

# The Demand for Warrants and Issuer Pricing Strategies\*

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## Abstract

We develop a model for the demand of warrants by individual investors with regard to their sensitivity to issuer margins, defined as the relative overpricing with respect to the theoretical value. Based on an empirical data set we show that investors are relatively margin-sensitive; that is, given similar warrants from different issuers or warrants with similar characteristics, investors tend to buy those with the lowest margin. Investors are, however, not absolutely margin-sensitive; that is, demand is not influenced by the overall margin level. Relative margin sensitivity is particularly observed regarding out-of-the-money warrants, while it is merely existent for in-the-money warrants. Our model suggests that issuers react to different levels of margin sensitivity by different pricing strategies. Consistent with the model's predictions, we find that issuers charge higher margins for in-the-money warrants and lower margins for out-of-the-money warrants. This reaction to different levels of margin sensitivity explains the dependence of issuer margins on a product's moneyness, which has been documented in the literature for several retail derivative products.

JEL Classification: G11, G12, G13, G21

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# 1 Introduction

The importance of the retail market for derivative products has grown immensely over recent decades. Banks and other financial institutions now issue a wide assortment of financial instruments for small investors. Besides structured products such as discount certificates, bonus certificates, or reverse convertibles, securitized plain-vanilla options, also referred to as warrants, are very successful. In contrast to classical warrant markets, where warrants are usually written on the issuer's own stock, these bank-issued warrants have a broad range of underlying securities; for example various single stocks, stock indices, or commodities. While "traditional" warrants entitle the holder to buy new shares of the issuing companies, bank-issued warrants refer to existing shares, or, they are cash-settled, in other words, they pay the holder a cash amount equal to the intrinsic value at maturity. After issuance, the warrants are traded at an exchange. In many European and Asian countries, markets for bank-issued warrants coexist with "classical" options markets, organized by options exchanges. At these options exchanges, market participants deal with a central counterpart and a number of (competing) market makers. In contrast, the market maker for bank-issued warrants is the issuing bank itself. A further major difference is the market access for small investors. To trade at an options exchange, an individual investor usually must sign a special agreement with a broker. Furthermore, minimum trading lots apply, which can be too high for small investors. Bank-issued warrants, on the other hand, are especially designed for small investors who can trade these instruments with small volumes and fewer restrictions.

In this paper, we analyze the habits of investors who buy bank-issued warrants with respect to their margin sensitivity. As the issuers of the warrants are simultaneously the market

makers, traded prices are not directly the result of supply and demand, but are prone to the price-setting policy of the issuer. As former research shows (e.g., Bartram et al., 2008, ter Horst and Veld, 2008), quoted prices include a margin above the theoretical fair product value (*overpricing*). The existence of a margin is justified by market restrictions for small investors, who are not able to trade similar options, but are dependent on issuers' offers and quotes of warrants.

It is well known that individual investors often do not act rationally or skillfully in their investment decisions.<sup>1</sup> In contrast to easily observable prices e.g. for consumer goods, these margins are not readily observable. Therefore, standard theories about supply and demand lack validity in our context. In fact, the identification of margins is a mentally demanding task which requires a considerable amount of attention, cognitive abilities and time. According to psychological standard models such as Kahneman (1973), however, attention is a limited resource and, accordingly, valuation skills of individual investors are limited. Although some brokers and financial information providers offer internet tools which reduce the difficulty of a margin sensitive investment, a margin comparison is not as straightforward as with consumer goods, since warrants from different issuers may vary in terms of key characteristics, such as strike price and maturity date. Due to the aforementioned limitations of individual investors, it remains to ascertain whether margins are opaque to individual investors, or if retail investors consider the size of the margin in their investment decision.

While recent papers have analyzed margins of warrants and other retail derivatives (see the overview in Section 2), none have focused on investor reactions to these margins. The

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<sup>1</sup>See for example Barber and Odean (2013) for an overview of irrational stock trading behavior of individual investors, and Bauer et al. (2009) or Meyer et al. (2014) for retail derivatives markets.

primary goal of this paper is to shed light on this largely unexplored field. Its major contribution is twofold: First, we develop a theoretical model of warrant demand with regard to investor margin sensitivity and carry out a game-theoretic analysis of issuer pricing strategies within this model. Second, we calibrate this model by conducting an empirical analysis of small investors' warrant demand which is dependent on issuer pricing. The results widen our understanding of retail investor behavior at derivatives markets and corresponding issuer pricing policies.

The model features three key variables that describe aggregate investor preferences with respect to margin sensitivity: (i) relative margin sensitivity with respect to the issuing bank; that is, the degree to which investors are willing to change their preferred issuer for the sake of lower margins; (ii) relative margin sensitivity with respect to warrant characteristics; that is, the degree to which investors are willing to buy warrants with characteristics that deviate from their preferences for the sake of lower margins; and (iii) absolute margin sensitivity; that is, the degree to which investors are leaving the warrant market and do not invest at all if there is no warrant that sufficiently meets their preferences in terms of issuer, characteristics, and margin.

Based on a homogeneous data set of bank-issued warrants traded on the world's largest warrant market, the EUWAX (European Warrant Exchange), the results show that relative margin sensitivity with respect to the issuing bank is high; in other words, investors (at least some of them) compare margins of different issuers and choose the cheapest one. Investors are also relatively margin-sensitive with respect to warrant characteristics; that is, they compare margins of similar warrants offered by the same issuer. In contrast, investors are not absolutely margin-sensitive.

Differentiating between in-the-money and out-of-the-money warrants, we find that relative

margin sensitivity, with respect to the issuing bank, is particularly high for in-the-money warrants. Consistent with this finding, issuers differentiate their pricing strategy in a way that incorporates lower margins when investors are more margin-sensitive, and vice versa. The remainder of the paper is organized as follows. Section 2 reviews the literature. Section 3 develops the theoretical model of warrant demand. Section 4 describes our approach for empirically calculating warrant margins. The section also illustrates the data sample and provides some descriptive statistics of investor trading activity and issuer margins. Section 5 presents the empirical results, first by providing a statistical analysis to calibrate the theoretical model, and second, by showing how issuers react to investor demand. Section 6 concludes the paper with a discussion of the results.

## **2 Literature Review**

Despite the importance of the retail warrant market, research on this segment is sparse. Bartram and Fehle (2007) and Bartram et al. (2008) analyze the price quotes of warrants on the EUWAX and its options exchange counterpart, the Eurex, concentrating on bid-ask spreads instead of issuer margins. ter Horst and Veld (2008) compare quotes of warrants and options on the Dutch market. They report large price differences between the two markets, biased to an overpricing of warrants relative to their options counterparts which reaches values of up to 30%. These findings underscore the fact that warrants are primarily designed for the small and uninformed investor who is not able to trade at the options exchange for the aforementioned reasons. As an additional argument, ter Horst and Veld mention the framing effect first brought up by Kahneman and Tversky (1979), and applied to the design and marketing of financial products by Shefrin and Statman (1993). Within

this line of reasoning, banks have created a special image for warrants through an active marketing campaign. They have managed to frame warrants in such a way as to appear like a completely different financial instrument than options.

Schmitz and Weber (2012) analyze the trading behavior of individual investors in warrants based on a data set of a discount broker ending in 2001. They find a negative feedback trading for short-term past returns, meaning that investors tend to buy warrants after their prices have declined, and to sell warrants after their prices have increased. The main reason for trading is speculation—hedging does not play an important role for buying options, as only in very rare cases do investors who buy put options hold the underlying stock in their portfolio.<sup>2</sup> Dorn (2012) finds that retail warrant investors rely on behavioral search heuristics; for example, based on advertising or low nominal prices.

While Schmitz and Weber (2012) and Dorn (2012) are the only studies we are aware of which explicitly analyze the trading behavior of retail warrant investors, neither of them relates this trading behavior to the amount of overpricing by the issuer. The overpricing itself is well studied. The margin, as a measure for overpricing, depends on the time to maturity (*life cycle hypothesis*) and the moneyness of the embedded option (Wilkens et al., 2003, Stoimenov and Wilkens, 2007, Baule et al., 2008, Entrop et al., 2009, among others). But none of these papers establishes a link between overpricing and investor demand.

Investor demand for discount certificates<sup>3</sup> is studied by Baule (2011), who reveals timing preferences of investors for their buying decisions and shows that some issuers utilize their market experience to anticipate these preferences by adjusting their quotes in order to

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<sup>2</sup>Bauer et al. (2009) come to similar conclusions for individual option traders, arguing that gambling and entertainment are important trading motives.

<sup>3</sup>Discount certificates combine an investment in the underlying with a short call.

generate an additional profit. For the warrant market, Ruf (2011) reaches similar results. However, both papers consider investor demand as a given, and analyze issuer reaction to this demand in terms of price-setting. Our paper is the first to analyze the interrelation between issuer pricing and investor reaction to this pricing in terms of investment decisions, and, in turn, the optimal pricing policy given the demand structure.

### 3 A Theory of Warrant Demand

#### 3.1 Model Setup

In this section we develop a formal model to describe how investors choose a specific warrant depending on their margin sensitivity. A priori, an investor has a preference for a certain issuing bank and for certain warrant characteristics (such as strike price and maturity). Some investors are *relatively margin-sensitive*, which means, they are willing to deviate from their preferences and buy a different warrant for the sake of a lower margin. A further (potentially overlapping) group of investors is *absolutely margin-sensitive*, in other words, if all of the warrants that these investors consider preferable are offered at a margin that is too high, they will leave the market and will not buy any warrants. Finally, some investors are not margin-sensitive; that is, they stick to their preferred warrant despite its potentially high margin.

