1990 (formerly called DTB, now EUREX). Even at the time of writing, according to the EUREX website (*http://www.eurex.de*), there are a mere 2 German brokers that offer retail investors access to EUREX products. The fact that warrants share most of the institutional features with structured products makes them closely related and any insight that we gain on the price dynamics of warrants should hold true for structured products as well.

Warrants enjoy the aforementioned benefits of SPs regarding liquidity and binding quotes, but they also offer some advantages over regular options. While stock options listed on the CBOE or EUREX trade in lots representing 100 shares of the underlying, warrants can be traded in much smaller increments; warrants representing one tenth of a share are common. For indices, the contrast is similarly large as EUREX contracts trade in lots of 5 while the typical ratio for warrants is 1 to 100. Being able to trade in small increments versus a rather large contract size at the option exchange again seems to be tailored to the small sums with which retail investor invest.

The literature on warrants is quite small and so far only covers markets in Europe and Australia. In line with the literature on structured products, empirical studies on bank-issued warrants find a pattern of overpricing relative to identical options from derivative exchanges that is particularly strong around issuance; see e.g. Chan and Pinder (2000) for Australia; Horst and Veld (2008) for the Netherlands; Abad and Nieto (2010) for the Spanish market.

Other studies focus on the bid/ask spread of warrants. Bartram and Fehle (2007) and Bartram, Fehle, and Shrider (2008) investigate the effects of competition and adverse selection on bid/ask spreads between German bank-issued warrants and options on the European derivatives exchange EUREX. The first study finds that the bid/ask spread for both options and warrants is lowered if a comparable instrument exists on the other market, thereby documenting that competition between these markets lowers transaction costs in both even though instruments traded in one market are not fungible in the other. The second study relates the much higher bid/ask spread for options to the potential for adverse selection that the market makers face as informed investors are more likely to be encountered on the options exchange EUREX. They find the ask price for warrants to be slightly higher than for options, but the bid price to be much higher. As a consequence the round trip costs are lower for warrants, even though the cost of entering the position and thus the value at risk is larger. The authors suggest that investors who are planning on holding the instrument for only a short period should be willing to pay more initially if they can sell it back at a better bid price relative to EUREX.

3 Description of data and methodology

We combine data from a number of sources. All datasets cover at least the period from June 2007 through May 2009. This time period contains a large fraction of the credit crisis that started in August of 2007. Therefore, the sample is well-suited to investigate the impact of credit risk on structured products.

For simplicity, we consider warrants and options on a single underlying, the German stock index DAX. The DAX consists of the 30 biggest German firms and is a performance index, i.e. dividends are assumed to be reinvested in the index. Our sample consists of 8,750 warrants with expiration dates between April 2008 and December 2012, while the options in the sample expire between June 2007 and December 2012.

To compute moneyness and deltas we acquire second-by-second tick values of the DAX index from KKMDB database at the University of Karlsruhe. Supplemental data such as issuer CDS spreads and the closing value of the German volatility index VDAX (the equivalent of the CBOE VIX) were taken from DATASTREAM.

We acquired all DAX warrant transactions taking place on Scoach from Deutsche Boerse AG, while transaction data from EUWAX comes from the KKMDB at the University Karlsruhe. Bid/ask quotes for the warrants are from Boerse Stuttgart AG. EUREX transaction data was supplied by Deutsche Boerse AG in Frankfurt; it covers all trades that took place in options on the German stock index DAX during the sample period.

3.1 Warrant data

In Germany, warrants are traded in one of two ways. Each issuer offers an OTC platform, in which investors can trade directly with the issuer via the online interface of their broker. Within seconds of the investor requesting a quote, the issuer transmits a binding offer for selling or buying back warrants which is valid for the next 2-3 seconds. Investors thus have the opportunity to quickly trade for prices known in advance. Conversations with issuers revealed that more than half of all trading in warrants and structured products takes place through this channel. In a sample of actual retail investor transactions used in Dorn (2010), over 80% of warrant trades are executed this way. The remaining trade takes place in special segments of the regular stock exchanges: in Frankfurt this segment is called Scoach; in Stuttgart it is called EUWAX (European warrants exchange); the other regional exchanges play virtually no role in the trading of these instruments.

In their study, Garleanu, Pedersen, and Poteshman (2009), henceforth GPP, make use of a particular dataset that reports daily open interest by investor group (public customers and proprietory traders) and derive the level of net demand facing market makers. The unique features of the market for warrants allow us to do something similar. Every transaction takes place with an investor on one side and the issuing bank on the other. Therefore, a transaction with a price above the mid quote likely constitutes a buy by an investor increasing the total of outstanding product; a price below the mid quote constitutes the opposite.

Unfortunately, we only observe warrants transactions that take place on the regular exchanges; data on OTC transactions with the issuer is not available. Representing less than half of all transactions, the sum of buys minus the sum of sells from the exchanges yields only a very noisy picture of the true number of warrants currently in the hands of investors; in fact, summing up buys and sells over time leads to negative numbers for numerous warrants in our sample, which is obviously not possible. Instead of investigating how the *level of demand* impacts the *price level* of warrants like GPP, we focus on investigating if *changes in net demand* have an influence on *changes in prices*.

We are confident though that over the course of a trading day, the net change in demand derived from observed transactions is a suitable proxy of the true net change in demand from all transactions. This is valid as long as the observed trades are an unbiased subsample of all trades.

Identification of transaction type

We acquired quote data for 8,750 individual warrants totalling more than 4 billion quotes over 2 years. To identify if a transaction was a buy or a sell by an investor, each trade is matched with the currently valid bid/ask quote. Unfortunately, the time stamp of the quote data is only given up the full second for all but the last day in the sample, i.e. the quote could have been updated any time during that 1 second interval. In contrast, transaction data is given with milliseconds. Thus, if the second of the quote and the transaction coincide we do not know for certain which came first, i.e. if the quote was already in place at the time of the trade, or rather if the trade came first and triggered an update of the quote from the issuer. This occurs for 8.5% of all trades. We proceed as follows: If the transaction happens in the first half-second, we assume it to having arrived before the quote, therefore the previous quote is assumed to be valid. Naturally, this is what we do with transactions that do not coincide with a quote. In the other case, we assume that the same-second quote came first and use it to evaluate the type of the trade. If this does not bring a decision because the transaction price is equal to the mid quote, we use the other quote.

If the type of the trade could not be identified up to this point, we consider the following quote as long as it occurs within 60 seconds of the transaction. If the mid quote increased we consider the transaction a buy, and a sell if otherwise. Trade for which no decision could be made are not considered in the aggregation of net demand. All in all, this algorithm fails to identify 2,506 transactions, or 0.27 percent, out of a total of 925,000 transactions for which we had quote data. We identify 54.36% of all transactions as buys and 45.37% as sells. This seems reasonable as a certain share of warrants will likely remain on the books of investors until they expire.

Construction of European warrant prices

Warrant bid/ask quotes are updated frequently over the course of the day. In most of our analysis we therefore make use of multiple quotes per day. Once every hour from 9:30CET to 17:30CET we extract the latest quote for each warrant from the data. We eliminate quotes that are older than 1 hour so as to have no overlap between measurements.

Most warrants are of American exercise type and are thus not immediately comparable to European EUREX options. Since the underlying does not distribute dividends, only put options potentially incorporate an early exercise premium (EEP). Since our study deals with warrants, many of which are longer dated, this premium is not negligible even for contracts that are at-the-money. We find the EEP to be 5 percent on average for a one-year at-the-money (ATM) option/warrant.

We proceed as follows: First, we back out the implied volatility of the American warrant ask quote via the BBSR algorithm[6] algorithm developed by Broadie and Detemple (1996). We choose the ask price because it is a frequent occurence for options in all markets that mid-quotes of far-in-the-money or close-to-expiry contracts violate the no-arbitrage bounds. We would like to retain as much of the sample as possible and not lose valid quotes because the mid-quote is too low for the Black-Scholes model. The error that we incur is small because in-the-money (ITM) contracts have very small bid/ask spreads. In a second step, we use the implied volatility (IV) of the ask quote as input into the Black Scholes formula holding all other parameters constant to get a European ask quote. We deduct the originally observed spread to back out the new bid quote. The parts of the analysis that genuinely require IV estimates as inputs are based on Black-Scholes IVs from mid quotes.

3.2 Option data

Option implied volatility functions (IVF)

As we lack access to bid/ask quotes on EUREX options (the dataset has a price tag of over EUR 10,000), we focus on transactions data. The goal is to compute the premium that a warrant demands over an identical EUREX option at a particular point in time. It is generally not very likely to find a transaction for a EUREX option in close temporal proximity to each warrant quote with identical or very similar features regarding strike, expiration date and type.

Instead we opt for a different route: Over a small time interval (e.g., a trading day or less), we collect all option trades for a given maturity and type, compute their moneyness at the time of the transaction and back out Black Scholes implied volatilities from prices;

[6]BBSR is a binomial tree algorithm that uses the Black-Scholes formula in the ultimate step of the tree as well as a two-point Richardson extrapolation.

this step is straightforward as all DAX options are of European exercise style and there are no dividends to consider. Bartram and Fehle (2007) report that the difference between bid and ask prices can be relatively large on EUREX (8-9 percent in their year 2000 data); in practice, however, trades take place within a much smaller effective bid/ask spread, which should be somewhere in the vicinity of the mid-quote that one would otherwise use.

Then we fit a 3rd degree polynomial through all IVs as functions of moneyness to get an implied volatility function (IVF) for each maturity and type, separately for each time interval. We require a minimum of 12 observations per interval to include the IVF in the sample and we save the moneyness levels of the most extreme observations that went into estimating the IVF. When matching this IVF with warrant quotes we only allow quotes whose moneyness lies within these bounds to avoid any issues resulting from extrapolation. We stop creating IVFs if the time to maturity is 5 days or less, because the tails of IVFs tend to go vertical as maturity approaches. In addition, if the range of moneyness levels observed in trades falls below a certain width, the estimate is dropped from the sample regardless of the number of observations. A too narrow moneyness range may result in unrealistic IVFs. On average, the R-squared from the fit of the polynomial is a very high 95 percent.

As for the choice of the length of the interval, we face a tradeoff between higher accuracy of the IVF and smaller number of trades as we decrease the time window over which to estimate the IVF. Even though the sample is substantially reduced as we go from daily IVFs to hourly IVFs, we still opt for hourly IVF estimates for most of the analysis given the rather volatile sample period.[7] To derive hourly IVFs, we split the trading day (from 9:00CET to 17:30CET) into 9 time intervals, the first half-hour from 9:00CET to 9:30CET (having the highest trading volume of the day), and the following 8 one-hour intervals up to 17:30CET.

Implicit in this estimation method is the assumption that the IVF stays more or less constant in terms of moneyness over the course of the respective intraday interval. Obviously, on volatile trading days this may not hold, but this is purely an issue of noise, not a systematic bias.

Premium computation

Parts of the empirical analysis require the computation of a premium of the warrant price over the price of a EUREX option with identical features. We use the mid quote from the

[7]We find that results using the less exact matching technique are generally similar, but due to the greater noise, levels of significance are somewhat reduced.

warrant and compute its moneyness at the time of the quote extraction, e.g. 10:30CET. We require an hourly estimate of the EUREX IVF with expiration in the same month as the warrant and for the same type. We match the option IVF estimated from trades taking place between e.g. 9:30CET and 10:30CET to the warrant quotes that were valid at 10:30CET (i.e. issued sometime between 9:30CET and 10:30CET). The moneyness of the warrant quote is plugged into the option IVF to compute the IV for a virtual EUREX option, which in turn is used to compute a European option price. The simplest version of the premium is the percentage difference between warrant mid quote and this artificial EUREX option price.

In each calendar month, almost all warrants in the sample expire 2-4 days prior to the EUREX expiration date depending on the issuer. We exclude warrants with other expiration dates from the analysis. However, we still face a slight time to maturity mismatch. One way to adjust for this is to use the time to maturity of the warrant instead of that of the option in the Black Scholes formula when computing an artificial option price. This implicitly assumes that the shape of the IVF does not systematically change when shifting the maturity by a few days. We know that this assumption will be violated for options close to maturity. Therefore, our empirical analysis will exclude observations with less than 20 days to maturity. We call the second premium the adjusted premium and the first one unadjusted.

We develop two more versions of the warrant premium. Implied volatilities do not only exhibit a smile shape across the strike price dimension, they also exhibit a specific term structure along the maturity dimension. For instance, during volatile times short-term options have a much higher implied volatility than long-dated options, while the opposite holds during calm periods. The reason for this tapering off is the mean-reverting behavior of volatility.

We can therefore use the information between two adjacent expiration dates to infer implied volatilities for options with expiration dates in between. In order to avoid erroneous interpolation, we require that both IVFs used in the process extend to the moneyness of the warrant for which we intend to compute a premium. The interpolated IV is simply the linearly weighted average of the IVs derived by plugging in the warrant moneyness into both IVFs. Since 2-4 days is relatively close to one of the end points, the error from using a linear fit remains small, even if the IV terms structure is strongly concave or convex.

One problem of this method is that it requires an IVF for the expiration date of the previous month. Yet the previous month IVF is no longer available close to its expiration.