For the following stylized analysis we assume that there are two banks,  $B_1$ ,  $B_2$ , each of them offering two warrants with characteristics  $C_1$  and  $C_2$ . A priori, warrant demand is uniformly distributed, which means, that there is an identical demand normalized to 1 for each combination  $(B_i, C_j)$ . Banks now choose between a low margin  $L$  and a high margin  $H > L$ , separately for each of their warrants. If a warrant is priced at a high margin, the



warrant loses demand because of relative or absolute margin sensitivity of some investors. A share  $b \in [0; 1]$  of all investors is relatively margin-sensitive with respect to the issuing bank, which means, they are willing to change the preferred bank if the same warrant is offered at a low margin by the other bank. Analogously, a share  $c \in [0; 1]$  of the investors is relatively margin-sensitive with respect to warrant characteristics. They are willing to change the preferred characteristics if the same bank offers the other warrant at a low margin. Relative margin sensitivity with respect to the bank and to the characteristics are independent, a share  $b \cdot c$  of the investors is willing to change both if necessary to achieve a low margin.<sup>4</sup> Finally, a share  $a \in [0; 1]$  of the investors is absolutely margin-sensitive, that is, if their preferred warrant and all other warrants that they might switch to are priced at a high margin, they will leave the warrant market. Again, relative and absolute margin sensitivity are independent. This means, for example, a share  $a \cdot b$  of the investors would change the bank to get a low margin, but would leave the market if both banks offer the desired warrant at a high margin.

Figure 1 provides an illustrative example. In this case, Bank 1 chooses a low margin for both warrants, while Bank 2 prices Warrant 1 at a low margin and Warrant 2 at a high margin. Consider the investors that a priori prefer the high-priced Warrant  $(B_2, C_2)$ . A share  $b$  of these investors is willing to go to Bank 1, while a share  $c$  is willing to buy Warrant 1 from Bank 2. The intersection of these two groups, a share  $b \cdot c$ , is equally split. Hence, Warrant  $(B_1, C_2)$  attracts  $b(1 - c/2)$  of the investors who originally preferred  $(B_2, C_2)$ , and Warrant  $(B_2, C_1)$  attracts  $c(1 - b/2)$  of them. Of the remaining  $(1 - b)(1 - c)$  investors, a fraction  $a$  completely leaves the warrant market. The rest,  $(1 - a)(1 - b)(1 - c)$ ,

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<sup>4</sup>If changing one preference (either the bank or the characteristics) is sufficient to achieve a low margin, half of the group  $(b \cdot c/2)$  chooses to change the bank, and the other half chooses to change the characteristics.

are not margin-sensitive, thus remaining with  $(B_2, C_2)$ .

[Insert Figure 1 about here.]

Regarding the resulting profits,  $(B_1, C_1)$  faces a demand of 1 and contributes a profit of  $L \cdot 1$ . Warrant  $(B_1, C_2)$  faces a demand of  $1 + b(1 - c/2)$  and contributes a profit of  $L \cdot (1 + b(1 - c/2))$ . Analogously, the profit contributions for Bank 2 sum up to  $L \cdot (1 + c(1 - b/2)) + H \cdot (1 - a)(1 - b)(1 - c)$ .

Similarly, for any combination of bank pricing strategies, the resulting profit contributions can be calculated depending on the model parameters  $a$  (absolute margin sensitivity),  $b$  (relative margin sensitivity regarding a change in the issuing bank), and  $c$  (relative margin sensitivity regarding a change in the warrant characteristics).

Formally, both banks choose a strategy  $X$  out of the strategy space  $\mathcal{S} = \{LL, LH, HL, HH\}$ .<sup>5</sup>

A combination of strategies of both banks,  $(X_1, X_2) \in \mathcal{S} \times \mathcal{S}$ , results in profit contributions  $\pi_1(X_1, X_2)$  and  $\pi_2(X_1, X_2)$ , which are summarized in Table 1. Both banks seek to optimize their profit which is dependent on the other bank's action, thus resulting in a strategic game for the pricing process.

[Insert Table 1 about here.]

### 3.2 Model Evaluation

Depending on the model environment defined by the three parameters, the strategic game results in different equilibria. The detailed analysis carried out in the appendix yields:

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<sup>5</sup>A strategy  $LL$  means that both warrants are priced with a low margin,  $LH$  means that Warrant 1 is priced with a low margin and Warrant 2 with a high margin,  $HL$  vice versa, and  $HH$  means that both warrants are priced with a high margin.

**Theorem 1** *Let all model parameters be non-trivial; that is, strictly positive and smaller than 1. Then*

1.  $(HH, HH)$  represents a Nash equilibrium if and only if

$$H(1 - a) \geq L(1 + b). \quad (1)$$

2.  $(LL, LL)$  represents a Nash equilibrium if and only if

$$\frac{L}{1 - b} \geq H(1 - a). \quad (2)$$

3.  $(LH, LH)$  and  $(HL, HL)$  represent Nash equilibria if and only if both  $(HH, HH)$  and  $(LL, LL)$  also represent Nash equilibria and furthermore

$$c \leq \frac{H(1 - a) - L(1 + b)}{H(1 - a) - L(1 + b/2)} \quad (3)$$

*holds.*

Proof. See Propositions 1–3 in the appendix. Propositions 4–7 show that there is no other equilibrium. ◇

**Corollary 1** *In the model setup, there is always at least one Nash equilibrium.*

Proof. As  $L(1 + b) \leq L/(1 - b)$ , either (1) or (2) is fulfilled. ◇

If both absolute margin sensitivity and relative margin sensitivity with respect to the bank are low, (1) is fulfilled. Investors then tend to stick to their preferred bank in a loyal way, so that high margins are optimal. If, on the other hand, absolute margin sensitivity and relative margin sensitivity with respect to the bank are high, (2) is fulfilled. Investors then easily leave their preferred bank when margins are high, so that low margins are optimal. Between these distinct cases, within some parameter combinations, both a high-high strategy and a low-low strategy can represent a Nash equilibrium. Figure 2 illustrates

the statement of Theorem 1 and shows which parameter combinations lead to which kind of equilibrium.

[Insert Figure 2 about here.]

The existence of equilibria in “pure strategies”<sup>6</sup> solely depends on the two parameters absolute margin sensitivity,  $a$ , and relative margin sensitivity with respect to the bank,  $b$ . The third parameter, relative margin sensitivity with respect to warrant characteristics,  $c$ , decides whether there are also equilibria in “mixed strategies”; that is, when a bank prices one warrant with a high margin and the other warrant with a low margin. For such equilibria to occur, two conditions must be fulfilled: First, both equilibria in pure strategies must exist (high-high and low-low). Second, relative margin sensitivity with respect to characteristics must be sufficiently low. Otherwise, a bank would lose too much demand from its high-priced warrant to its own low-priced warrant, leading to a drop in total profit.

### 3.3 Calibration Approach

In the following, we carry out an empirical analysis to calibrate the model in terms of the nature of its three parameters. The purpose of the empirical investigation is to conclude to which extent retail warrant investors are absolutely margin-sensitive and/or relatively margin-sensitive. Of course, the real world is far more complex than our simple model setting with two banks and two warrants. We therefore cannot expect to calibrate the

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<sup>6</sup>In slight deviation from standard game theory wording, we use the term *pure strategy* for a strategy that prices both warrants equally, that is, a HH or LL strategy. Analogously, a *mixed strategy* is not a randomized strategy, but a strategy that prices the two warrants differently, that is, a LH or HL strategy.

actual model by acquiring quantitative estimates for the parameters  $a$ ,  $b$ , and  $c$ . We can, however, carry out a qualitative analysis by investigating whether:

- (a) Demand for a warrant decreases if its margin is high in absolute terms.
- (b) Demand for a warrant decreases if margins for the same warrant offered by other banks are lower.
- (c) Demand for a warrant decreases if margins for similar warrants offered by the same bank are lower.

The basic approach for answering these question is to regress the demand of warrant  $i$  at date  $t$ ,  $DEMAND_{i,t}$ , on its margin and that of comparable warrants:

$$\begin{aligned}
 DEMAND_{i,t} = & \alpha + \beta_a MARGIN_{i,t} \\
 & + \beta_b \Delta MARGIN_{i,t}^{banks} \\
 & + \beta_c \Delta MARGIN_{i,t}^{characteristics} \\
 & + \gamma^T Controls_{i,t} + \epsilon_{i,t}.
 \end{aligned} \tag{4}$$

$MARGIN_{i,t}$  is the margin of the respective warrant  $i$  at date  $t$ ,  $\Delta MARGIN_{i,t}^{banks}$  the margin difference to the same warrant offered by other banks ( $MARGIN_{i,t}$  minus margin of other banks),  $\Delta MARGIN_{i,t}^{characteristics}$  analogously, the margin difference to similar warrants offered by the same bank.  $Controls_{i,t}$  is a vector of control variables. This vector and other details of the approach are described in Section 5.1.

If a considerable share of investors is now relatively margin-sensitive with respect to the issuing bank, demand for a warrant should decrease when margins for the same warrant offered by other banks are lower (that is, when  $\Delta MARGIN_{i,t}^{banks}$  is positive)—thus, the regression coefficient  $\beta_b$  should be negative. Analogously, if a considerable share of investors

is relatively margin-sensitive with respect to warrant characteristics, the regression coefficient  $\beta_c$  should be negative. Finally, if after considering changing the bank and/or changing the warrant, a significant amount of investors leaves the market (that is, is absolutely margin-sensitive), demand for a warrant should decrease if its margin  $MARGIN_{i,t}$  is high—thus, the regression coefficient  $\beta_a$  should be negative. (We will discuss the issue of causality in Section 5.1.)

## 4 Margin Calculation and Empirical Data

### 4.1 Warrant Pricing

To calculate the margin incorporated in a warrant quote, we must have the theoretical fair value as a benchmark. It is standard practice to take this theoretical value from the corresponding options market (see for example, ter Horst and Veld, 2008). However, due to the variety of products in terms of strike prices and maturity dates, usually no exactly matching option is available. Therefore, data from the options market have to be interpolated to match the exact features of the warrant under consideration. It is also common practice to calculate implied volatilities for instruments at the options market and transfer these implied volatilities to the retail derivative, that is, the warrant.

For calculating implied volatilities for call and put options, we use the classical framework of Black and Scholes (1973).<sup>7</sup> In general, implied call and put volatilities are not identical because of market imperfections and a possible mismatching in the assignment of the

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<sup>7</sup>Note that we do not assume that the restrictive assumptions of the Black-Scholes model hold. The implied volatilities are only needed for the purpose of interpolation. Instead, we could directly interpolate options prices without using a valuation model. The interpolation of implied volatilities however leads to a higher smoothness.

underlying level. Following Hentschel (2003), we do not rely on a simple average between the call and put volatility but rather make use of the put-call parity. Given a pair of call price  $c_t$  and put price  $p_t$  of European-style options with identical strike price  $X$  and maturity  $\tau$ , put-call parity provides an implied level of the underlying which matches both the call and the put price:

$$S_t^{implied} = c_t - p_t + X e^{-r(\tau-t)}, \quad (5)$$

where  $r$  is the risk-free rate. The calculation of implied volatilities with this underlying level results in identical values for calls and puts.

Given implied volatilities for the complete range of options at the respective date, we assign options with strike prices and maturity dates similar to the considered warrant and calculate an interpolated implied volatility. In particular, we apply a successive two-dimensional interpolation for the dimensions time to maturity and strike.<sup>8</sup>

As the DAX is a performance index, no dividend payments have to be considered and hence the standard Black-Scholes formula can be employed to obtain the theoretical value  $W_{i,t}$  of a call warrant  $i$  at time  $t$ :

$$W_{i,t} = S_t N(d_1) - X_i e^{-r(\tau_i-t)} N(-d_1 + \sigma_{i,t} \sqrt{\tau_i - t}) \quad (6)$$

with

$$d_1 = \frac{\log(S_t/X_i) + (r + \sigma_{i,t}^2/2)(\tau_i - t)}{\sigma_{i,t} \sqrt{\tau_i - t}}. \quad (7)$$

$S_t$  stands for the price of the underlying at time  $t$ , and  $\sigma_{i,t}$  is the assigned interpolated volatility.  $X_i$  is the strike price of the warrant,  $\tau_i$  its expiry date. Additionally, we correct the prices for default risk by using the Hull and White (1995) approach. According to this

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<sup>8</sup>See Baule (2011) for details on this interpolation.

approach, the default-adjusted value of a claim is its default-free value, discounted by the issuer’s credit spread:

$$W_{i,t}^{adj} = e^{-(\tau_i - t)s_{j(i),t,\tau_i}} W_{i,t}, \quad (8)$$

where  $s_{j(i),t,\tau_i}$  is the credit spread at time  $t$  for maturity  $\tau_i$  of the issuer  $j$  of warrant  $i$ .

The resulting default-adjusted theoretical value  $W_{i,t}^{adj}$  will be compared to the quoted warrant price  $W_{i,t}^{quote}$ . The difference is the absolute gross margin charged by the issuer.

We define the margin relative to the theoretical value:

$$MARGIN_{i,t} = \frac{W_{i,t}^{quote} - W_{i,t}^{adj}}{W_{i,t}^{adj}}. \quad (9)$$

## 4.2 Data

Our warrants data set covers all trades of plain-vanilla DAX call warrants on the EUWAX for a one-year period, from January through December 2009. We concentrate on call warrants in order to avoid incorporating the early exercise premium of American-style put warrants as a potential source of pricing uncertainty. Furthermore, to have a homogeneous sample, we restrict our analysis to warrants with a remaining lifetime between 1 and 12 months, and to a moneyness between  $-15\%$  and  $+15\%$ .<sup>9</sup> This restriction rules out warrants with a value of a few cents (which are short-termed and/or deep out of the money). We further concentrate on the five largest issuers.<sup>10</sup>

For our analysis, we need to distinguish between trades in which the investor originally buys a warrant, and trades in which the investor sells a warrant back to the issuing bank. To identify investor buy and sell trades, we match the trade price with the corresponding

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<sup>9</sup>Moneyness is defined as the relative difference between underlying and strike price,  $(S - X)/S$ .

<sup>10</sup>We actually only neglect issuers with less than 100 executed trades in our sub-sample and issuers for which no daily credit spreads are available.



bid-ask quote of the market maker (the issuing bank). If possible, the exact (to the second) bid-ask quote is assigned to each trade. Otherwise, the closest foregoing quote is applied. If such a quote does not exist for the respective trading day, the trade is omitted. In case the trade price equals the assigned ask quote, the trade is classified as an investor buy trade. If the trade price equals the assigned bid quote, the trade is classified as an investor sell trade. Due to missing values in the quote data, the trade price does not always exactly match a bid or ask quote. Therefore, we extend the classification of an investor buy to all trades with a price higher than the assigned ask quote, and an investor sale to all trades with a price lower than the assigned bid quote.<sup>11</sup> If the observed trading price ranges between the bid and ask quote, the trade is omitted. In total, about 7.5% of our observations are not classifiable and are therefore omitted. About 60% of the trades can be identified as an investor buy.<sup>12</sup> After finally deleting trades which appear to be not reasonable (trades with an order size of only 1 warrant), we end up with a data sample of about 23,000 evaluated investor buy trades.

To calculate the warrant values and margins, we need additional market data. For calculating implied volatilities, we employ option prices at the Eurex, using all available call and put series on the DAX. We use daily settlement prices to obtain implied underlying levels according to (5). Despite the fact that in our analysis we concentrate on call warrants only, we also use information from put option prices in order to avoid a synchronization

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<sup>11</sup>Basically, this procedure equals that applied by Baule (2011).

<sup>12</sup>There are two reasons why there are more investor buys than investor sales: First, some investors hold their warrant until expiry and do not sell it back at all. Second, investors tend to build up their position in a single warrant in several trades, but settle their position by selling back all the warrants within a single trade.

of call prices with the underlying market, which would be an additional source of error. For applying the Black-Scholes formula to calculate warrant prices, we use DAX tick data from the electronic trading system XETRA with a frequency of one second.<sup>13</sup> For the risk-free interest rate structure we use the Svensson (1994) function estimated for governmental spot rates by the Deutsche Bundesbank. Finally, as our sample is restricted to certificates with maturities of less than one year, we use the issuer's one-year spread for senior credit default swaps (obtained from Datastream) for the default risk adjustment.

### 4.3 Measuring Demand and Margins

For the measurement of demand, we follow three different approaches. First, we consider the daily traded volume of a warrant in Euros; second, we examine the delta-adjusted number of traded warrants per day; and third, we review the daily number of executed orders. While the first approach is a straightforward measure which recognizes the size of a trade, the third measure shifts attention to smaller investors as all trades are equally considered, independent of their order size. The second measure also considers the size of a trade; however, it does so with an adjustment correcting for the leverage effect of different warrants. This adjustment is applied by multiplying the number of traded warrants with the warrant delta ( $N(d_1)$ ) to obtain a demand for a delta-equivalent position in the underlying.

The key dependent variables are based on issuer margins; however, if we only relied on margins of executed trades, we would suffer from a severe selection bias. This bias is easily illustrated: Assume that there are two groups of otherwise identical warrants, expensive

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<sup>13</sup>As the official DAX trading ends at 5:30 p.m., trades occurring after that time have to be omitted, as no underlying level can be assigned.

warrants and cheap warrants. If all investors were margin-sensitive, they would only buy the cheap warrants. If we then based our analysis on these actual trades, we would observe constant margins and could not conclude a margin sensitivity.

In fact, we also need to consider warrants which are not traded at all. Therefore, we cannot rely on margins of actually executed trades; instead, we use a demand-independent measure of margins. For all warrants, the EUWAX records one fictitious trade with volume 0 around midday, based on the binding issuer bid quote at that time. We use this midday quote as a representative for the pricing of the respective warrant for each day.<sup>14</sup>

This procedure implicitly assumes that the margin calculated with the midday quote is a good proxy for all other margins of the day. To analyze this assumption, we regress the observed margins  $MARGIN_{i,t}^{act}$  of actual trades on the corresponding midday margins  $MARGIN_{i,t}$ . The result is summarized as

$$MARGIN_{i,t}^{act} = \begin{matrix} 1.83\% \\ (0.02\%) \end{matrix} + \begin{matrix} 0.769 \\ (0.005) \end{matrix} MARGIN_{i,t} + \epsilon_{i,t}, \quad r^2 = 0.516. \quad (10)$$

Although there is no perfect relationship, the fact that the regression coefficient is not far from 1 and the (adjusted)  $r^2$  is relatively large, is a good indication that midday margins are a reasonable proxy for actual margins.<sup>15</sup>

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<sup>14</sup>Although most of the midday quotes are recorded between 12 a.m. and 1 p.m., sometimes the “midday” quote is recorded early in the morning or late in the afternoon. Furthermore, there are cases where more than one midday quote is recorded. In these cases we apply the earliest quote of the day. In some rare cases, the earliest midday quote is recorded after 5:30 p.m. As with the actual trades, these midday quotes have to be omitted, as no underlying level can be assigned to determine the margin.