Furthermore, the range of traded strikes contracts rapidly as expiration approaches. To mitigate this effect, we compute one more premium version. Here, the estimated IVF is based on the EUREX IVF with expiration in the same month as the warrant and the one closest to expiration after that. This means that we extrapolate 2-4 days outside of the two observation points. The requirement that both IVFs extend to the desired moneyness level is maintained, however.

This solves the issue of losing a large fraction of the sample on the short end, but it leads to larger losses at the long end. For instance, to compute the premium of a December 2010 warrant, the IVFs for December 2010 and the next available expiration are required. During the year 2008, this was likely December 2011 as additional expirations are only filled in much later. As EUREX options do not trade much this far into the future, the likelihood of having enough trades to estimate both IVFs on the same day are very small.

Both interpolated and extrapolated premium have higher data requirements and samples are therefore smaller. On the other hand, the first premium based on a mismatch is inaccurate and in fact biased. We use the interpolated version of the premium for a large fraction of the empirical analysis.

4 Empirical Analysis

4.1 Preference and overpricing

The comparison of warrants and options is an almost ideal laboratory set up where two distinct groups of investors trade in two separate market segments. Warrants and other structured products are most successful in countries, where retail investors are subject to high barriers to entry into derivative exchanges. Germany is such a case among developed markets, where a derivatives exchange was only established in 1990 and to the present is difficult to access by small investors. The lack of access is likely the main reason why those countries have flourishing markets for structured products. The EUWAX in Germany, for instance, is the world's largest exchange for SPs by number of products with more than 500,000 securities outstanding.[8]

In principle, there are no barriers that keep large investors from trading warrants or any other structured product. In practice, however, the design of the market place is geared towards small transactions and the needs of retail investors, because 1) bid/ask

[8]See https://www.boerse-stuttgart.de/en/marketandprices/marketandprices.html. As of February 15th, 2011, Stuttgart stock exchange listed more than 230,000 warrants, 100,000 knock-out products and over 250,000 certificates.

spreads and the stand-by liquidity are only binding up to a certain order size (EUR 3,000-10,000) and 2) the amount of units outstanding per product is generally not very large (warrants, e.g., are typically issued in batches of 1-10 million units; on the CBOE this would equal just 100-1000 index option contracts). In addition, sophisticated investors can easily replicate all payoffs more cheaply by themselves and will certainly want to avoid the overpricing and the credit risk involved.

Thus, we argue the segmentation is strong and comparing trading pattern between the two markets offers insight into the different motivations of private investors relative to institutional investors. In particular, we can see where the demand for warrants differs from the demand for options on the EUREX.

Table 1 depicts the relative frequency of transactions across different ranges of time to maturity and moneyness. We use the frequency of trades as a proxy for net demand, because the data does not allow accurate measurement of true net demand. Notable is the extremely strong concentration of EUREX option transactions close to expiration as well as at-the-money (ATM). More than 80% of all transactions happen in contracts with less than 3 months to expiration and over half of all trading occurs in a narrow 5% band around the money; there is barely any trading in in-the-money (ITM) options. In contrast, warrants transactions are much more dispersed across maturities and moneyness. Far-in-the-money and far-out-of-the-money warrants experience larger demand than comparable options. Particularly, the demand for out-of-the-money (OTM) call warrants greatly exceeds the trading activity in OTM call options. In addition, there is asymmetry in the demand for OTM call vs. OTM put warrants. More than 36% of all trades in long-term warrants happen in excess of 25% OTM; for puts this number is just 15%.

In buying warrants that are even more OTM than what option traders buy, warrant traders exhibit a greater preference for high-leverage securities paying off in states with low probability. This supports recent findings that warrant traders are motivated by speculation (Glaser and Schmitz, 2007) and entertainment (Bauer et al., 2009), rather than hedging. The activity in far-ITM warrants on the other hand is quite puzzling. Leverage is rather low and warrant unit prices are high in this region. Further, given that Glaser and Schmitz (2007) report the median holding period of warrants to be 3 days, it is hard to understand why more than one third of trading is concentrated in securities with a remaining life time in excess of 6 months.

In summary, we recognize that there are clear differences in the demand pattern between warrant and option market participants. Given these differences in demand it would be interesting to see if the warrant premium shows a pattern that reflects the pattern in demand. Does the premium differ across regions of moneyness or maturity?

Because the moneyness range of actively traded warrants declines for closer-to-expiration contracts, we use the (absolute of the) warrant's delta rather than its raw moneyness to make the pattern in overpricing more comparable across different maturities. When computing delta we replace the warrant's IV with the IV of the matching option. Otherwise the degree of overpricing of the warrant would directly impact its delta. To further avoid influence of outliers we first cut off the top and bottom 1% of premiums, then we cut off the lowest and largest 1% delta values for each issuer.

Figure 1 shows the median premium as a function of the warrant's delta for the 6 largest issuers in the sample based on quote data, separately for puts and calls. The sample is split into the maturity bins that correspond to the maturity bins in Table 1. All graphs exhibit the same striking pattern where low-$|\Delta|$, far-OTM warrants command much higher premiums than ATM or ITM contracts. OTM calls are generally more overpriced than puts by the same issuer with the exception of some issuers over some moneyness regions for close-to-expiration warrants. This pattern corresponds to the asymmetry of demand for OTM contracts in Table 1.

One possible explanation is that retail investors find it much harder to determine the fair price of an OTM warrant, which consists of time value only, relative to ITM warrants, which are mostly intrinsic value. Carlin (2009) suggests an equilibrium model in which more complex products can be overpriced more heavily. If we consider OTM warrants as being more complex than ITM warrants, our finding is in line with his model.

Alternatively, investors with different beliefs may choose warrants with different degrees of moneyness and thus leverage. It seems intuitive that a very optimistic investor would choose warrants with higher leverage anticipating higher returns relative to a less optimistic investor. The issuer is then able to extract some portion of the consumer surplus (with regards to the beliefs of the investor) by charging a relatively higher premium.

If the demand pattern in Table 1 drives prices, one might have expected to see some overpricing for far-ITM warrants as well. We notice a kink in the premium for far-ITM puts but none for calls. This suggests that the elasticity of demand differs in those areas. The charged premium and the demand for warrants by investors are equilibrium outcomes. One possible explanation is that issuers exploit the lack of good alternatives for investors who would like to express negative views with low leverage securities, while there are plenty of instruments for going long with low leverage.[9] Hence, issuers can

[9]For regulatory and historical reasons, retail investors cannot short stocks in their accounts at Germany-based brokerages. One would have to open an account with a foreign broker. Also, during the sample period there were no so-called inverse ETFs listed on the German market.

charge a premium for ITM puts, but cannot demand a premium for ITM calls. Thus, this section provides some basic evidence for the hypothesis that issuers take advantage of investors' demand for certain payoffs through overpricing. We turn to a more systematic investigation of the dynamics of the overpricing in the following section.

4.2 Demand pressure vs Demand anticipation

Issuers of structured products in Europe maintain binding quotes for all of their products and stand by to buy and sell if investors want to trade. From conversations with issuers, we understand that it is literally unheard of that a trade is executed between two private investors. Without the issuer there would be no liquidity. The flip side of this coin is that the issuer determines the price and investors have no choice but to accept that price if they want to trade.

Given this monopoly power, the issuer has some incentive to skew the price in his favor. One way to extract profits from trading in excess of the clearly defined bid/ask spread would be to offer higher than usual prices on days when investors predominantly buy and offer lower than usual prices on days investors are mainly selling. This requires some degree of predictability for the change in net demand, i.e. the order flow of structured products. As we will show below, we find evidence for such predictability. The frequency at which order flows change are quite high and depend mostly on the returns of the underlying in the immediate past (yesterday's return and the overnight return) and as a consequence, predictability as well as price impacts are also limited to very short horizons.

Our time frame is thus distinctively different from the literature on option demand pressure (Bollen and Whaley, 2004; Garleanu, Pedersen, and Poteshman, 2009). Both studies relate private investor demand to relative prices of options, i.e. the skew of the option smile, at a monthly frequency. Similarly, Amin et al. (2004) condition on large returns over the past 60 days to explain changes in the implied volatility of options. Lemmon and Ni (2010) combine those findings and posit that market sentiment along with lagged market returns drive option demand which in turn impacts option prices. Their analysis is also at the monthly frequency.

Our analysis is similar to Lemmon and Ni (2010) in that we show that returns drive demand which in turn drives warrant prices.[10] However, the channel that we propose is quite different from the limits-to-arbitrage explanation suggested by Bollen and Whaley (2004) (BW) and formalized by Garleanu et al. (2009) (GPP).

[10]Since our analysis is at the daily or even intra-daily frequency we are precluded from using measures of sentiment.

BW argue that market makers in the options market face limits to arbitrage because their access to capital and thus, their tolerance for intermediate losses is limited. In this case a growing net position causes increasing 'hedging costs and/or volatility-risk exposure' for market makers. Consequently, market makers are willing to supply additional options only at increasingly higher prices. For instance, institutional investors have a large demand for index puts for which there is no natural counter-party in the market. Market makers absorb this demand imbalance at a premium, which according to BW can partially explain the volatility smile observed in index options.

GPP suggest discontinuous trading, price jumps and/or stochastic volatility as causes for the inability of market makers to hedge perfectly and derive analytically how demand pressure increases option prices in the presence of these frictions.

By contrast, we suggest that issuers use their position and knowledge of future order flow to adjust prices at a relatively high frequency to extract additional profits from investors. This is not to say that issuers in the warrants market could not be subject to demand pressures at the monthly frequency as well. However, with our quite short time series we must leave this question to future research.

Finally, we should point that e.g. Lemmon and Ni (2010) find sentiment and market returns to have strong effects on equity options but less so on index options because small investors account for only 3 percent of trading in index options, but 18 percent in stock options in the U.S. options market. In our case, the separation between small and large investors happens already with the choice of exchange. As we pointed out earlier, both index and stock warrants are overwhelmingly the domain of retail investors trading on EUWAX and Scoach, while large investors trade in the derivatives exchange EUREX.

Aggregate Demand

We start by investigating the dynamics of daily aggregate demand for warrants, separated by type of warrant and type of transaction. First, we allow contemporaneous variables to explain demand. In a second step, we predict aggregate demand using only variables that are known prior to the arrival of demand.

Using a rare dataset of actual transactions by retail investors in the German warrants market, Glaser and Schmitz (2007) study the motives of retail warrant investors and find that hedging considerations play virtually no role as the median holding period of both put and call index warrants is a remarkably short 3 days. This indicates that most retail investors use warrants to speculate on very short-term movements in the market. When partitioning sells into profitable vs. losing trades, they find that investors tend to hold warrants twice as long when they are trading at a loss vs. at a gain: median holding periods are 4 vs. 2 days, and average holding periods are 24 vs. 12 days. This shows that warrant traders are also affected by the disposition effect documented for stocks by Shefrin and Statman (1985) and Odean (1998).

These observations make it evident that contemporaneous and immediate past returns will play a prominent role in determining selling decisions in particular. The buyer of a index call warrant appears to be very likely to sell within 1 or 2 days if he experiences a positive return over this period. Likewise, the buyer of a index put will sell within the next day or two if the market declines over that period. Further, since the holding period is quite short regardless of gains, we think that recent buying activity should foretell selling activity as well.

First, we regress daily aggregate demand for warrants on lagged demand and lagged and contemporaneous returns. Returns are measured from yesterday's closing of the regular market to today's closing (1730CET). We measure today's demand as aggregate Euro volume per category (Calls vs. puts, buys vs. sells). Warrant trading continues until 2200CET each day, but at much lower volumes than during regular trading hours. We would like to measure returns and order flow over identical time periods, therefore we assign any trading activity that occurs after the official closing to the next trading day. Lagged demand is defined as the sum of daily demand per category over the preceding 3 trading days. In addition, we include total unsigned trading volume over the previous 2 weeks as well as the lagged change and the level in market volatility as control variables. Total volume should help us to distinguish the impact of generally higher trading activity from short-term buying and selling pressure. Including volatility variables will help to measure the effect of market returns on demand more precisely because of the well-known negative correlation between returns and volatility.

Explanatory power in Table 2 is very high. In line with our predictions we find a high propensity to sell after positive returns for calls and after negative returns for puts. Lagged buys and sells positively impact today's buys and sells. Somewhat surprising, both puts and calls are more likely to be bought following negative returns. Total lagged unsigned demand is strongly significant and positive indicating more trading activity in the present given higher trading activity in the recent past. Interestingly, the coefficients on volatility levels and changes are of opposite sign. Times of higher volatility are associated with generally lower trading volumes, while a positive shock to volatility during the previous day causes more selling activity today. Presumably, an increase in volatility makes all warrants worth more and thus the chances of a position being profitable increase, leading to faster selling by investors.

In order to avoid undue influence from extreme returns over the rather volatile sample period, we repeat the analysis with all return variables winsorized at 3 per cent. Results are qualitatively the same, albeit R-squared are slightly lower.

Having found a contemporaneous connection between demand and returns, we turn our attention to the predictive power of lagged demand and returns with regards to future demand. This is important because we would like to know if issuers can anticipate order flows, for instance at the beginning of a trading day. If this is the case then issuers are in a position to adjust prices to take advantage of investors' demand before it arrives.

To this end, we will form expectations of intraday demand pressure that occurs between 930CET and 1730CET. As explanatory variables we use data that is known to the issuers at 930CET, i.e. yesterday's return and net demand as well as return and demand occurring between 1730CET yesterday and 930CET today. We call this the overnight return and the overnight demand.

Compared to the results earlier R-squared in Table 3 are naturally lower but still very high. The results from the previous regression seem to carry through with regards to the signs and importance of returns on demand. As a robustness check, we repeat the analysis with return variabels winsorized at 3 percent and find results essentially unchanged.

It is remarkable that simply by using returns and order flows from the immediate past, we can explain over 60 percent of total variation in demand for puts over the course of the day. Calls are somewhat more difficult to predict, and we might thus expect that prices are more responsive to demand for puts than for calls.

We are aware that our predicted demand is an in-sample prediction. We choose this path because of the relatively short sample period and the fact that we only observe a subset of true demand, both of which might make out-of-sample predictions extremely noisy. Further, all we have to assume for this prediction to be attainable by issuers at the time is that coefficients of lagged demand and return stay constant over time. We have no reason to believe that e.g. investors switch their propensity to sell calls after markets went up from one year to the next.

The impact of demand on warrant prices

We now turn to investigating the connection between warrant prices and contemporaneous demand in two steps. First, we check if demand and prices are correlated contemporaneously. Second, we want to know if prices adjust before demand occurs or after.

One possible methodology would be similar to what existing literature has done: match each warrant with an option individually and estimate the relative premium of warrants over options. We follow this path in all other parts of the empirical analysis but for the effect of demand we choose a different route for several reasons.

First, our study is at a disadvantage to others because we do not have bid/ask quotes of options, only transactions data. We computed IVFs for options based on transactions but found the imputed option prices too noisy to be of use even when pooling transaction over the entire trading day. We would require hourly IVFs.

Secondly, assume we were to observe bid/ask quotes for options and were thus able to compute reliable estimates for warrant premiums. We try to identify the impact of warrant demand on warrant prices relative to option prices, which according to the findings of GPP also face price impact from demand pressure. Unlike GPP, we do not have access to a dataset that shows outstanding net option positions by investor group. We therefore have no way of knowing who bought and who sold a particular option contract as not all trades have to occur between a market maker and an investor. Then, given estimated net demand for options we would have to estimate the impact of option demand on the premium at the same time that we estimate the impact of warrant demand. This procedure appears to be dependent on too many moving parts that we know too little about.

Instead we opt for a different route that is able to circumvent our data limitations. We use option implied skewness proposed by Bakshi, Kapadia, and Madan (2003) (BKM) as our measure of choice. BKM use prices of OTM puts and calls to derive non-parametric moments of the option-implied expectations of the return distribution of the underlying. Relatively higher prices in some range of moneyness imply that investors assign a higher probability to the underlying being in that range at maturity. Intuitively, if prices of OTM puts are higher than prices of equally OTM calls, investors assign higher probabilities to negative outcomes, which leads to negative implied skewness. Additional details of constructing BKM measures as well as minimum number of options required are discussed in Dennis and Mayhew (2002).

Given the large quote dataset we have too many rather than too few warrant quotes available at each point in time. We have seen in Figure 1 that far-OTM warrants are subject to extreme overpricing. To guard against the results being driven by the large premia in low moneyness warrants we exclude put warrants that are more than 20% OTM and call warrants that are more than 25% OTM. The reason for the slight asymmetry lies in the weighting scheme of the BKM skewness which is based on the log of moneyness.

We compute BKM skewness for each warrant chain of each issuer once every hour. A warrant chain consists of all warrants by the same issuer that have a common expiration date. To compute skewness at e.g. 1730CET, we select the last mid quote of each OTM warrant issued prior to this time. If the quote is older than an hour it is discarded. Because the derivation of the BKM measures is based on European-type options, we transform quotes of American-type warrants into European-type prices via the binomial model described earlier.

In Table 4, we regress *daily changes in skewness* (1730CET to 1730CET) on several versions of net demand for puts and calls that are measured over the same time period. We include the lagged level of skewness and yesterday's return (split up into up and down part) as controls.

We find that total net demand for both calls and puts enters highly significantly. The signs of the coefficients indicate that demand is positively correlated with warrant prices: higher demand for calls coincides with higher skewness, which means that the right tail, i.e. calls, becomes more expensive than the left tail; higher demand for puts coincides with lower skewness, which means that the left tail becomes more expensive relative to the right tail. The issuer-specific net demands by itself have the same effect, albeit weaker. Because issuer-specific variables generally turn out to be quite weak, we will omit them from the following analysis. Using net demand by expiration instead of total demand has again similar effects but is also weaker. If we use it in addition to total demand, only the put demand remains significant.

In summary, we find that, on a daily horizon, demand is positively related to contemporaneous changes in skewness. The question is: Does demand cause prices to rise, in which case we would be in the world of Garleanu et al. (2009)? Or do prices adjust preemptively to expected demand? This would support the case for opportunistic price setting by issuing banks.

To distinguish between these two explanations, we compute the overnight change in skewness (measured from 1730CET of the previous day to 930CET of the next day). We choose 930CET, because the regular market opens at 900CET and we want to make sure that orders entered overnight are not counted towards the intraday demand.

We then split daily demand into two parts. Overnight demand consists of all transactions that occurred between 1730CET and 930CET, while intraday demand consists of all transactions that occur after 930CET until that day's closing at 1730CET. Table 5 shows results for both realized intraday demand as well as predicted demand. The latter is based on the fitted values from the regressions on total demand shown in Table 3 and identical regressions for demand by expiration not reported.

Note from column (1) in Table 5 that lagged and overnight demand alone only explain a small part of skewness changes, as some controls (not shown) are already highly significant. Further their signs are different from the previous table. In columns (2a-c) actual net demands that occur during the day after 930CET have been added. Explanatory power of the models is still relatively low and adds at most 3.4 percent over column (1). Compare that to columns (3a-c) where actual demand is replaced by predicted demand. Significances are generally higher and the explanatory power is raised substantially. With one exception, all predicted net demands enter with the right sign and are significant.

The results lend strong support to the view that price changes preempt demand. Future expected net demand for calls is met by increases in skewness, i.e. higher call prices, while future expected net demand for puts is met by a decrease in skewness, which indicates higher put prices relative to calls. Thus, issuers systematically short-change investors by overpricing warrants that are in net positive demand over the following hours, while underpricing warrants that will be redeemed on a net basis.

4.3 The life cycle hypothesis

Wilkens, Erner, and Röder (2003) analyze two types of SPs in the German market, reverse convertibles and discount certificates, and find that the overpricing present in these products declines as expiration comes closer, which they term the 'life cycle hypothesis' (LCH). Some subsequent studies find supporting evidence for a number of other structured products (Grünbichler and Wohlwend (2005), Stoimenov and Wilkens (2005), and Entrop, Scholz, and Wilkens (2009)), but Abad and Nieto (2010) fail to find such a pattern for warrants in the Spanish market. Wilkens and Stoimenov (2007) argue against using the LCH for products with knock-out feature[11] because expiration is a random event in that case.

The idea behind LCH is as follows: At issuance, most SPs are in possession of the issuer (although active marketing of upcoming IPOs is meant to place a portion of the product with investors ahead of issuance). Over time, as investors buy the product, the chances of some of them wanting to redeem securities from the issuer increase. Since bid and ask prices are bound together rather closely (by exchange regulation), an asking price far above fair value would imply a bid price that is also too high. Thus, by keeping the bid price too high for long, the issuer risks being sold back some of her product at inflated prices. Wilkens et al. (2003) argue that investor buying activity should generally decline as maturity comes closer, while selling activity will likely increase. To optimally profit

[11] A knock-out feature causes the instrument to expire worthless as soon as the underlying hits a pre-determined level for the first time.

from the life cycle of demand, the issuers should gradually reduce the overpricing over the life time of the product.

Neither Wilkens et al. (2003) nor any of the subsequent studies are able to test this hypothesis directly because of the lack of demand data. In this study, we only have access to a fraction of total demand. Thus, estimates of net demand over periods longer than a few days are likely too noisy. Nevertheless, using daily net demand, we documented in Section 4.2 how issuers adjust prices on a daily basis to exploit high-frequency changes in net demand. It would not be surprising to find such a pattern at longer horizons as well. However, the unavailability of OTC transaction data on warrants and other structured products makes testing this hypothesis directly rather difficult.

In the following, we revert to proxying for the effect of life time net demand by using the time to maturity just like previous studies did. Where we differ from previous research, however, is how we compute the warrant premium. Wilkens et al. (2003) and Stoimenov and Wilkens (2005) use a simple hierarchical matching, which with slight deviations is employed by related studies as well. For each transaction (or quote) of a structured product, all transactions (quotes) of EUREX options are considered that minimize the difference in strike prices; in the next step, among all matches of the first step, the difference in time to maturity in minimized. In a third step, the difference in time stamps is either minimized or used as a filter criterion. Wilkens et al. (2003) are able to match strike prices quite well, but generally match EUREX options with a maturity half as long as that of the SP. Similarly, Stoimenov and Wilkens (2005) report average deviations in maturities of 5-7 months.

To evaluate the effect of maturity on the premium, it seems crucial to compute premia from options that are very close precisely in the dimension of maturity. Section 3.2 describes how premia are constructed for the purpose of this study. In contrast to previous studies, we match warrant quotes with implied volatility functions constructed from option trades that take place in the same hour using options that expire in the same month as the warrant. Further, we impose a minimum requirement on the number of options, the range of moneyness of the option transactions and we require that the moneyness of the warrant at the time of the quote is covered by that range. Daily averages of premia are calculated and admitted if there are more than 2 premiums observed for a warrant on a given day.

In the absence of option quotes (which could be easily matched one-to-one with warrant quotes), we feel this is a robust way to compute premia. As mentioned in Section 3.2, the method is not free of bias because issuers choose expiration dates in a systematic fashion:

most warrants expire between 2 and 4 days prior to the option expiration date.[12] To see if this mismatch impacts any conclusions drawn with regards to the life cycle hypothesis, we compare the raw unadjusted premium with the three other versions of the warrant premium developed in Section 3.2.

Table 6 depicts the results of a regression of warrant premium on the time to maturity TTM (in years). The sample data is split by warrant type and further into 3 maturity bins to see if the effect changes over the life time of the warrant. In addition within each subsample, the coefficient of TTM is allowed to vary depending on the delta of the warrant. Panels A-D repeat the analysis using a different version of the warrant premium. To conserve space, we omit the coefficients of the control variables that are included. Because we explicitly use them in the next section as well, we will discuss them there in detail. Standard errors of all coefficients are based on two-way clustering by date and issuer following Thompson (2009).

The difference between the unadjusted premium and the remaining three versions is quite striking. Practically all coefficients in Panel A are highly significant and positive, indicating a premium that decreases as maturity comes closer. The fact that t-statistics reach levels of 20 and more, should be reason for concern. This is clearly the manifestation of the mismatch that we described in much detail above. If the warrant expires 2-4 days earlier its time value sinks at a increasing rate, ahead of the time value of the option. This is what the TTM coefficient is picking up. Thus, it appears as if the overpricing is declining strongly.

By contrast, Panels B-D use warrant premia that are adjusted for this mismatch in one of three ways. Even though the adjustment used in Panel B is quite crude, its results are already much in line with the more data-intensive versions using intrapolation (Panel C) or extrapolation (Panel D). Our preferred method is the intrapolated premium, because the sample size is not much smaller than for the first two methods and the long-term maturity bin contains several times more observations than in the extrapolated case. All three panels show similar results across moneyness and maturity. It appears that the premia of OTM calls and more significantly, OTM puts tend to appreciate during the last 3 months of their lives at a rate of 2 and 4% annually. ITM warrants as well as OTM warrants with more than 3 months till expiration generally experience a decline in premium on the order of 2% per year.

The reversal in premium decline for close-to-maturity OTM warrants is somewhat

[12]We randomly compared expiration dates of warrants and other structured products in the German market and found that they cluster at precisely the same dates.

puzzling. We can think of 2 potential explanations. The first is based on the disposition effect, i.e. behavioral. Glaser and Schmitz (2007) find that warrant investors are prone to this effect. The second is based on the transaction cost structure that prevails in most retail financial markets.

First, in a Black-Scholes framework, the change in option price with respect to time as a fraction of the option price, i.e. θ_t/P_t, is stronger for OTM options than for ITM options. This difference in decline becomes much wider as maturity approaches. This intuitively makes sense, as ITM options have some intrinsic value, which makes up an increasing part of the total option price, while OTM options are time value only. To give one stylized example, assume $\sigma = .25$, $r_f = 0$, $S = 100$, $K_1 = 107$ and $K_2 = 94$. At one year to maturity, the daily loss of time value is 0.31% (0.25%) for a call with strike K_1 (K_2), but at two weeks to maturity the daily rate of price decline has increased to 11.0% (3.6%).

On average, it seems plausible then that contracts that are close to maturity and far-OTM have the highest likelihood of being a losing position to investors. If the current warrant holders resist redeeming those warrants because they have an aversion to realize losses, the issuer is free to charge higher premiums to newly arriving investors without having to fear large redemptions at high premiums.