<sup>15</sup>The constant of 1.83% refers to the fact that midday margins are based on bid quotes, while actual trade margins are based on ask quotes.

#### 4.4 Descriptive Statistics

In this subsection, we provide some descriptive statistics on the demand for call warrants and our data set. Figure 3 illustrates an overview of the aggregate demand, separated by the key characteristics, moneyness and (remaining) time to maturity. The graph covers all issuer buy trades of call warrants on the EUWAX within our one-year investigation period without the restrictions described above.

[Insert Figure 3 about here.]

Demand is highest for warrants at or near the money with a relatively short time to maturity. It decreases considerably with times to maturity that are larger than 6–12 months, and with absolute moneyness larger than 15%. This observation justifies our restriction to the data set, which leaves us with a homogenous subsample with the benefits described above, and still covering 48% of the overall demand.

Table 2 shows the key figures regarding the trading activity and pricing policy, as grouped by the issuer. It illustrates the number of trades, delta-adjusted number of traded warrants, trading volume in Euros, average margin of investor buy trades and the standard deviation of this margin. All figures refer to DAX call warrants with a moneyness of  $-15\%$  to  $+15\%$  and time to maturity between 1 and 12 months, traded in the investigation period on the EUWAX.

[Insert Table 2 about here.]

## 5 Empirical Evidence

### 5.1 Investor Price Sensitivity

This section provides the results of our model calibration, which is, the structure of investor demand and margin sensitivity. We therefore carry out the basic regression approach (4) in more detail. As discussed in Section 4.3,  $MARGIN_{i,t}$  is the midday margin of warrant  $i$  at date  $t$ , and  $DEMAND_{i,t}$  is one of three measures: Volume, delta-adjusted number of traded warrants, and number of trades.

Regarding the margin differences to other warrants,  $\Delta MARGIN_{i,t}^{banks}$  is the margin difference to the best-priced warrant (that is, the warrant with the lowest margin) with identical strike price and maturity of competing banks.<sup>16</sup> (The difference is negative if warrant  $i$  has a lower overpricing than all competitors.) On average, a single warrant in our dataset is offered by 3.3 different banks.

As for characteristics, we distinguish between the two main warrant features—strike price and time to maturity. We consider two variables that refer to relative margin sensitivity with respect to characteristics (model parameter  $c$ ):  $\Delta MARGIN_{i,t}^{char.strike}$  and  $\Delta MARGIN_{i,t}^{char.mat}$ . The first is the margin difference to the better priced warrant out of the two warrants of the same issuer with identical maturity and directly adjacent strike prices.<sup>17</sup> The second is the margin difference to the best-priced warrant of the same issuer

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<sup>16</sup>Maturities are clustered around the expiry dates of the option exchange (Eurex), with slight differences across the issuers. For instance, one issuer might have warrant series maturing on March 23rd and June 22nd, while another issuer has series maturing on March 21st and June 19th. We consider maturity dates as identical if they refer to the same option expiry date.

<sup>17</sup>For example, for a warrant  $i$  with strike price 6200, we consider warrants with strike prices 6150 and 6250, if existent, or 6100 and 6300 otherwise as directly adjacent.

with identical strike price and directly adjacent maturities.

Besides the potential effect of the margin, demand for a certain warrant can be driven by a number of influencing factors which we control for. First, we consider a fixed effect for each trading day,  $DAY_t$ . These fixed effects cover the influence of daily market conditions, such as signed and unsigned market returns, volatility levels, etc., which are identified by Schmitz and Weber (2012) as influencing factors of warrant demand. By incorporating trading day dummies, we do not have to explicitly control for all these market factors. We additionally consider a fixed effect for each issuer,  $ISSUER_{k(i)}$ , as well as a dummy for the exercise style of the warrant,  $AMERICAN_i$ , which takes the value 1 if the warrant is American-style and 0 if it is European-style.

As discussed, Figure 3 shows that the demand for warrants depends on the warrant characteristics time to maturity and moneyness. We recognize these effects by incorporating further control variables:  $TIME_{i,t}$  is the remaining time to maturity in years,  $MONEY_{i,t}$  the moneyness as defined above. We also control for moneyness squared, as Figure 3 shows a maximum in demand for warrants near the money, and decreasing demand when moneyness either decreases or increases from 0.

It became obvious that certain warrant characteristics tend to attract investors extraordinarily. Investors seem to have strong preferences for “round” strike prices. They prefer, for example, a warrant with a strike price of 6,000 over an otherwise identical warrant with a strike price of 6,050, although they are very similar from an economic perspective.<sup>18</sup> We therefore include a set of control dummy variables,  $ROUND_{\rho,i}$  with

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<sup>18</sup>Round strike prices obviously are attention-grabbing features. This argumentation is in line with Barber and Odean (2008), who show that investors prefer investing in companies which frequently appear in the news.

$\rho \in R := \{1,000; 500; 200\}$ , into the regression framework. The dummy variable  $ROUND_{\rho,i}$  takes the value 1 for warrant  $i$  if  $\rho$  is the largest divisor out of the set  $R$  so that the division  $X_i/\rho$  is feasible without rest. By means of this definition, we can take a look on the effect of the feature “strike price divisible by  $\rho$ ” for the divisors  $\rho \in R$  in descending order.

Summing up, the basic approach (4) takes the explicit form

$$\begin{aligned}
DEMAND_{i,t} = & \alpha + \beta_a MARGIN_{i,t} + \beta_b \Delta MARGIN_{i,t}^{banks} \\
& + \beta_{c1} \Delta MARGIN_{i,t}^{char.strike} + \beta_{c2} \Delta MARGIN_{i,t}^{char.mat} \\
& + \gamma_1 TIME_{i,t} + \gamma_2 MONEY_{i,t} + \gamma_3 MONEY_{i,t}^2 \\
& + \gamma_4 AMERICAN_i + \sum_{k=1}^5 \gamma_{4,k} ISSUER_{k(i)} \\
& + \gamma_{6,t} DAY_t + \sum_{\rho \in \{1,000;500;200\}} \gamma_{7,\rho} ROUND_{\rho,i} + \epsilon_{i,t}. \quad (11)
\end{aligned}$$

In order to correct for heteroscedasticity and autocorrelation of up to five lags, we employ Newey and West (1987) corrected standard errors.

The regression approach calls for discussion in terms of causality. Do the margins drive the demand, or does the demand drive the margins? For this, we tested the time series of demand and margins individually for each warrant for Granger causality. The null hypothesis of the test, “Demand does not Granger-cause margins” has to be rejected for about 10% of all warrants on a 5% significance level. Randomly, we would expect a number of 5%, so we can infer that we do not face a severe causality problem. As part of our robustness checks, we exclude those 10% warrants from our sample.<sup>19</sup>

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<sup>19</sup>Besides this statistical analysis, there is another strong argument for the assumed causality: If issuers reacted to investor demand according to standard economic theory, margins should increase with the demand—we would see a positive relationship between the two variables. If on the other hand investors react to issuer pricing, demand should decrease with the margins—we would see a negative relationship.

The results are given in Table 3. To analyze relative margin sensitivity, we take a look at the regression coefficients  $\beta_b$ ,  $\beta_{c1}$ , and  $\beta_{c2}$ . Regarding relative margin sensitivity with respect to the bank, the coefficient  $\beta_b$  is highly significant for all of our three demand measures. A one percentage point increase of overpricing of the cheapest competing bank increases the daily demand by about 270 Euros. This figure amounts to about 13% of average daily trading volume (see Table 2) and is thus economically meaningful. (Note that this amount refers to a single warrant—scaled to the overall turnover with DAX warrants restricted to our sample in 2009, the value amounts to 26 million Euros.) We can therefore conclude that relative margin sensitivity with respect to the bank is high, meaning that customer loyalty is low. Warrant investors are willing to switch to an otherwise identical warrant of a different issuer with lower margin.

Such “bank picking” is aided by internet-based comparison tools. Looking at the same warrant offered by different banks, investors can directly compare *prices* instead of calculating margins. Thus, substituting the issuing bank is an easier task than substituting warrant characteristics, as it requires no valuation skills, only a comparison effort. The specialty of the warrants market and of the warrant investors might be the reason why we observe that bank loyalty is not as pronounced as in other recent studies.<sup>20</sup>

[Insert Table 3 about here.]

Regarding relative margin sensitivity with respect to characteristics, the coefficient  $\beta_{c1}$  for

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Foretelling the sign of our results, the found negative relationship is further strong evidence for the suggested causality.

<sup>20</sup>For example, Baumann et al. (2007) provide survey results which suggest that most bank customers would not necessarily leave their bank even if competitors offered lower charges and/or better interest rates and find it rather unlikely that they will be looking for a new bank within the next six months.



the strike price is also highly significant for all three demand measures. Thus, investors are relatively margin-sensitive with respect to the strike price: They compare similar warrants of their preferred issuer and tend to choose a warrant with a comparatively low margin. The size of this effect is even stronger than for competing banks: An increase of one percentage point of the overpricing of the cheapest warrant with a similar strike increases the daily demand by about 470 Euros, or 23%. Obviously, a significant share of investors is able to compare not only prices, but also incorporated margins. Again, internet tools can support such comparisons, as they provide figures such as implied volatilities that are related to the margins.