The second explanation is based on the fact that transaction costs are typically a percentage of transaction volume above some minimum amount. An investor currently holding warrants has the choice between holding on until expiration, at which point he does not incur any transaction costs[13], or to sell prior to maturity incurring the cost. As in the previous explanation, on average, OTM warrants close to maturity are the most likely to be worth less than when they were originally purchased. Thus, the minimum transaction cost becomes large as a percentage of the transaction amount and can tilt the investor towards holding on to the warrants until maturity. This again leads to less selling pressure and the opportunity for the issuer to extract higher premiums from new investors.[14]

How do our results relate to other classes of SPs? Based on our findings we suggest to divide SPs into two categories, one in which time value plays a subordinate role vs. one where the price is essentially all time value. SPs with principles that are paid back at expiration fall into the first category, i.e. discount certificates, as do ITM warrants. In line with previous research mentioned at the beginning of this section, these products

[13]At maturity, contracts are cash-settled and if in the money, the value is credited to the investor's account without any additional fees.

[14]We plan on formalizing both channels in a simple model in future versions of the paper.

exhibit a declining pattern in overpricing.

In contrast, far-OTM warrants and SPs based on exotic options fall into the second category. In particular if they are close to the knock-out barrier or far from the knock-in barrier etc., most of the price consists of time value, i.e. of moving into the money. Again, in line with previous research mentioned above (Wilkens and Stoimenov (2007), Abad and Nieto (2010)), our findings suggest that the degree of overpricing for these products is not driven by the LCH.

4.4 The effect of credit risk

Credit risk has been a long overlooked issue in the literature on structured products, at least empirically. Structured products in general, and warrants in particular, are unsecured debt obligations by the issuing bank and as such they are likely to receive a low recovery value in the case of bankruptcy. Most studies, however, ignore credit risk in their analysis. A common misconception is expressed in Bartram and Fehle (2007): 'the issuer is obligated ... to hedge all options sold. Thus, bank-issued options [i.e. warrants] are generally considered to be free of default risk.' Some studies explicitly incorporate default risk into the fair value computation. Stoimenov and Wilkens (2005) and Wilkens and Stoimenov (2007) use discount rates derived from issuer bonds instead of a default free rate to discount cash flows. Baule, Entrop, and Wilkens (2008) explicitly starts in the vulnerable options framework of Hull and White (1995) and Klein (1996). These studies decrease the fair value of structured products, but do not investigate if observed prices react to changes in credit risk.

Until recently, the default risk of large banks has not been a major concern. The credit crisis that started in 2007 will likely have changed that perception. German retail investors have become acutely aware of the risk involved in structured products after the collapse of Lehman Brothers caused a total loss in high-yield Lehman certificates. These were previously thought of and marketed to small investors as riskless[15]. Similar products underwritten by Lehman caused small investors severe losses in the U.S.[16], in Great Britain[17] and in Hong Kong[18]. Due to recent worries about the default of sovereign debt in the Eurozone and the consequences this may have for European banks in particular, we are seeing yet another spike in the CDS spreads for European commercial banks, many of

[15]New York Times, October 14th, 2008, 'Lehmans Certificates Proved Risky in Germany'

[16]Wall Street Journal, December 5th, 2009, 'Investor Wins Lehman Note Arbitration'

[17]Wall Street Journal, October 27th, 2009, 'FSA to Clean Up Structured-Products Market'

[18]Wall Street Journal, May 31st, 2010, 'The Fine Print is Enlarged, But Will Investors Read It?'

which are active participants in the issuance of warrants and structured products. Issuer default risk therefore seems to remain an important topic to investors.

Figure 2 shows the evolution of unsecured 1-year CDS premiums for the issuers in our sample that do have traded CDS contracts. For Citigroup we use the senior secured contract, because the unsecured contract contains too many stale quotes. Issuer default risk is clearly non-negligible for a large fraction of the time period that is covered by our sample. It seems therefore worthwhile to ask if the market for structured products (and warrants) is efficient in the sense that observed prices incorporate the effects of issuer credit risk.

It is entirely possible that retail investors are unable to properly incorporate credit risk in their demand function for a particular product and, as a consequence, issuers enjoy a form of cheap borrowing from unknowing retail clients. The results of Baule, Entrop, and Wilkens (2008) could be seen as supportive of this view. Based on 2004 data they find that average overpricing has declined relative to the data of Wilkens, Erner, and Röder (2003) from the year 2000, but that imputed credit risk constitutes a larger share of the total premium in their sample.

Instead of computing fair values of warrants that implicitly incorporate credit risk, we take a different route by investigating if observed premiums are sensitive to credit risk, i.e. if the overpricing of warrants diminishes if issuer credit risk increases. Credit risk is measured as last trading day's premium on a 1-year CDS for unsecured debt of the issuer (ScaledCDS). We describe the construction of premiums of warrants over options in Section 3.2 of the paper. In our analyis of the effect of credit risk and other factors on the individual warrant premium, we focus on the interpolated version of the warrant premium because it strikes a good balance between sample size and accuracy.

Warrants in the sample can differ along several dimensions: issuer, expiration date, strike, and type. Due to this multi-dimensionality we are careful to include a number of control variables. Issuer dummies are a natural candidate, because they take care of persistent issuer fixed effects. Previous studies typically find strong differences in the average premium between issuers and our study is no exception. Presumably, issuers differ by their fixed costs and margins as well as by bid/ask spreads which may affect premia. We also include the warrant's $|\Delta|$ as well as Δ^2 (computed with the IV of the option) motivated by the observation that the warrant premium decreases with delta in a convex fashion (as documentes in Figure 1). We exclude warrants with extreme levels of moneyness. Specifically, for each issuer, we cut off the 5% of warrants with the lowest and the highest values of delta. For the remaining warrants, we get an approximate range of $0.1 \leq |\Delta| \leq 0.8$.

Motivated by Bartram, Fehle, and Shrider (2008), we include 2 competition dummies. D_{Comp} is set to one on a given day for a particular warrant, if at least another warrant exists that expires in the same month with the same strike and type. D_{EUREX} is set to one for a particular warrant, if a EUREX option with identical features existed on a given day. Time to maturity (TTM) is meant to catch a general change in premium over the life time of the warrant. Lastly, LagWarVol is the warrant-specific trailing total volume (buys plus sells) over the previous 14 days. A large fraction of warrants outstanding do not trade at all or only very sparsely, while the most traded warrants achieve daily turnover in excess of one million EUR. It is conceivable that premia differ between warrants with low and high volume.

Table 7 contains the basic result with regards to the effect of credit risk on warrant premium based on the full sample. Results are reported separately by warrant type, i.e. put vs. call and by the method of computing premiums, in this case the adjusted, the interpolated and the extrapolated version. We exclude the unadjusted premium from the remaining analysis because of the biased results discovered in the previous section with regards to time to maturity.

Since Figure 2 shows that our sample contains a relatively calm early period and a period of heightened credit fears caused by the sudden collapse of Lehman Brothers, it seems plausible that credit risk did not play a role in the first period because investors in general and retail investors in particular were not concerned with the possibilty of bank failures. Table 8 presents those results. As a minor difference to the previous table, the variable for credit risk is split up into 4 parts to allow different effects of credit risk on premium depending on the delta of the warrant.

In both tables, R-squared are generally quite high at between $40-50$ percent. Credit risk has a strongly significant negative effect on the warrant premium for the full sample shown in Table 7. The sample split in Table 8 reveals, however, that the effect is entirely due to the post-Lehman period. It is possible that the early period suffers from a lack of signal in the credit risk variable rather than lacking attention by investors.

With regards to the control variables, the two delta terms pick up the declining and convex pattern visible in Figure 1 and the issuer dummies pick up differences in the level of overpricing that were also visible in Figure 1. The size of the dummy coefficients is of no importance to the analysis.

There seems to be some evidence that the existence of identical warrants by other issuers decreases the extent of the overpricing. Thus, competition does have an effect on prices. The result is much weaker for competition from an identical option listed on EUREX, which supports the idea of strong segmentation between the two markets. The level of volatility does have a strongly negative effect on premia but again, only after Lehman. The complex pattern of the TTM coefficient was the topic of the previous section, thus we will disregard it here. Lastly, lagged warrant turnover is consistently negative and significant. It is also economically important for high-volume warrants than can have around 1M EUR in daily turnover. Such a warrant may experience a decline in premium of around 2% relative to low-volume or no-volume warrants.

The correlation of payoff and default

The coefficient on credit risk in the previous tables suggested that there is an effect of issuer default risk on overpricing, at least post-Lehman, but is its size reasonable? Because of the scaling we applied, a coefficient of -1 indicates that premia decline by 1% for each additional 100 bp in issuer credit risk. This is what a naive model of default risk would predict as coefficient for a vulnerable claim with one year to maturity. The observed values lie around -0.25, thus far away from the prediction.

Models of vulnerable options (Klein (1996)) suggest that options should be impacted to different degrees depending on the correlation between default risk and option payoff. Consider the most extreme case where the issuer was to issue warrants on its own stock price. An OTM call should not be affected by the issuer default risk at all, because all states of the world in which the issuer defaults are states in which the call payoff is zero anyways. An OTM put, on the other hand, potentially pays the most in states where the issuer share price goes to zero, which would likely coincide with bankruptcy. Being an unsecured debt obligation, the warrant would lose its value in line with other debt instruments of equal seniority. Therefore, moneyness should matter for the pricing impact of credit risk on warrants.

In our case, the warrants are issued on the DAX, the German headline market index. It is not difficult to assume that the default risk of issuers, many of which German banks, is negatively related to market returns, in particular, because the time period was already termed a banking crisis at the time. Thus, DAX calls pay out in states where the market has risen, which are most likely states of the world in which banks survived. DAX puts pay out in states of further market declines, a scenario that could have been likely triggered by bad news from the banking sector.

The credit risk variable in Table 8 is split into moneyness regions. Contrary to theoretical predictions, far-OTM puts are the least sensitive to credit risk; in fact, the post-

Lehman sample exhibits declining coefficients for credit risk from ITM to OTM. Calls on the other hand exhibit an increasing for the full sample and a flat pattern for the post Lehman sample. Next we split the sample into maturity bins to test a second natural prediction of a default risk model, namely that the sensitivity to default risk should increase with the time to maturity. We maintain the division of the credit risk variable according to the delta of the warrant.

Table 9 shows the results. While the patterns are rarely monotonic we would argue that it appears as if for both types sensitivity to credit risk is more pronounced for OTM warrants. So, while we find evidence of credit risk being a factor across all maturities, we cannot argue that this is because of investors rationally relating the payoff of warrants with the likelihood of the issuer's default. Further, with maybe the exception of OTM calls, it is hard to argue that there is an increase in default risk sensitivity for longer maturity contracts.

We conclude that investors do not fully incorporate the effects of credit risk into their demand. The Lehman bankruptcy may have served as a wake-up call to retail investors that issuer credit risk is not negligible but the size of the effect suggests that issuers can continue to use structured products as a source of cheap financing.

The issuance of SPs should not be underestimated in this regard. According to the monthly market volume statistics issued by the industry group 'Deutscher Derivate Verband' (DDV) [19], open interest in structured products in the German market amounted to 76 billion EUR in the month of May 2009, the last month of the sample period. The number is based on 14 reporting member banks. The DDV estimates the total open interest at around 90 billion EUR for that time. In April 2010, estimates of total open interest were in excess of 100 billion EUR. Curiously, about 60% of the total amount outstanding is invested in capital protection certificates that are marketed as conservative and safe investments with the primary goal of principal protection. Similarly, retail structured products in the U.S. reported sales volumes of over $100 billion USD in 2007[20].

5 Conclusion and Outlook

This study investigates the price setting behavior of issuers of structured products in the secondary market. Issuers are the sole liquidity providers for their products and do not allow short-selling. In particular, for the securities that we study, bank-issued warrants

[19] http://www.derivateverband.de/DEU/Presse

[20] Wall Street Journal, May 28th, 2009, 'Twice Shy On Structured Products?'

in the German market, trading is only possible with the issuer being on one side of the transaction. This allows the issuer to exert great power over pricing.

Previous literature has consistently reported overpricing in structured products in general, for the U.S. (Bernard et al., 2009), for Germany (Wilkens et al., 2003) and for Switzerland (Grünbichler and Wohlwend, 2005), and for warrants in particular (Horst and Veld, 2008; Abad and Nieto, 2010) when compared to products on derivatives exchanges.

The extent of overpricing can be sufficiently large to ensure that expected returns lie below the risk-free rate (Henderson and Pearson, 2010) and thus there is no reason for rational investors to buy some of these products. Other studies point out how issuers take advantage of investors' susceptability to certain mental errors like over-optimism (Bernard et al., 2009), how they optimally increase complexity to maintain overpricing (Carlin, 2009) and increase search costs (Dorn, 2010).

We add to this literature by pointing out a number of ways in which issuers take advantage of the demand of investors for certain payoffs as well as the lack of financial literacy. Our results are as follows: First, retail investors exhibit a preference for high-leverage, OTM warrants. Issuers exploit this demand by overpricing those securities the most. Issuers seem to benefit either from investors that cannot easily spot the overpricing or from investors with sufficiently optimistic beliefs that makes them willing to pay higher premiums. Among ITM warrants, puts are more overpriced than calls, because of the general lack of ways to express negative views on stock markets in Germany.

Second, issuers are able to predict net demand at the daily horizon, because transactions, especially sales, are heavily influenced by recent returns. Knowing future net demand, issuers opportunistically adjust prices ahead of time and thus are able to extract additional gains in excess of the officially quoted bid/ask spread. In turn, this lowers realized profits for investors.