The coefficient  $\beta_{e2}$  for the time to maturity is significant for two of the three measures; however, only at the 5% level, and with a considerably lower size. Investors are only slightly influenced by margins of warrants with the same strike but with other maturities. Observing a low relative margin sensitivity with respect to time to maturity is, however, not very surprising, as opposed to strike prices, offered maturity dates are rather sparse. Basically, there are only four maturity dates per year, related to the quarterly option expiry dates at the Eurex. Therefore, investors cannot change their desired time to maturity by just a little, they would have to deviate by about three months. For example, switching from a preferred maturity of six months means choosing between three or nine months, which is in any case an economically substantial deviation. Thus, given the sparse set of available maturities, we cannot draw a concise conclusion about relative margin sensitivity with respect to maturity—maybe investors would like to change the desired maturity by one month, but there is no warrant to do so. In the following, we therefore concentrate on the strike price as the key characteristic when discussing relative margin sensitivity with respect to characteristics.

Finally, as the regression coefficient  $\beta_a$  shows, there is no significant impact of the warrant margin itself on the demand after controlling for margin differences to similar warrants and other issuers (among the other control variables). Hence, we can conclude that no substantial share of warrant investors who are absolutely margin-sensitive exists.

Summing up, the results of the qualitative model calibration are as follows:

- (a) Absolute margin sensitivity is low.
- (b) Relative margin sensitivity with respect to the bank is high.
- (c) Relative margin sensitivity with respect to the characteristics (strike price) is high.

These findings are robust to a number of checks. As it is questionable if retail investors actually perceive default risk, we checked for different outcomes when refraining from incorporating issuer credit risk.<sup>21</sup> Our results are virtually identical to the base case with risk-adjustment. Additionally, addressing the potential problem of causality, we excluded all warrants for which we had to reject the null of our Granger causality test. Again, our main results do not alter. Furthermore, it is worth mentioning that our findings hold for three different measures of demand, which can be seen as a robustness check by itself.

## 5.2 Issuer Pricing Strategies

The empirical results regarding the two model parameters  $a$  and  $b$  do not allow for a clear derivation of an optimal pricing strategy, as absolute margin sensitivity is low, while relative margin sensitivity with respect to the bank is high. Figure 2 indicates that the

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<sup>21</sup>Several empirical papers on warrant pricing do not consider issuer default risk, including Bartram and Fehle (2007), Bartram et al. (2008), and ter Horst and Veld (2008).

warrant market is in the upper left region, where both a low-margin strategy and a high-margin strategy can represent an equilibrium. However, as the parameter estimation is only a qualitative result, such a conclusion should be seen carefully. In this subsection, we establish a link between the model-implied equilibrium results, the observed investor behavior in terms of margin sensitivity, and actual issuer pricing strategies.

Previous research has repeatedly shown that issuer margins of retail derivatives depend on the time to maturity and the moneyness of the product (see the literature overview in Section 2). The first dependency is the life cycle hypothesis which is well understood as an economic necessity: Issuers incorporate a positive margin at the beginning of a product's lifecycle to make a profit, while the margin must be close to zero near maturity for transparency reasons.<sup>22</sup> The second dependency, though frequently observed, is still lacking a satisfying explanation. Why does the margin depend on the moneyness of a product? Before considering this question in our framework, we carry out a margin regression to confirm the dependencies for the warrants market.

As it is common practice in margin regressions, we analyze each issuer separately. Furthermore, we conduct a combined regression and include all issuers with issuer dummies  $ISSUER_{k(i)}$ . The combined margin regression model reads

$$\begin{aligned}
 MARGIN_{i,t} &= \alpha + \beta_1 TIME_{i,t} + \beta_2 MONEY_{i,t} \\
 &+ \beta_3 MONEY_{i,t}^2 + \beta_4 AMERICAN_i + \sum_{k=1}^5 \beta_{5,k} ISSUER_{k(i)} + \epsilon_{i,t}, \quad (12)
 \end{aligned}$$

where  $TIME_{i,t}$  is the remaining time to maturity, and  $MONEY_{i,t}$  is the moneyness of warrant  $i$  at date  $t$ . Results are displayed in Table 4. The regression estimates confirm the life cycle dependency and a strong influence of the moneyness on the margin, which

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<sup>22</sup>See e.g. Baule (2011) for details.

is consistent throughout all issuers.

[Insert Table 4 about here.]

To see the size of the moneyness effect, Table 4 also shows the average margins for in-the-money and out-of-the-money warrants. It becomes evident that margins for out-of-the-money warrants are on average more than twice as large as for in-the-money warrants.

Thus, issuers choose different pricing strategies for different segments of the warrants market. Within the light of our model, such a behavior can be explained if either a mixed strategy is optimal, or the model parameters describing investor margin sensitivity vary for different segments. To shed light on this issue, we run the demand regression (11) separately for in-the-money and out-of-the-money options. Table 5 shows the results.

[Insert Table 5 about here.]

Indeed, the results exhibit differences in the margin sensitivity, particularly in relative margin sensitivity. The observed relative margin sensitivity with respect to the issuing bank for the overall sample almost exclusively stems from in-the-money warrants, while for out-of-the-money warrants, no relative margin sensitivity is evident. So there are considerable differences in investor margin sensitivity for different segments of the warrants market: For out-of-the-money warrants, we observe the patterns of relative margin sensitivity as described for the overall sample, while for in-the-money warrants, margin sensitivity is much lower.

To explain this different behavior, one might consider different investors in the two segments. Out-of-the-money warrants exhibit extreme leverage ratios with respect to the underlying and are thus highly speculative. Such characteristics might attract speculative-oriented investors with small investment horizons (for example, day traders who buy and

sell warrants at the same day), who carefully consider and compare offered prices and margins. In-the-money warrants, on the other hand, with moderate leverage ratios could attract other investors with a longer investment horizon who do not spend too much effort in comparing quotes and margins.

Putting our findings about investor margin sensitivity and issuer pricing together, we ascertain a coherent picture of the market: With low relative margin sensitivity (with respect to the issuing bank), together with low absolute margin sensitivity, a high-margin strategy is optimal, as is pursued by the issuers for out-of-the-money warrants according to Table 4. With higher relative margin sensitivity (lower bank loyalty), as observed for in-the-money warrants, lower margins become optimal. Indeed, issuers price lower margins for in-the-money warrants.

In this light, we can now provide an economically reasonable explanation for the moneyness effect that several studies analyzing retail derivative markets have observed: The margins depend on the moneyness, because investor margin sensitivity (relative with respect to the issuing bank) depends on the moneyness. Issuers react to different margin sensitivity in different market segments by charging higher margins when relative margin sensitivity is low, and charging lower margins when relative margin sensitivity is high. According to our theoretical analysis, such strategies represent Nash equilibria, meaning that it is not reasonable for single issuers to deviate from their pricing strategy.

## **6 Conclusion**

We investigate the demand and margin sensitivity of retail warrant investors on the world's largest warrants exchange, the EUWAX. Issuers, as market makers, charge a margin on

top of the theoretical warrant values. As this margin is not directly observable to retail investors, it is questionable whether investors recognize the extent of issuer overpricing. Investors can, however, spend efforts to acquire information about the margin size by using internet valuation and comparison tools.

By regressing investor demand on warrant margins, our study shows that, on average,

- investors are margin-sensitive with respect to identical warrants issued by other banks, that is, their loyalty to a preferred bank is limited;
- investors are margin-sensitive with respect to similar warrants offered by the same bank; and
- investors are not absolutely margin-sensitive in the sense that they do not leave the market if all considerable warrants are priced with a margin that is too high.

These results show that individual warrant investors are not as uninformed or irrational as recent literature (e.g., Meyer et al., 2014) suggests for other segments of the retail derivative markets. A significant share of investors is able to compare prices and even margins, and incorporates this information into their investment decisions.

A closer look at relative price sensitivity reveals that it is particularly pronounced for out-of-the-money warrants. Consistent with this different price sensitivity for different market segments, issuers pursue different pricing strategies: For out-of-the-money warrants, incorporated margins are more than twice as large as for in-the-money warrants. Such a dependency of issuer pricing of product moneyness has been observed for several other retail derivative products in the past years. For the first time, we can offer a satisfactory explanation for this effect. Issuers pursue different pricing strategies as a response to different investor margin sensitivity.

## Appendix: Equilibria of the Game-Theoretic Model

In this appendix we formally evaluate the game-theoretic model and show, under which conditions certain strategies represent an equilibrium. Each bank chooses a strategy  $X$  out of the strategy space  $\mathcal{S} = \{LL, LH, HL, HH\}$ . A combination of strategies of both banks,  $(X_1, X_2) \in \mathcal{S} \times \mathcal{S}$  results in profit contributions  $\pi_1(X_1, X_2)$  and  $\pi_2(X_1, X_2)$  according to Table 1. Such a combination is a Nash equilibrium if and only if no bank can increase its profit contribution by switching to a different strategy, that is,  $\pi_1(X_1, X_2) \geq \pi_1(X, X_2) \forall X \in \mathcal{S}$  and  $\pi_2(X_1, X_2) \geq \pi_2(X_1, X) \forall X \in \mathcal{S}$ . The model parameters  $a$ ,  $b$ , and  $c$  are restricted to the interval  $[0; 1]$ . For technical reasons, we assume that all parameters are strictly positive and smaller than 1.