Third, for warrants other than close-to-expiration OTM warrants we find evidence that the extent of overpricing is decreasing over the life time of the warrant. Thus, issuers extract additional gains from investors holding warrants for longer periods, diminishing investors' returns. In contrast, close-to-expiration OTM warrants appear to decrease less or even increase in overpricing. We suggest that it is the relative importance of time value as a share of the total price that gives rise to this divergent behavior and propose two channels through which the relatively larger rate of time decay keeps existing holders of OTM warrants from selling, thus enabling issuers to decrease prices less.

Last, we investigate the effect of issuer credit risk on the extent of overpricing. We find that only since the collapse of Lehman Brothers, is there a discount in prices due to credit risk. However, the effect is too small relative to vulnerable options models and additional predictions by these models cannot be confirmed in the data. Once again, issuers seem to be able to profit from the lack of financial knowledge of investors. We point out that given the large amount of structured products outstanding (currently 100 billion EUR in Germany alone) underestimation of credit risk amounts to a non-negligible source of cheap financing for issuing banks.

Implications for other structured products

Admittedly, warrants are the most simple structured product available. It is an open question if our results carry through to other classes of these instruments. Given that structured products share most if not all institutional features like trading mechanisms, secondary markets, liquidity provision, marketing channels and issuers, we are confident that the main findings apply to all structured products. In particular, success of the practice of adjusting prices in anticipation of future demand is completely independent of the instrument, rather it depends on two factors. First, that investors are forced to trade with the issuer either by market design (as in Germany) or by lack of liquidity (as for some U.S. products) and second, that daily demand can be anticipated reasonably well.

Our finding that the effect of maturity on overpricing depends on the importance of time value relative to total price is also not tied to warrants alone. We argue that all structured products that pay back the principle will behave similar to ITM warrants because for both the time value of the option part of the product gets smaller as maturity approaches. In contrast, SPs that payoff nothing in some states of the world (knock-out, knock-in features) are more similar to OTM warrants in that their price is mostly driven by time value.

Finally, with regards to credit risk, we see no reason why retail investors would fail to correctly price default risk into warrants, but would correctly discount other structured products carrying exactly the same risk.

We are looking forward to seeing an investigation into the predictability of demand for other structured products as well as the potential exploitation by issuers. We would also be interested in understanding cross-sectional patterns in demand for other structured products. For instance, is there a preferred habitat for retail investors with regards to leverage (in speculative, convex-payoff products) or with regards to the proximity to the participation cap (in concave products) or the knock-out barrier (in more exotic products)?

References

D. Abad and B. Nieto. Analysing bank-issued option pricing. Forthcoming, The European Journal of Finance, 2010.

K. Amin, J. D. Coval, and H. N. Seyhun. Index option prices and stock market momentum. *The Journal of Business*, 77(4):835–874, 2004.

G. Bakshi, N. Kapadia, and D. Madan. Stock Return Characteristics, Skew Laws, and the Differential Pricing of Individual Equity Options. *Review of Financial Studies*, 16 (1):101–143, 2003.

S. M. Bartram and F. Fehle. Competition without fungibility: Evidence from alternative market structures for derivatives. *Journal of Banking & Finance*, 31(3):659 – 677, 2007.

S. M. Bartram, F. Fehle, and D. G. Shrider. Does adverse selection affect bid-ask spreads for options? *Journal of the Futures Markets*, 28(5):417–437, May 2008.

R. Bauer, M. Cosemans, and P. Eichholtz. Option trading and individual investor performance. *Journal of Banking & Finance*, 33(4):731 – 746, 2009.

R. Baule, O. Entrop, and M. Wilkens. Credit risk and bank margins in structured financial products: Evidence from the german secondary market for discount certificates. *Journal of Futures Markets*, 28(4):376 – 397, 2008.

B. A. Benet, A. Giannetti, and S. Pissaris. Gains from structured product markets: The case of reverse-exchangeable securities (RES). *Journal of Banking & Finance*, 30(1): 111 – 132, 2006.

D. B. Bergstresser. The retail market for structured notes: Issuance patterns and performance, 1995-2008. Working Paper, Harvard Business School, 2009.

C. Bernard, P. P. Boyle, and W. Gornall. Locally-Capped Investment Products and the Retail Investor. Working paper, 2009.

J. Bethel and A. Ferrell. Policy Issues Raised by Structured Products. *Brookings-Nomura Papers On Financial Services, Yasuki Fuchita, Robert E. Litan, Eds., Brookings Institution Press*, 2007.

N. P. B. Bollen and R. E. Whaley. Does net buying pressure affect the shape of implied volatility functions? *The Journal of Finance*, 59(2):pp. 711–753, 2004.

M. Broadie and J. Detemple. American option valuation: New bounds, approximations, and a comparison of existing methods. *The Review of Financial Studies*, 9(4):1211–1250, 1996.

C. Brown and K. J. Davis. Dividend protection at a price. *The Journal of Derivatives*, 12:62–68, 2004.

S. Burth, T. Kraus, and H. Wohlwend. The pricing of structured products in the Swiss market. *Journal of Derivatives*, 9:1074–1240, 2001.

B. I. Carlin. Strategic price complexity in retail financial markets. *Journal of Financial Economics*, 91(3):278 – 287, 2009.

H. W.-H. Chan and S. M. Pinder. The value of liquidity: Evidence from the derivatives market. *Pacific-Basin Finance Journal*, 8(3-4):483 – 503, 2000.

A. H. Chen and J. W. Kensinger. An analysis of market-index certificates of deposit. *Journal of Financial Services Research*, 4:93–110, 1990.

K. C. Chen and R. S. Sears. Pricing the SPIN. *Financial Management*, 19(2):pp. 36–47, 1990.

N. K. Chidambaran, C. S. Fernando, and P. A. Spindt. Credit enhancement through financial engineering: Freeport McMoRan's gold-denominated depositary shares. *Journal of Financial Economics*, 60(2-3):487 – 528, 2001.

P. Dennis and S. Mayhew. Risk-neutral skewness: Evidence from stock options. *Journal of Financial and Quantitative Analysis*, 37(03):471–493, 2002.

D. Dorn. Investors with too many options? Working paper, 2010.

O. Entrop, H. Scholz, and M. Wilkens. The price-setting behavior of banks: An analysis of open-end leverage certificates on the german market. *Journal of Banking & Finance*, 33(5):874 – 882, 2009.

N. Garleanu, L. H. Pedersen, and A. M. Poteshman. Demand-based option pricing. *Review of Financial Studies*, 22(10):4259–4299, 2009.

M. Glaser and P. Schmitz. Privatinvestoren am Optionsscheinmarkt. *Die Zeitschrift für Bankrecht und Bankwirtschaft*, 19:214–230, 2007.

A. Grünbichler and H. Wohlwend. The valuation of structured products: Empirical findings for the Swiss market. *Financial Markets and Portfolio Management*, 19:361–380, 2005.

B. J. Henderson and N. D. Pearson. The dark side of financial innovation. Forthcoming, Journal of Financial Economics, 2010.

J. t. Horst and C. Veld. An empirical analysis of the pricing of bank issued options versus options exchange options. *European Financial Management*, 14(2):288–314, 2008.

J. Hull and A. White. The impact of default risk on the prices of options and other derivative securities. *Journal of Banking & Finance*, 19:299–322, 1995.

R. A. Jarrow and M. O'Hara. Primes and Scores: An essay on market imperfections. *The Journal of Finance*, 44(5):pp. 1263–1287, 1989.

P. Klein. Pricing Black-Scholes options with correlated credit risk. *Journal of Banking & Finance*, 20(7):1211 – 1229, 1996.

M. L. Lemmon and S. X. Ni. The effects of investor sentiment on speculative trading and prices of stock and index options. Working paper, 2010.

W. K. Newey and K. D. West. A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3):pp. 703–708, 1987.

W. K. Newey and K. D. West. Automatic lag selection in covariance matrix estimation. *The Review of Economic Studies*, 61(4):pp. 631–653, 1994.

T. Odean. Are investors reluctant to realize their losses? *Journal of Finance*, 5:1775 – 1798, 1998.

T. Pratt. Equity derivatives vanish and explanations multiply. *The Investment Dealers' Digest*, 61:15, 1995.

R. J. Rogalski and J. K. Seward. Corporate issues of foreign currency exchange warrants : A case study of financial innovation and risk management. *Journal of Financial Economics*, 30(2):347 – 366, 1991.

H. Shefrin and M. Statman. The disposition to sell winners too early and ride losers too long: Theory and evidence. *Journal of Finance*, 40(3):777 – 790, 1985.

H. Shefrin and M. Statman. Behavioral aspects of the design and marketing of financial products. *Financial Management*, 22(2):pp. 123–134, 1993.

P. A. Stoimenov and S. Wilkens. Are structured products 'fairly' priced? an analysis of the German market for equity-linked instruments. *Journal of Banking & Finance*, 29 (12):2971 – 2993, 2005.

Implementation Rules relating to the Exchange Rules. Stuttgart Stock Exchange, https://www.boerse-stuttgart.de/media/dokumente/regelwerke/eng/Implementation Rules Derivative Securities.pdf, December 2010a.

Exchange Rules of the Stuttgart Stock Exchange. Stuttgart Stock Exchange, https://www.boerse-stuttgart.de/media/dokumente/regelwerke/eng/Exchange Rules.pdf, 2010b.

S. B. Thompson. Simple formulas for standard errors that cluster by both firm and time. Working paper, 2009.

W. Wasserfallen and C. Schenk. Portfolio insurance for the small investor in Switzerland. *The Journal of Derivatives*, 3:37–43, 1996.

S. Wilkens and P. A. Stoimenov. The pricing of leverage products: An empirical investigation of the German market for 'long' and 'short' stock index certificates. *Journal of Banking & Finance*, 31(3):735 – 750, 2007.

S. Wilkens, C. Erner, and K. Röder. The pricing of structured products in Germany. *Journal of Derivatives*, 11(1):55 – 69, 2003.

	OTM			ATM	ITM			All
	> 25%	15-25%	5-15%	± 5%	5-15%	15-25%	> 25%	
Panel A: Calls								
Warrants								
Maturity (in months)								
1 - 3m	6.3	9.2	28.6	40.0	2.3	0.2	12.9	**37.9**
4 - 6m	15.3	19.4	30.1	20.4	2.1	0.3	12.1	**19.7**
≥ 7m	36.3	14.4	16.6	15.9	2.9	0.7	12.9	**42.3**
All	**20.8**	**13.4**	**23.8**	**25.9**	**2.5**	**0.5**	**12.7**	**100.0**
Options								
Maturity (in months)								
1 - 3m	1.2	4.2	34.0	58.4	1.7	0.1	0.2	**84.3**
4 - 6m	8.6	17.5	42.9	26.7	2.9	0.5	0.5	**7.9**
≥ 7m	28.4	16.3	24.5	22.8	4.6	0.9	2.1	**7.6**
All	**3.8**	**6.2**	**34.0**	**53.1**	**2.0**	**0.2**	**0.3**	**100.0**
Panel B: Puts								
Warrants								
Maturity (in months)								
1 - 3m	3.4	7.6	26.9	39.7	6.8	1.4	13.8	**44.6**
4 - 6m	7.2	9.6	22.2	34.4	10.6	2.7	13.0	**22.4**
≥ 7m	15.1	10.9	21.3	25.9	9.4	3.9	13.2	**32.9**
All	**8.1**	**9.1**	**24.0**	**34.0**	**8.5**	**2.5**	**13.4**	**100.0**
Options								
Maturity (in months)								
1 - 3m	1.4	5.9	34.6	53.9	2.8	0.5	0.5	**84.6**
4 - 6m	7.4	14.4	33.2	36.8	5.5	1.0	1.4	**8.0**
≥ 7m	18.9	14.7	25.9	27.2	8.0	2.4	2.6	**7.3**
All	**3.2**	**7.3**	**33.8**	**50.5**	**3.4**	**0.7**	**0.7**	**100.0**

Table 1: Relative occurence of trades (in %) by type, maturity range and moneyness, separately for warrants and options. The table shows the relative frequency of transactions by moneyness category (out-of-the-money (OTM); at-the-money (ATM); in-the-money (ITM)) for several maturity ranges (1-3 months, 4-6 months and 7 or more months) and for the full sample. Numbers represent percent shares of row totals, i.e. within maturity bin, with the exception of the last column 'All', where they represent the share of each maturity of the total sample. The analysis is done separately for warrant transaction on EUWAX/SCoach and options on EUREX and further split by calls and puts.