**Proposition 1** *A  $(LL, LL)$  strategy represents an equilibrium if and only if*

$$L \geq H(1 - a)(1 - b). \quad (13)$$

Proof. According to the symmetry, it is sufficient to consider Bank 1. Let the strategy choice be  $(LL, LL)$ .

(i) The bank would not profit from a switch to a  $HH$  strategy if and only if (13) holds:

$$\begin{aligned} \pi_1(LL, LL) = 2L &\geq 2H(1 - a)(1 - b) = \pi_1(HH, LL) \\ \Leftrightarrow L &\geq H(1 - a)(1 - b). \end{aligned}$$

(ii) Let  $L \geq H(1 - a)(1 - b)$ . The bank would not profit from a switch to a  $LH$  or  $HL$  strategy:

$$\begin{aligned} \pi_1(LL, LL) &= 2L \\ &\geq 2L - L \cdot b/2 \end{aligned}$$

$$\begin{aligned}
&= L(1 + c(1 - b/2)) + L(1 - c) \\
&\geq L(1 + c(1 - b/2)) + H(1 - a)(1 - b)(1 - c) \\
&= \pi_1(HL, LL) = \pi_1(LH, LL).
\end{aligned}$$

◇

**Proposition 2** *A (HH, HH) strategy represents an equilibrium if and only if*

$$H(1 - a) \geq L(1 + b). \quad (14)$$

Proof. According to the symmetry, it is sufficient to consider Bank 1. Let the strategy choice be (HH, HH).

(i) The bank would not profit from a switch to a LL strategy if and only if (14) holds:

$$\begin{aligned}
\pi_1(HH, HH) = 2H(1 - a) &\geq 2L(1 + b) = \pi_1(LL, HH) \\
\Leftrightarrow H(1 - a) &\geq L(1 + b).
\end{aligned}$$

(ii) Let  $H(1 - a) \geq L(1 + b)$ . The bank would not profit from a switch to a LH or HL strategy:

$$\begin{aligned}
\pi_1(HH, HH) &= 2H(1 - a) \\
&\geq 2H(1 - a) - c[H(1 - a) - L(1 + b)] \\
&= H(1 - a) + L \cdot c(1 + b) + H(1 - a)(1 - c) \\
&\geq L(1 + b) + L \cdot c(1 + b) + H(1 - a)(1 - c) \\
&= L(1 + b + c + bc) + H(1 - a)(1 - c) \\
&= \pi_1(HL, HH) = \pi_1(LH, HH).
\end{aligned}$$

◇



**Lemma 1** *A necessary condition for the (LH, LH) strategy to be an equilibrium is that both the (LL, LL) and the (HH, HH) strategies are also equilibria, that is,*

$$L(1 + b) \leq H(1 - a) \leq \frac{L}{1 - b}. \quad (15)$$

Proof. According to the symmetry, it is sufficient to consider Bank 1. Let the strategy choice be (LH, LH).

(i) If  $H(1 - a) < L(1 + b)$ , the bank would profit from a switch to a LL strategy:

$$\begin{aligned} \pi_1(LL, LH) - \pi_1(LH, LH) &= L(2 + b(1 - c/2)) - [L(1 + c) + H(1 - a)(1 - c)] \\ &= L(1 + b) - cL(1 + b/2) - H(1 - a)(1 - c) \\ &> L(1 + b)(1 - c) - H(1 - a)(1 - c) \\ &= [L(1 + b) - H(1 - a)](1 - c) \\ &> 0. \end{aligned}$$

(ii) If  $H(1 - a) > L/(1 - b)$ , the bank would profit from a switch to a HH strategy:

$$\begin{aligned} \pi_1(HH, LH) &= H(1 - a)(2 - b - bc) \\ &= H(1 - a)(1 - b)(1 + c) + H(1 - a)(1 - c) \\ &> L(1 + c) + H(1 - a)(1 - c) \\ &= \pi_1(LH, LH) \end{aligned}$$

◇

**Lemma 2** *Given a strategy LH of Bank 2, the payoff to Bank 1 of a LH strategy is greater or equal than the payoff of a HL strategy if and only if  $L \leq H(1 - a)$ .*

Proof.

$$\pi_1(LH, LH) \geq \pi_1(HL, LH)$$

$$\begin{aligned}
&\Leftrightarrow L(1+c) + H(1-a)(1-c) \geq L(1+b+c-bc) + H(1-a)(1-b)(1-c) \\
&\Leftrightarrow 0 \geq L(b-bc) - Hb(1-a)(1-c) \\
&\Leftrightarrow 0 \geq L - H(1-a).
\end{aligned}$$

◇

**Proposition 3** *A (LH, LH) and a (HL, HL) strategy represent equilibria if and only if both the (LL, LL) and the (HH, HH) strategies are also equilibria and furthermore*

$$c \leq \frac{H(1-a) - L(1+b)}{H(1-a) - L(1+b/2)} \quad (16)$$

*holds.*

Proof. For symmetry, it is sufficient to consider the (LH, LH) strategy. According to Lemma 1, it is necessary that both the (LL, LL) and (HH, HH) strategies are equilibria. Let therefore  $L/(1-b) \geq H(1-a) \geq L(1+b)$  in the following. Thus,  $L < H(1-a)$  holds, and according to Lemma 2, a bank cannot profit from a switch to a HL strategy. It remains to show that a bank cannot profit from a switch to a LL or HH strategy if and only if (16) holds. For symmetry, it is sufficient to consider Bank 1. We first consider a switch to a LL strategy:<sup>23</sup>

$$\begin{aligned}
c &\leq \frac{H(1-a) - L(1+b)}{H(1-a) - L(1+b/2)} \\
&\Leftrightarrow c[H(1-a) - L(1+b/2)] \leq H(1-a) - L(1+b) \\
&\Leftrightarrow c[L(1+b/2) - H(1-a)] \geq L(1+b) - H(1-a) \\
&\Leftrightarrow c[L - H(1-a)] + H(1-a) \geq L(1+b - bc/2) \\
&\Leftrightarrow Lc + H(1-a)(1-c) \geq L(1+b(1-c/2))
\end{aligned}$$

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<sup>23</sup>Note that the denominator of (16) is positive, as  $H(1-a) \geq L(1+b) > L(1+b/2)$ .

$$\Leftrightarrow L(1+c) + H(1-a)(1-c) \geq L(2+b(1-c/2))$$

$$\Leftrightarrow \pi_1(LH, LH) \geq \pi_1(LL, LH).$$

Furthermore, the bank cannot profit from a switch to a HH strategy. Otherwise,  $c$  must be negative, which is impossible:

$$\pi_1(HH, LH) > \pi_1(LH, LH)$$

$$\Leftrightarrow L(1+c) + H(1-a)(1-c) < H(1-a)(2-b-bc)$$

$$\Leftrightarrow L(1+c) - cH(1-a) < H(1-a)(1-b-bc)$$

$$\Leftrightarrow c(L - H(1-a)) + L < H(1-a)(1-b) - cbH(1-a)$$

$$\Leftrightarrow c(L - H(1-a)(1-b)) < H(1-a)(1-b) - L$$

$$\Leftrightarrow c < \frac{H(1-a)(1-b) - L}{L - H(1-a)(1-b)} = -1.$$

Together, if both the (LL, LL) and (HH, HH) strategies are equilibria, condition (16) is both sufficient and necessary.  $\diamond$

**Lemma 3** *Given a (LH, HL) strategy, Bank 1 profits from a switch to a LL strategy if*

$$L(1+b) > H(1-a).$$

Proof. Let  $L(1+b) > H(1-a)$ .

$$\begin{aligned} \pi_1(LH, HL) &= L(1+b+c-bc) + H(1-a)(1-b)(1-c) \\ &< L(1+b+c-bc) + L(1+b)(1-b-c+bc) \\ &= L(2+b(1-b-c+bc)) \\ &= L(2+b(1-c/2)) + Lb(-b-c/2+bc) \\ &< L(2+b(1-c/2)) \\ &= \pi_1(LL, HL). \end{aligned}$$

◇

**Proposition 4** *A (LH, HL) strategy is never an equilibrium.*

Proof. According to Lemma 2, a necessary condition for a (LH, HL) strategy to be an equilibrium is  $L > H(1 - a)$ . According to Lemma 3, a necessary condition is  $L(1 + b) \leq H(1 - a)$ . Both conditions cannot be fulfilled at the same time. ◇

**Proposition 5** *A (LL, LH) strategy is never an equilibrium.*

Proof. (i) If  $H(1 - a)(1 - b) \geq L$ , it is profitable for Bank 2 to switch to HH:

$$\begin{aligned}
 \pi_2(LL, LH) &= L(1 + c(1 - b/2)) + H(1 - a)(1 - b)(1 - c) \\
 &\leq H(1 - a)(1 - b)(1 + c(1 - b/2)) + H(1 - a)(1 - b)(1 - c) \\
 &= H(1 - a)(1 - b)(2 - bc/2) \\
 &< 2H(1 - a)(1 - b) \\
 &= \pi_2(LL, HH)
 \end{aligned}$$