	Calls		Puts	
	Buys	**Sells**	**Buys**	**Sells**
$\text{TotWarVol}_{t-14,t-1}$	0.43	0.41	0.68	0.77
	***[6.07]	***[6.81]	***[4.73]	***[5.00]
ΔVDAX_{t-1}	7.19	8.52	5.50	15.98
	*[1.78]	***[3.43]	[1.21]	**[2.07]
VDAX_{t-1}	-3.67	-4.13	-3.13	-3.63
	***[-4.63]	***[-5.89]	***[-2.89]	**[-2.38]
Buys^{C}_{t-1}	0.12	0.12		
	***[5.81]	***[5.33]		
Sells^{C}_{t-1}	0.04	0.05		
	*[1.87]	**[2.45]		
Buys^{P}_{t-1}			0.11	0.09
			***[4.55]	***[3.22]
Sells^{P}_{t-1}			0.07	0.11
			***[2.91]	***[3.14]
Ret^{-}_{t-1}	-10.21	10.78	-16.87	-38.20
	[-1.09]	[1.33]	[-1.59]	**[-2.57]
Ret^{+}_{t-1}	13.04	36.20	-4.62	-42.11
	[1.38]	***[3.55]	[-0.53]	***[-4.07]
Ret^{-}_{t}	-31.90	-5.51	-40.34	-107.60
	***[-4.93]	[-0.94]	***[-3.56]	***[-5.37]
Ret^{+}_{t}	3.50	63.41	18.12	-32.14
	[0.57]	***[7.00]	[1.28]	***[-2.61]
# Observations	504	504	504	504
R^2	0.391	0.523	0.667	0.695

Table 2: Regression results for daily aggregate demand for warrants. This table show the results of a regression of aggregate daily demand for warrants on a number of lagged demand and market return and volatility variables. Regressions are done separately by type of warrant (calls and puts) and type of transaction (buys and sells). Aggregate daily demand on day t is defined as the sum of all transactions occurring between 1730CET of the previous day and 1730CET of day t. Explanatory variables are total unsigned warrants volume over the past 2 weeks ($\text{TotWarVol}_{t-14,t-1}$), lagged change in and level of volatility (ΔVDAX_{t-1}, VDAX_{t-1}), lagged demand by type of transaction and type of warrant (e.g. Buys^{C}_{t-1}) as well as lagged and contemporaneous market returns (e.g. Ret^{-}_{t-1}). A negative sign indicates that the variable is equal to the market return of that period if negative and zero otherwise; a positive sign indicates the opposite. Standard errors are computed following Newey and West (1987, 1994).

	Calls		Puts	
	Buys	**Sells**	**Buys**	**Sells**
$\text{TotWarVol}_{t-14,t-1}$	0.3912	0.4517	0.5028	0.5232
	***[5.77]	***[5.90]	***[4.02]	***[3.15]
Δ VDAX_{t-1}	7.2715	7.195	6.6414	5.7717
	***[2.69]	***[2.69]	[1.44]	[0.76]
VDAX_{t-1}	-2.3378	-3.1864	-1.8793	-2.3297
	***[-3.41]	***[-3.98]	*[-1.90]	*[-1.74]
Ret^{-}_{t-1}	11.7337	19.1834	8.0943	14.2664
	*[1.68]	**[2.25]	[0.68]	[1.23]
Ret^{+}_{t-1}	-0.9331	12.1836	-18.3902	-43.4377
	[-0.16]	*[1.71]	**[-2.12]	***[-5.41]
Ret^{-}_{ON}	-16.7453	0.2643	-27.5442	-100.191
	[-1.58]	[0.03]	***[-2.77]	***[-6.51]
Ret^{+}_{ON}	-2.835	58.9149	7.0739	-74.673
	[-0.29]	***[3.90]	[0.37]	***[-4.46]
$\text{Buys}^{C}_{t-3,t-1}$	0.0667	0.0512		
	***[3.28]	**[2.13]		
$\text{Sells}^{C}_{t-3,t-1}$	0.0273	0.0196		
	[1.33]	[1.04]		
$\text{Buys}^{P}_{t-3,t-1}$			0.0664	0.0105
			***[2.84]	[0.39]
$\text{Sells}^{P}_{t-3,t-1}$			0.0601	0.0962
			***[2.83]	***[3.65]
Buys^{C}_{ON}	0.3352	0.3237		
	*[1.85]	[1.53]		
Sells^{C}_{ON}	0.0742	0.2262		
	[0.44]	*[1.65]		
Buys^{P}_{ON}			0.494	0.3644
			**[2.45]	[1.31]
Sells^{P}_{ON}			-0.0217	0.71
			[-0.17]	**[2.17]
# Observations	504	504	504	504
R^2	0.32	0.411	0.603	0.614

Table 3: Regression results for aggregate intraday demand for warrants. This table show the results of a predictive regression of aggregate intraday demand for warrants on a number of lagged and overnight demand, lagged and overnight market return and lagged volatility variables. Regressions are done separately by type of warrant (calls and puts) and type of transaction (buys and sells). Aggregate intraday demand on day t is defined as the sum of all transactions occurring between 930CET and 1730CET of day t. Explanatory variables are total unsigned warrants volume over the past 2 weeks ($\text{TotWarVol}_{t-14,t-1}$), lagged change in and level of volatility (ΔVDAX_{t-1}, VDAX_{t-1}), lagged signed market return (Ret^{-}_{t-1} and Ret^{+}_{t-1}), overnight signed market return (Ret^{-}_{ON} and Ret^{+}_{ON}), cumulative demand over the previous three trading days by type ($\text{Buys}^{C}_{t-3,t-1}$ etc.) as well as overnight demand by type (Buys^{C}_{ON} etc.). The definitions of overnight returns and demand are consistent with the times that define intraday demand, i.e. overnight return is defined as the change in the level of the DAX between 1730CET of trading day $t-1$ and 930CET of day t. A negative sign indicates that the variable is equal to the market return of that period if negative and zero otherwise; a positive sign indicates the opposite. Standard errors are computed following Newey and West (1987, 1994).

	(1)	(2)	(3)	(4)	(5)
TTM	-0.042	-0.043	-0.046	-0.044	-0.045
	***[-3.52]	***[-3.71]	***[-4.09]	***[-3.84]	***[-4.02]
SKEW_{t-1}	-0.058	-0.059	-0.058	-0.060	-0.059
	***[-6.47]	***[-6.69]	***[-6.61]	***[-6.54]	***[-6.54]
Ret_{t-1}	-0.061	0.104	0.181	0.652	0.644
	[-0.29]	[0.49]	[0.91]	***[3.07]	***[3.00]
ISS_NetDem_t^C		0.049			0.010
		***[3.44]			*[1.85]
ISS_NetDem_t^P		-0.027			0.008
		*[-1.87]			[0.88]
EXP_NetDem_t^C			0.025		0.003
			***[4.04]		[0.56]
EXP_NetDem_t^P			-0.035		-0.011
			***[-6.86]		***[-3.17]
TOT_NetDem_t^C				0.010	0.009
				***[3.45]	***[3.07]
TOT_NetDem_t^P				-0.010	-0.009
				***[-6.70]	***[-5.88]
# Issuers			9		
# Days			488		
# Observations			12,608		
R^2	0.026	0.046	0.066	0.118	0.121

Table 4: Regression results for the day-over-day change in implied skewness of warrant chains. This table shows the results of regressions of day-over-day changes in implied skewness of warrant chains on contemporaneous demand measures and control variables. A warrant chain is the set of all warrants by the same issuer with the same expiration date. Implied skewness is defined as in Bakshi et al. (2003) using all OTM warrants per warrant chain. Change in skewness is computed as the difference in the level of implied skewness at 1730CET of day $t-1$ and 1730CET of day t. Control variables are the time to maturity of the warrant chain (TTM), the lagged level of the skewness of the warrant chain (SKEW_{t-1}) and the market return on day $t-1$ (Ret_{t-1}). Explanatory variables are contemporaneous net demands (i.e. buys minus sells) by type of warrant and either aggregated by issuer ($\text{ISS\_NetDem}_t^{C/P}$), by expiration ($\text{EXP\_NetDem}_t^{C/P}$) or summed over all expirations and issuers ($\text{TOT\_NetDem}_t^{C/P}$). Regressions are OLS with 2-way clustered standard errors following Thompson (2009), clustered by issuer and date.

	Lagged only	Actual Day Demand			Predicted Day Demand		
	(1)	(2a)	(2b)	(2c)	(3a)	(3b)	(3c)
EXP_NetDem$^{C}_{\mathrm{Day}}$			0.007	0.000		0.430	0.242
			**[2.23]	[-0.08]		***[7.53]	***[4.78]
EXP_NetDem$^{P}_{\mathrm{Day}}$			-0.014	-0.001		-0.078	-0.036
			***[-3.84]	[-0.45]		***[-6.80]	***[-3.15]
TOT_NetDem$^{C}_{\mathrm{Day}}$		0.001		0.001	0.095		0.072
		[0.74]		[0.76]	***[8.93]		***[6.72]
TOT_NetDem$^{P}_{\mathrm{Day}}$		-0.006		-0.006	-0.012		0.001
		***[-4.54]		***[-4.57]	**[-2.22]		[0.24]
TOT_NetDem$^{C}_{t-3,t-1}$	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
	**[-2.50]	**[-2.12]	**[-2.42]	**[-2.12]	***[-2.87]	***[-2.75]	***[-2.85]
TOT_NetDem$^{P}_{t-3,t-1}$	0.000	0.001	0.001	0.001	0.000	0.000	0.000
	[0.82]	*[1.86]	[1.15]	*[1.86]	[0.90]	[1.39]	[0.57]
TOT_NetDem$^{C}_{\mathrm{ON}}$	0.017	0.013	0.016	0.013	0.004	0.000	-0.001
	**[2.49]	**[2.22]	**[2.45]	**[2.22]	[0.91]	[-0.10]	[-0.13]
TOT_NetDem$^{P}_{\mathrm{ON}}$	0.008	0.010	0.009	0.010	0.005	0.007	0.004
	**[2.00]	**[2.26]	**[2.10]	**[2.26]	[1.43]	**[2.27]	[1.16]
TTM	-0.010	-0.011	-0.011	-0.011	-0.015	0.004	-0.009
	[-1.16]	[-1.23]	[-1.30]	[-1.23]	*[-1.83]	[0.40]	[-1.00]
SKEW$_{t-1}$	-0.025	-0.024	-0.024	-0.024	-0.029	-0.015	-0.027
	***[-3.69]	***[-3.78]	***[-3.68]	***[-3.78]	***[-4.43]	***[-2.73]	***[-4.39]
Ret$_{t-1}$	-0.093	0.012	-0.070	0.012	0.531	0.270	0.507
	[-0.50]	[0.06]	[-0.38]	[0.06]	**[2.50]	[1.46]	**[2.46]
R^2	0.034	0.068	0.043	0.068	0.145	0.125	0.155

Table 5: Regression results for the overnight change in implied skewness of warrant chains. This table shows the results of predictive regressions of overnight changes in implied skewness of warrant chains on future intraday (actual and predicted) demand measures as well as lagged and overnight demand and control variables. A warrant chain is the set of all warrants by the same issuer with the same expiration date. Implied skewness is defined as in Bakshi et al. (2003) using all OTM warrants per warrant chain. The overnight change in skewness is computed as the difference between the level of implied skewness at 1730CET of day $t-1$ and 930CET of day t. Control variables are the time to maturity of the warrant chain (TTM), the lagged level of the skewness of the warrant chain (SKEW$_{t-1}$) and the market return on day $t-1$ (Ret$_{t-1}$).

All demand measures are split by type of warrant (i.e. puts vs. calls) and by time period. Lagged demand is the cumulative total net demand (buys minus sells) over the previous three trading days (TOT_NetDem$^{C/P}_{t-3,t-1}$). Overnight demand is the sum of all buys minus all sells of warrants between 1730CET of trading day $t-1$ and 930CET of day t (TOT_NetDem$^{C/P}_{ON}$). Future intraday demand is either total aggregated net demand by type (TOT_NetDem$^{C/P}_{Day}$) or split by expiration date (EXP_NetDem$^{C/P}_{Day}$). In columns (2a-c) the actual realized intraday demand is used; in column (3a-c) we use the fitted values derived from the regressions in Table 3 for total demand and from unreported, but identical regressions for demand by expiration date. Regressions are OLS with 2-way clustered standard errors following Thompson (2009), clustered by issuer and date. Numbers of clusters and observations are as in Table 4, but omitted to conserve space.

	Call Warrants			Put Warrants		
	Short 1-3 months	**Medium** 4-6 months	**Long** > 7 months	**Short** 1-3 months	**Medium** 4-6 months	**Long** > 7 months
Panel A: Unadjusted						
$\lvert\Delta\rvert < .25$	0.297	0.079	0.036	0.248	0.047	0.001
	***[22.08]	***[5.61]	***[4.20]	***[22.68]	***[6.60]	[0.31]
$.25 < \lvert\Delta\rvert < .35$	0.250	0.065	0.029	0.200	0.043	0.005
	***[24.69]	***[5.43]	***[4.65]	***[24.79]	***[6.72]	[1.51]
$.35 < \lvert\Delta\rvert < .50$	0.221	0.063	0.025	0.174	0.046	0.009
	***[27.06]	***[6.04]	***[5.49]	***[24.49]	***[7.50]	***[2.58]
$.50 < \lvert\Delta\rvert$	0.180	0.055	0.016	0.122	0.046	0.009
	***[24.87]	***[5.70]	***[3.80]	***[16.73]	***[7.35]	***[2.62]
Panel B: Adjusted						
$\lvert\Delta\rvert < .25$	-0.047	0.037	0.026	-0.070	0.009	-0.006
	***[-3.83]	***[2.60]	***[3.05]	***[-7.08]	[1.32]	[-1.21]
$.25 < \lvert\Delta\rvert < .35$	-0.041	0.027	0.021	-0.059	0.011	0.000
	***[-4.54]	**[2.29]	***[3.42]	***[-8.25]	*[1.75]	[-0.10]
$.35 < \lvert\Delta\rvert < .50$	-0.007	0.031	0.020	-0.022	0.020	0.004
	[-0.98]	***[2.99]	***[4.28]	***[-3.71]	***[3.34]	[1.20]
$.50 < \lvert\Delta\rvert$	0.006	0.027	0.011	-0.002	0.026	0.006
	[0.87]	***[2.86]	***[2.77]	[-0.25]	***[4.29]	[1.64]
Panel C: Intrapolated						
$\lvert\Delta\rvert < .25$	-0.020	0.029	0.027	-0.043	0.013	-0.003
	[-1.57]	**[2.28]	**[2.49]	***[-4.11]	*[1.83]	[-0.70]
$.25 < \lvert\Delta\rvert < .35$	-0.022	0.023	0.023	-0.037	0.015	0.002
	**[-2.46]	**[2.17]	***[3.27]	***[-4.83]	**[2.27]	[0.48]
$.35 < \lvert\Delta\rvert < .50$	-0.003	0.025	0.018	-0.014	0.021	0.005
	[-0.45]	***[2.69]	***[3.86]	**[-2.20]	***[3.40]	[1.46]
$.50 < \lvert\Delta\rvert$	0.005	0.020	0.011	-0.008	0.024	0.004
	[0.76]	**[2.36]	***[2.94]	[-1.17]	***[3.70]	[1.06]
Panel D: Extrapolated						
$\lvert\Delta\rvert < .25$	-0.036	0.080	0.081	-0.068	0.007	0.030
	**[-2.35]	***[2.64]	[0.48]	***[-6.13]	[0.50]	**[2.32]
$.25 < \lvert\Delta\rvert < .35$	-0.033	0.065	-0.188	-0.056	0.016	0.043
	***[-2.86]	**[2.56]	[-0.90]	***[-6.72]	[1.12]	***[3.32]
$.35 < \lvert\Delta\rvert < .50$	-0.004	0.069	-0.237	-0.021	0.029	0.044
	[-0.44]	***[3.11]	[-0.94]	***[-2.89]	**[2.21]	***[2.93]
$.50 < \lvert\Delta\rvert$	0.004	0.053	-0.139	-0.007	0.036	0.041
	[0.54]	***[2.63]	[-0.91]	[-0.97]	***[2.66]	**[2.38]

Table 6: The effect of time to maturity on the warrants premium, by method of premium calculation. The table shows the coefficients of the time to maturity variable in a regression on the warrant premium. Panels A-D represent the four different versions of the premium computation. Within each panel, the sample was split by type (i.e. call vs. put) and further by maturity range (short-term, medium-term, long-term). In addition, the coefficients are allowed to differ by the delta of the warrant within each regression. To conserve space, the coefficients of the control variables were omitted. They include issuer dummies, $|\Delta|$ and Δ^2, dummies for competition from other warrants (D_{Comp}) and from EUREX (D_{EUREX}), yesterday's market volatility (VDAX_{t-1}), the warrant's cumulative volume over the previous 2 weeks (LagWarVol) and lagged issuer CDS premium (CDS_{t-1}). Regressions are OLS with 2-way clustered standard errors following Thompson (2009), clustered by issuer and date.

	Adjusted		Intrapolated		Extrapolated	
	Call	**Put**	**Call**	**Put**	**Call**	**Put**
D_{BNP}	0.133	0.102	0.130	0.096	0.148	0.115
	***[37.85]	***[43.58]	***[32.79]	***[39.26]	***[21.64]	***[33.21]
D_{CBK}	0.110	0.089	0.108	0.080	0.124	0.098
	***[32.42]	***[40.78]	***[28.00]	***[35.56]	***[18.37]	***[30.12]
D_{CITI}	0.135	0.114	0.131	0.104	0.156	0.128
	***[38.06]	***[46.65]	***[31.43]	***[40.93]	***[22.41]	***[35.29]
D_{DRBK}	0.125	0.101	0.122	0.092	0.144	0.115
	***[35.43]	***[40.60]	***[29.83]	***[35.43]	***[20.21]	***[31.08]
D_{DTBK}	0.116	0.089	0.113	0.080	0.130	0.098
	***[33.42]	***[39.39]	***[27.97]	***[33.87]	***[18.78]	***[28.58]
D_{SCGN}	0.154	0.112	0.148	0.104	0.162	0.118
	***[30.93]	***[35.80]	***[28.58]	***[32.85]	***[18.68]	***[27.83]
D_{TRBK}	0.104	0.082	0.102	0.073	0.119	0.091
	***[30.01]	***[37.22]	***[25.77]	***[32.52]	***[17.67]	***[27.82]
$\lvert\Delta\rvert$	-0.336	-0.211	-0.303	-0.175	-0.366	-0.222
	***[-31.84]	***[-34.57]	***[-26.45]	***[-26.70]	***[-27.87]	***[-26.80]
Δ^2	0.267	0.159	0.235	0.133	0.305	0.171
	***[23.68]	***[25.60]	***[19.05]	***[18.31]	***[20.95]	***[17.87]
D_{Comp}	-0.004	-0.002	-0.005	-0.001	-0.009	-0.004
	**[-2.54]	*[-1.75]	**[-2.50]	[-0.77]	***[-2.77]	**[-2.01]
D_{EUREX}	0.003	-0.002	0.003	-0.003	0.007	-0.001
	*[1.68]	[-1.63]	[1.12]	**[-2.03]	[1.48]	[-0.24]
VDAX_{t-1}	0.006	-0.010	-0.012	-0.024	-0.012	-0.029
	[1.15]	***[-3.82]	***[-2.72]	***[-9.50]	**[-2.22]	***[-7.57]
CDS_{t-1}	-0.234	-0.201	-0.224	-0.197	-0.355	-0.244
	***[-6.03]	***[-6.70]	***[-6.23]	***[-6.42]	***[-7.05]	***[-6.23]
TTM	0.004	-0.010	0.008	-0.006	0.005	-0.015
	**[2.37]	***[-6.84]	***[4.25]	***[-3.94]	[0.75]	***[-2.76]
LagWarVol	-0.003	-0.002	-0.003	-0.002	-0.005	-0.002
	***[-5.88]	***[-5.28]	***[-6.12]	***[-5.17]	***[-5.44]	***[-4.61]
# Obs.	93,957	123,035	80,309	107,837	44,251	57,453
R^2	0.433	0.469	0.406	0.424	0.420	0.492

Table 7: Regression results for warrant premiums by method of premium calculation. Warrant premiums are computed by three different methods: adjusted, intrapolated and extrapolated. Explanatory variables are issuer dummies, $|\Delta|$ and Δ^2, dummies for competition from other warrants (D_{Comp}) and from EUREX (D_{EUREX}), lagged market volatility (VDAX_{t-1}), lagged issuer CDS premium (CDS_{t-1}), the warrant's time until expiration (TTM) and its cumulative volume over the previous 2 weeks (LagWarVol). Regressions are OLS with 2-way clustered standard errors following Thompson (2009), clustered by issuer and date.

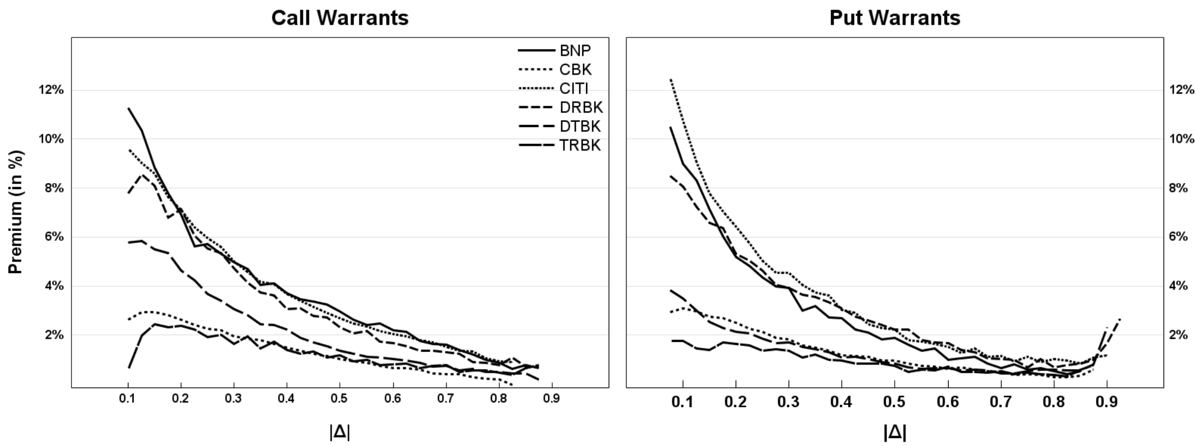
	Call Premium			Put Premium		
	Full Sample	Before Lehman	Post Lehman	Full Sample	Before Lehman	Post Lehman
D_{BNP}	0.132	0.125	0.125	0.097	0.096	0.087
	***[30.72]	***[14.76]	***[16.43]	***[35.57]	***[16.10]	***[22.70]
D_{CBK}	0.111	0.106	0.096	0.081	0.082	0.066
	***[25.87]	***[13.24]	***[13.01]	***[31.75]	***[15.40]	***[17.28]
D_{CITI}	0.134	0.133	0.114	0.105	0.108	0.086
	***[29.20]	***[16.23]	***[13.76]	***[37.43]	***[20.37]	***[18.56]
D_{DRBK}	0.125	0.127	0.104	0.093	0.099	0.073
	***[27.97]	***[15.02]	***[15.13]	***[32.22]	***[17.78]	***[17.97]
D_{DTBK}	0.116	0.122	0.091	0.081	0.086	0.062
	***[26.02]	***[14.89]	***[12.85]	***[30.34]	***[15.59]	***[16.50]
D_{SCGN}	0.151	0.145	0.164	0.105	0.102	0.114
	***[27.56]	***[15.83]	***[15.86]	***[31.13]	***[17.39]	***[16.22]
D_{TRBK}	0.105	0.105	0.087	0.073	0.073	0.061
	***[24.06]	***[12.51]	***[12.66]	***[29.60]	***[12.88]	***[16.28]
$\|\Delta\|$	-0.310	-0.307	-0.252	-0.178	-0.202	-0.127
	***[-22.37]	***[-15.00]	***[-11.10]	***[-22.63]	***[-18.53]	***[-11.68]
Δ^2	0.235	0.231	0.189	0.136	0.153	0.099
	***[16.30]	***[11.76]	***[7.84]	***[16.68]	***[13.29]	***[9.03]
D_{Comp}	-0.004	-0.007	-0.004	-0.001	-0.003	0.001
	**[-2.40]	***[-2.58]	***[-2.76]	[-0.76]	[-1.57]	[0.80]
D_{EUREX}	0.002	-0.002	0.003	-0.003	0.000	-0.004
	[1.05]	[-0.39]	[1.15]	**[-2.03]	[-0.00]	***[-2.97]
VDAX_{t-1}	-0.012	0.020	-0.012	-0.024	-0.011	-0.029
	***[-2.79]	[0.59]	[-1.55]	***[-9.46]	[-0.46]	***[-6.71]
TTM	0.008	0.001	0.015	-0.006	-0.014	0.002
	***[4.31]	[0.62]	***[5.57]	***[-3.93]	***[-6.38]	[1.29]
LagWarVol	-0.003	-0.003	-0.002	-0.002	-0.002	-0.002
	***[-6.16]	***[-4.77]	**[-2.54]	***[-5.16]	***[-4.30]	***[-4.99]
$\mathbf{CDS}_{t-1}$						
$\|\Delta\| < .25$	**-0.302**	**0.078**	**-0.169**	**-0.210**	**0.196**	**-0.048**
	*****[-5.14]**	**[0.18]**	***[-1.92]**	*****[-4.67]**	**[0.92]**	**[-0.84]**
$.25 < \|\Delta\| < .35$	**-0.296**	**-0.129**	**-0.233**	**-0.216**	**0.063**	**-0.136**
	*****[-6.92]**	**[-0.37]**	*****[-3.38]**	*****[-6.74]**	**[0.31]**	*****[-3.08]**
$.35 < \|\Delta\| < .50$	**-0.194**	**-0.083**	**-0.204**	**-0.167**	**0.199**	**-0.165**
	*****[-5.78]**	**[-0.28]**	*****[-3.43]**	*****[-6.04]**	**[0.95]**	*****[-4.17]**
$.50 < \|\Delta\|$	**-0.118**	**-0.133**	**-0.157**	**-0.193**	**0.007**	**-0.209**
	*****[-4.09]**	**[-0.47]**	*****[-3.11]**	*****[-5.99]**	**[0.03]**	*****[-5.12]**
# Observations	80,309	39,957	40,354	107,837	58,723	49,114
R^2	0.407	0.502	0.351	0.425	0.468	0.400

Table 8: Regression results for warrant premiums, split into a pre- and post-Lehman sample. Results are presented for the full sample, and for two subperiods: One from June 2007 - September 2008, the other from October 2008 - May 2009. This roughly coincides with the bankruptcy of Lehman brothers on September 15th, 2008. Warrant premiums are computed by intrapolation method. Explanatory variables are issuer dummies, $|\Delta|$ and Δ^2, dummies for competition from other warrants (D_{Comp}) and from EUREX (D_{EUREX}), yesterday's market volatility (VDAX_{t-1}), the warrant's time until expiration and its cumulative volume over the previous 2 weeks (LagWarVol). Lagged issuer CDS premium (CDS_{t-1}) is split up into 4 variables to allow for different slopes conditional on the delta of the warrant. Regressions are OLS with 2-way clustered standard errors following Thompson (2009), clustered by issuer and date.