(ii) If  $H(1 - a)(1 - b) < L$ , it is profitable for Bank 2 to switch to LL:

$$\begin{aligned}
 \pi_2(LL, LH) &= L(1 + c(1 - b/2)) + H(1 - a)(1 - b)(1 - c) \\
 &< L(1 + c(1 - b/2)) + L(1 - c) \\
 &= 2L - L \cdot bc/2 \\
 &< 2L \\
 &= \pi_2(LL, LL)
 \end{aligned}$$

◇

**Proposition 6** *A (HH, LH) strategy is never an equilibrium.*

Proof. (i) If  $H(1 - a) > L(1 + b)$ , it is profitable for Bank 2 to switch to HH:

$$\begin{aligned}
\pi_2(HH, LH) &= L(1 + b + c + bc) + H(1 - a)(1 - c) \\
&< H(1 - a) + L \cdot c(1 + b) + H(1 - a)(1 - c) \\
&= 2H(1 - a) + c[L(1 + b) - H(1 - a)] \\
&< 2H(1 - a) \\
&= \pi_2(HH, HH)
\end{aligned}$$

(ii) If  $H(1 - a) \leq L(1 + b)$ , it is profitable for Bank 1 to switch to LL:

$$\begin{aligned}
\pi_1(HH, LH) &= H(1 - a)(2 - b - bc) \\
&\leq L(1 + b)(2 - b - bc) \\
&= L(2 + b(1 - b - c - bc)) \\
&< L(2 + b(1 - c/2)) \\
&= \pi_1(LL, LH)
\end{aligned}$$

◇

**Proposition 7** *A (LL, HH) strategy is never an equilibrium.*

Proof. (i) If  $H(1 - a) > L(1 + b)$ , it is profitable for Bank 1 to switch to HH:

$$\begin{aligned}
\pi_1(LL, HH) &= 2L(1 + b) \\
&< 2H(1 - a) \\
&= \pi_1(HH, HH)
\end{aligned}$$

(ii) If  $H(1 - a) \leq L(1 + b)$ , it is profitable for Bank 2 to switch to LL:

$$\pi_2(LL, HH) = 2H(1 - a)(1 - b)$$

$$\leq 2L(1+b)(1-b)$$

$$= 2L(1-b^2)$$

$$< 2L$$

$$= \pi_2(LL, LL)$$

◇

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	LL	LH	HL	HH
LL	$2L$	$L(2 + b(1 - c/2))$	$L(2 + b(1 - c/2))$	$2L(1 + b)$
	$\circ$	$\circ$	$\circ$	$\circ$
LH	$2L$	$L(1 + c(1 - b/2))$ $+H(1 - a)(1 - b)(1 - c)$	$L(1 + c(1 - b/2))$ $+H(1 - a)(1 - b)(1 - c)$	$2H(1 - a)(1 - b)$
	$L(1 + c(1 - b/2))$ $+H(1 - a)(1 - b)(1 - c)$	$L(1 + c)$ $+H(1 - a)(1 - c)$	$L(1 + b + c - bc)$ $+H(1 - a)(1 - b)(1 - c)$	$L(1 + b + c + bc)$ $+H(1 - a)(1 - c)$
LH	$\circ$	$\circ$	$\circ$	$\circ$
	$L(2 + b(1 - c/2))$	$L(1 + c)$ $+H(1 - a)(1 - c)$	$L(1 + b + c - bc)$ $+H(1 - a)(1 - b)(1 - c)$	$H(1 - a)(2 - b - bc)$
HL	$L(1 + c(1 - b/2))$ $+H(1 - a)(1 - b)(1 - c)$	$L(1 + b + c - bc)$ $+H(1 - a)(1 - b)(1 - c)$	$L(1 + c)$ $+H(1 - a)(1 - c)$	$L(1 + b + c + bc)$ $+H(1 - a)(1 - c)$
	$\circ$	$\circ$	$\circ$	$\circ$
HL	$L(2 + b(1 - c/2))$	$L(1 + b + c - bc)$ $+H(1 - a)(1 - b)(1 - c)$	$L(1 + c)$ $+H(1 - a)(1 - c)$	$H(1 - a)(2 - b - bc)$
	$\circ$	$\circ$	$\circ$	$\circ$
HH	$2H(1 - a)(1 - b)$	$H(1 - a)(2 - b - bc)$	$H(1 - a)(2 - b - bc)$	$2H(1 - a)$
	$\circ$	$\circ$	$\circ$	$\circ$
HH	$2L(1 + b)$	$L(1 + b + c + bc)$ $+H(1 - a)(1 - c)$	$L(1 + b + c + bc)$ $+H(1 - a)(1 - c)$	$2H(1 - a)$
	$\circ$	$\circ$	$\circ$	$\circ$

**Table 1.** Bank profits depending on pricing strategies. The rows refer to the strategies of Bank 1, the columns to the strategies of Bank 2, where LL, LH, HL, and HH denote low and/or high margins for the two warrants, respectively. The upper expression in each cell is the resulting total profit of Bank 1, the lower of Bank 2. Model parameter are  $a$  (absolute margin sensitivity),  $b$  (relative margin sensitivity with respect to a change in bank), and  $c$  (relative margin sensitivity with respect to a change in warrant characteristics).

Issuer	Total Demand			Average Demand		Average Margin	
	Trades	Warrants	Volume	Trades/Day	Volume/Trade	Mean	Std.
Citibank	3,588	5,760	35.064	0.36	3,250	3.56%	3.91%
Commerzbank	4,329	6,935	32.486	0.32	2,208	1.48%	3.40%
Deutsche Bank	12,955	22,602	115.302	0.76	6,292	1.76%	3.15%
Goldman Sachs	1,894	2,937	12.241	0.60	3,529	3.85%	4.94%
HSBC Trinkaus	401	468	2.578	0.19	1,118	0.16%	4.52%
Total	23,167	38,702	197.671	0.51	3,965	2.13%	3.75%

**Table 2.** Descriptive statistics for DAX call warrants at the EUWAX in 2009. Separated by issuer, the table provides the trading volume (measured as number of trades, delta-adjusted number of traded warrants, and trading volume in mn. Euros), furthermore the average demand figures (number of trades per warrant and per day, volume per trade in Euros), and finally the average margin and the standard deviation of the margin. The figures are restricted to our subsample, that is, moneyness  $\pm 15\%$ , time to maturity 1–12 months. Furthermore, any trades that are omitted during the data processing because of non-assignable DAX levels, non-determinable trade direction, or unreasonable trade size, are not included.

	Euros	# Warrants	# Trades
<i>a</i> <i>MARGIN</i>	-4,059 (7,130)	-0.033 (0.178)	-0.267 (0.868)
<i>b</i> $\Delta MARGIN^{banks}$	-27,067*** (5,903)	-0.569** (0.173)	-3.218*** (0.922)
<i>c</i> <sub>1</sub> $\Delta MARGIN^{char.strike}$	-47,198*** (12,800)	-1.248** (0.427)	-6.378** (2.161)
<i>c</i> <sub>2</sub> $\Delta MARGIN^{char.mat}$	-4,345 (5,104)	-0.257* (0.125)	-1.300* (0.648)
<i>ROUND</i> <sub>1,000</sub>	11,434*** (1,583)	0.240*** (0.038)	1.417*** (0.202)
<i>ROUND</i> <sub>500</sub>	2,585*** (598)	0.068*** (0.019)	0.454*** (0.099)
<i>ROUND</i> <sub>200</sub>	1,443** (528)	0.035*** (0.010)	0.190*** (0.036)
<i>MONEY</i>	-11,602*** (2,900)	-0.461*** (0.068)	-3.232*** (0.334)
<i>MONEY</i> <sup>2</sup>	-198,461*** (39,121)	-4.645*** (0.716)	-27.630*** (3.149)
<i>TIME</i>	-8,586*** (1,061)	-0.241*** (0.026)	-1.218*** (0.133)
<i>AMERICAN</i>	1,045* (446)	0.011 (0.009)	0.143** (0.046)
<i>Constant</i>	6,275*** (1,213)	0.161*** (0.024)	0.778*** (0.109)
Observations	39,691	39,691	39,691
Adjusted <i>R</i> <sup>2</sup>	0.0194	0.0346	0,050

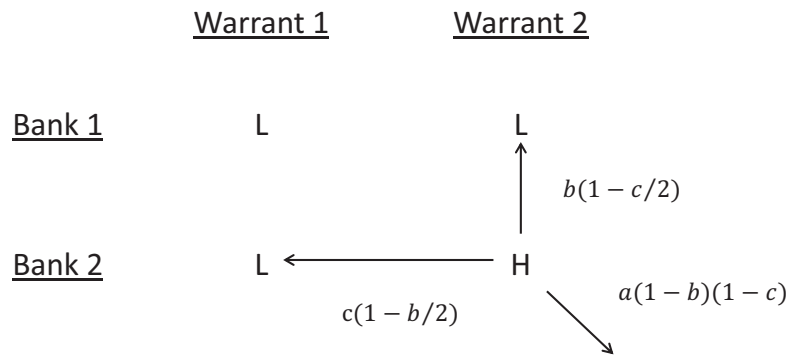
**Table 3.** Results of the demand regression (11). In the first column, demand as the dependent variable is measured by traded volume in Euros, in the second column by the delta-adjusted number of traded warrants, and in the third column by the number of trades. The first line shows the influence of the midday margin. The following three lines contain margin differences to similar warrants with deviation in issuer, strike price, and time to maturity, respectively. Control variables are dummies for round strikes, divisible by 1,000, 500, and 200, moneyness, moneyness squared, remaining time to maturity, and a dummy for American exercise style. Tradeday dummies and issuer dummies are omitted for the sake of brevity. Standard errors based on Newey and West (1987) with 5 lags are provided in parentheses. Significance at the 5% level is denoted by \*, at the 1% level by \*\*, and at the 0.1% level by \*\*\*.