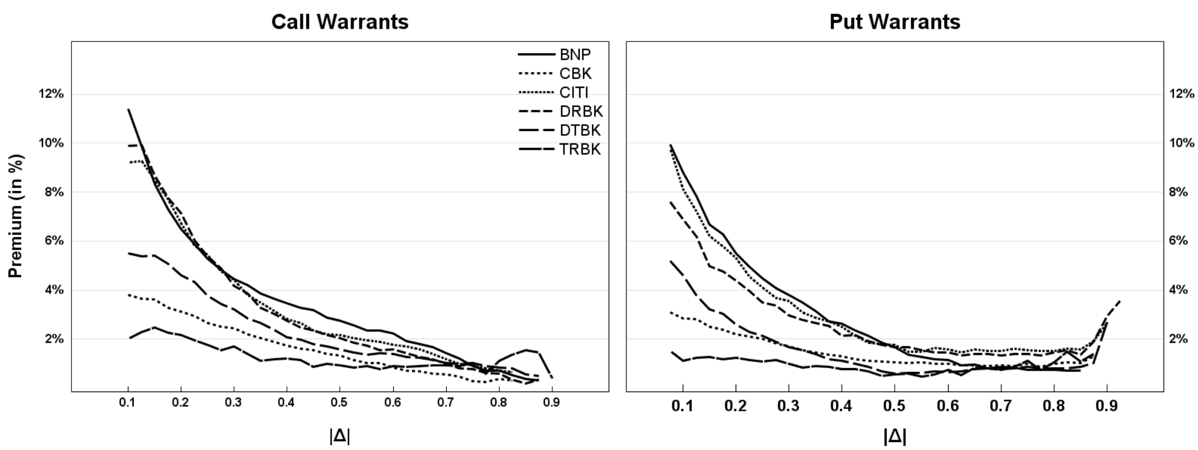
	Call Premium			Put Premium		
	Short 1-3 months	**Medium** 4-6 months	**Long** > 7 months	**Short** 1-3 months	**Medium** 4-6 months	**Long** > 7 months
D_{BNP}	0.145	0.109	0.151	0.110	0.089	0.077
	***[17.99]	***[14.73]	***[12.85]	***[25.22]	***[20.46]	***[14.76]
D_{CBK}	0.120	0.087	0.135	0.091	0.070	0.068
	***[15.10]	***[11.74]	***[11.68]	***[22.08]	***[17.19]	***[13.43]
D_{CITI}	0.149	0.108	0.147	0.121	0.092	0.085
	***[18.60]	***[14.10]	***[12.47]	***[27.59]	***[21.67]	***[15.72]
D_{DRBK}	0.143	0.104	0.134	0.113	0.084	0.071
	***[17.31]	***[13.44]	***[12.13]	***[25.04]	***[19.69]	***[13.01]
D_{DTBK}	0.127	0.094	0.135	0.091	0.072	0.065
	***[15.58]	***[12.55]	***[12.05]	***[21.22]	***[17.96]	***[12.61]
D_{SCGN}	0.153	0.135	0.177	0.112	0.097	0.092
	***[16.43]	***[14.41]	***[13.98]	***[21.93]	***[18.81]	***[15.98]
D_{TRBK}	0.119	0.079	0.121	0.084	0.062	0.062
	***[14.91]	***[10.47]	***[10.64]	***[20.62]	***[14.76]	***[12.42]
$\lvert\Delta\rvert$	-0.271	-0.277	-0.441	-0.195	-0.180	-0.187
	***[-19.64]	***[-12.63]	***[-9.00]	***[-20.51]	***[-14.07]	***[-9.41]
Δ^2	0.191	0.208	0.344	0.139	0.144	0.174
	***[14.08]	***[8.52]	***[6.56]	***[15.29]	***[9.45]	***[6.90]
D_{Comp}	-0.010	-0.002	0.005	-0.002	-0.002	0.004
	**[-2.47]	[-1.13]	*[1.82]	[-0.97]	[-1.10]	**[2.47]
D_{EUREX}	-0.002	0.004	-0.001	0.005	-0.005	-0.003
	[-0.41]	[0.89]	[-0.24]	[1.46]	**[-1.96]	*[-1.86]
VDAX_{t-1}	-0.029	0.000	-0.006	-0.043	-0.024	-0.010
	***[-6.13]	[-0.06]	[-0.63]	***[-12.28]	***[-6.11]	**[-2.08]
TTM	-0.009	0.025	0.019	-0.025	0.018	0.000
	[-1.11]	**[2.47]	***[3.65]	***[-3.72]	***[2.80]	[0.12]
LagWarVol	-0.004	-0.003	-0.002	-0.002	-0.001	-0.002
	***[-5.14]	***[-3.18]	***[-4.05]	***[-4.31]	**[-2.19]	***[-4.07]
$\mathbf{CDS}_{t-1}$						
$\lvert\Delta\rvert < .25$	**-0.269**	**-0.213**	**-0.567**	**-0.260**	**-0.207**	**-0.246**
	*****[-4.08]**	****[-2.41]**	*****[-4.03]**	*****[-5.38]**	*****[-2.70]**	*****[-3.48]**
$.25 < \lvert\Delta\rvert < .35$	**-0.305**	**-0.310**	**-0.347**	**-0.271**	**-0.178**	**-0.165**
	*****[-6.74]**	*****[-4.73]**	*****[-3.58]**	*****[-7.36]**	*****[-3.68]**	*****[-2.90]**
$.35 < \lvert\Delta\rvert < .50$	**-0.196**	**-0.191**	**-0.187**	**-0.195**	**-0.120**	**-0.163**
	*****[-5.66]**	*****[-3.55]**	****[-2.52]**	*****[-6.16]**	*****[-2.79]**	*****[-2.96]**
$.50 < \lvert\Delta\rvert$	**-0.125**	**-0.126**	**-0.060**	**-0.193**	**-0.128**	**-0.155**
	*****[-4.20]**	****[-2.31]**	**[-1.00]**	*****[-5.90]**	****[-2.02]**	***[-1.76]**
# Observations	35,724	24,185	20,403	47,162	33,974	26,703
R^2	0.473	0.449	0.307	0.513	0.49	0.271

Table 9: Regression results for warrant premiums, separately for different maturities. Warrant premiums are computed by intrapolation method. Explanatory variables are issuer dummies, $|\Delta|$ and Δ^2, dummies for competition from other warrants (D_{Comp}) and from EUREX (D_{EUREX}), yesterday's market volatility (VDAX_{t-1}), the warrant's time until expiration and its cumulative volume over the previous 2 weeks (LagWarVol). Lagged issuer CDS premium (CDS_{t-1}) is split up into 4 variables that condition on the delta of the warrant. Regressions are OLS with 2-way clustered standard errors following Thompson (2009), clustered by issuer and date.

(a) Short-term



(b) Medium-term



(c) Long-term

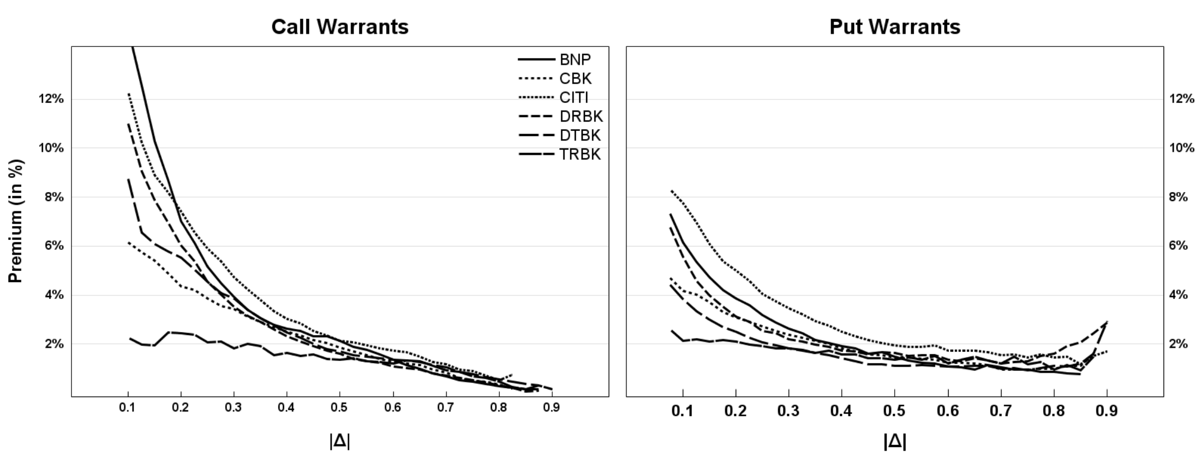


Figure 1: Median percentage premium of warrants over matching options. The figures show the median premium, i.e. percentage overpricing, of warrants relative to matching EUREX options as a function of the warrant's (absolute) delta for the six largest issuers for which we have bid/ask quotes. The sample is split by type (calls vs. puts) and into three maturity ranges matching those used in Table 1: Short-term (1-3 months); medium-term (4-6 months); long-term (7 and more months). Premia are based on warrant mid-quotes matched with imputed EUREX option prices.

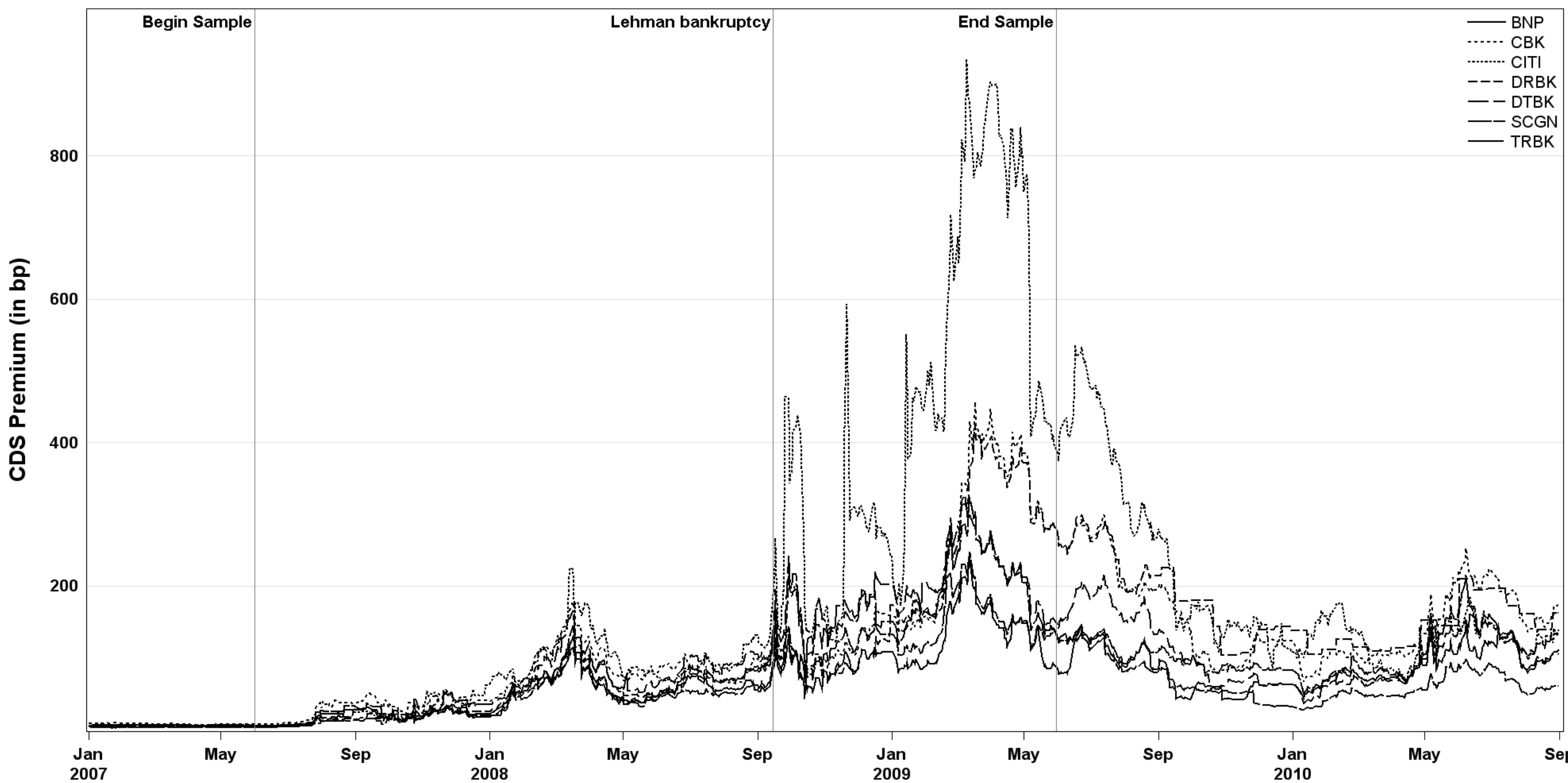


Figure 2: Daily issuer credit default swap premiums (in bp). The figure shows the evolution of credit risk for the 7 issuers in the sample for which credit default swaps (CDS) are traded from January 2007 through September 2010. The sample period covered by transaction and quote data is June 2007 - May 2009. The bankruptcy of Lehman Brothers took place September 15th, 2008. CDS Premiums are end-of-day mid-quotes of issuer 1-year CDS contracts on unsecured debt (except for Citigroup, where it is for 1-year senior secured debt).