	Citibank	Commerzbank	Deutsche Bank	Goldman Sachs	HSBC	Total
Panel A: Margin Regression						
<i>TIME</i>	+0.032*** (0.002)	+0.016** (0.002)	+0.000 (0.002)	+0.034*** (0.005)	+0.003 (0.006)	+0.016*** (0.001)
<i>MONEY</i>	-0.160*** (0.007)	-0.094*** (0.004)	-0.121*** (0.004)	-0.185*** (0.014)	-0.028* (0.013)	-0.120*** (0.003)
<i>MONEY</i> <sup>2</sup>	+0.668*** (0.092)	+0.0991*** (0.066)	+0.621*** (0.052)	+0.270 (0.190)	+0.164 (0.170)	+0.416*** (0.028)
<i>Constant</i>	+0.016*** (0.001)	+0.003** (0.001)	+0.012*** (0.001)	+0.016*** (0.002)	-0.002 (0.002)	+0.023*** (0.001)
Observations	11,444	15,947	19,980	3,725	2,557	53,653
Adjusted <i>r</i> <sup>2</sup>	0.181	0.068	0.132	0.116	0.003	0.088
Panel B: Average Margins						
In the money	+2.40% (2.12)	+0.68% (1.124)	+0.86% (1.044)	+1.81% (1.73)	+0.28% (5.09)	+1.18% (1.72)
Out of the money	+4.61% (4.78)	+2.06% (4.28)	+2.54% (4.04)	+4.57% (5.48)	-0.24% (0.92)	+2.84% (4.62)
ANOVA p-values	(0.000)	(0.000)	(0.000)	(0.000)	(0.016)	(0.000)

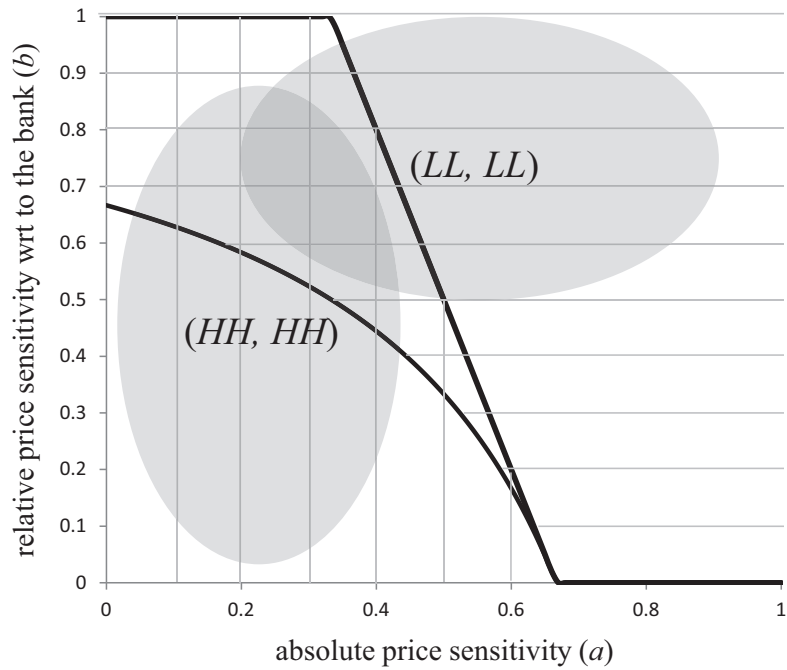
**Table 4.** Panel A: Results of the margin regression (12), separated by issuer, and aggregated for all issuers with issuer dummies. Each column provides results for a different issuer. The dummy for American exercise style and issuer dummies (for the last column only) are omitted for the sake of brevity. Standard errors based on Newey and West (1987) are provided in parentheses. Significance at the 5% level is denoted by \*, at the 1% level by \*\*, and at the 0.1% level by \*\*\*. Panel B: Average margins for each issuer separated by in-the-money and out-of-the-money warrants with standard deviations provided in parentheses. The last line shows the p-values of ANOVA analyses testing the null hypothesis of equal means.

		Euros	# Warrants	# Trades
Panel A: In-the-Money Warrants				
<i>a</i>	<i>MARGIN</i>	-208,500* (90,362)	-2.835 (1.556)	-5.423 (3.280)
<i>b</i>	$\Delta MARGIN^{banks}$	-960 (44,946)	-0.075 (0.784)	-3.910 (2.403)
<i>c</i> <sub>1</sub>	$\Delta MARGIN^{char.strike}$	-137,088 (128,342)	-2.411 (2.195)	-6.260 (4.632)
<i>c</i> <sub>2</sub>	$\Delta MARGIN^{char.mat}$	32,015 (72,591)	-0.159 (1.228)	1.939 (1.827)
	<i>Constant</i>	16,390*** (3,869)	0.283*** (0.066)	0.868*** (0.145)
	Observations	16,241	16,241	16,241
	Adjusted $R^2$	0.012	0.013	0.037
Panel B: Out-of-the-Money Warrants				
<i>a</i>	<i>MARGIN</i>	14,496 (10,532)	0.489 (0.312)	2.384 (1.665)
<i>b</i>	$\Delta MARGIN^{banks}$	-29,256*** (6,506)	-0.808*** (0.238)	-4.768*** (1.200)
<i>c</i> <sub>1</sub>	$\Delta MARGIN^{char.strike}$	-42,351** (13,119)	-1.274** (0.469)	-7.212** (2.470)
<i>c</i> <sub>2</sub>	$\Delta MARGIN^{char.mat}$	-11,358 (6,307)	-0.468* (0.199)	-2.686* (1.119)
	<i>Constant</i>	5,504*** (1,430)	0.132*** (0.031)	0.728*** (0.174)
	Observations	23,450	23,450	23,450
	Adjusted $R^2$	0.039	0.045	0.058

**Table 5.** Results of the demand regression (11), separately for in-the-money and out-of-the-money warrants.

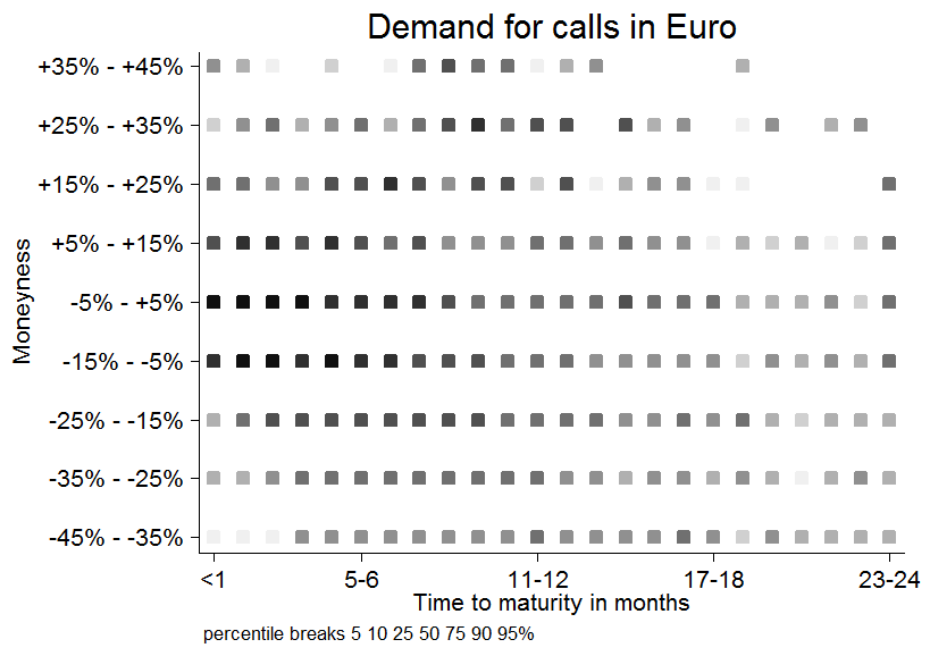


**Figure 1.** Exemplary illustration of demand migration. Bank 2 charges a high margin for Warrant 2. As a consequence, a fraction  $b(1 - c/2)$  of investors who a priori preferred this warrant migrates to Bank 1 (relative margin sensitivity with respect to the bank). A further fraction  $c(1 - b/2)$  migrates to Warrant 1 (relative margin sensitivity with respect to characteristics), and a fraction  $a(1 - b)(1 - c)$  leaves the market (absolute margin sensitivity).



**Figure 2.** *Nash equilibria of the strategic game. Depending on absolute margin sensitivity and relative margin sensitivity with respect to the bank, a high/high margin strategy (upper right corner, horizontal lines) or a low/low margin strategy (lower left corner, vertical lines) represents a Nash equilibrium. The intersection (upper left corner) is non-empty—here, both strategies represent Nash equilibria. Furthermore, depending on relative margin sensitivity with respect to characteristics, mixed low/high strategies can also represent a Nash equilibrium in the intersection. For this figure, the higher margin  $H$  has been set to three times the lower margin  $L$ .*





**Figure 3.** Trading activity for DAX call options on the EUWAX, separated by warrant characteristics. Warrants are clustered according to their remaining time to maturity and moneyness. The brightness of each cluster indicates the size of the trading volume in Euros, where a high volume is indicated by a dark cluster.