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RESEARCH ARTICLE

Hedging costs and joint determinants of premiums and spreads in structured financial products

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Abstract

Evaluating more than 317,000 discount certificates in the German secondary market, we find that premiums and spreads are endogenous and negatively related but depend on different key determinants. The fundamental determinants of the premiums are mainly profit-related, that is, dividends of the underlying, issuers' credit risk, lifecycle effect, and competition, whereas hedging costs are less important. However, initial hedging costs (IHC) are priced into the premium in the case of large inventory changes. The spread is mostly determined by hedging costs and risk components, such as IHCs, rebalancing costs, volatility, scalper risk, and overnight gap risk—but also by dividends.

KEYWORDS

derivatives, discount certificates, hedging, market microstructure, pricing, trading costs

JEL CLASSIFICATION

D40; G12; G21

1 | INTRODUCTION

A prominent and well-studied phenomenon of listed retail (investment) structured products—also commonly referred to as “(investment) certificates”—is their overpricing in the secondary market, that is both bid and ask quotes set by the issuers (as well as traded prices) exceed their mathematically “fair” theoretical values.¹ This is reflected in a positive premium defined as the relative difference between mid-quote and “fair” value.² A variety of studies described below have analyzed the determinants of this premium and acknowledge that the reported premiums do not represent issuers' net earnings, as premiums have to cover issuers' costs. However, these studies do not explicitly incorporate the issuers' cost side in their empirical analyses. Furthermore, the literature ignores the bid/ask spread, its potential determinants and the potential link between premium and spread.

This paper aims at deepening our understanding of issuers' price-setting behavior in the market for retail structured products by closing these gaps. To the best of our knowledge we are the first to incorporate the issuers' cost side into the

¹The overpricing can be found for a variety of certificates and local markets, see, for example, the German certificate market (Baule, 2011; Baule & Tallau, 2011; Baule et al., 2008; Entrop, Fischer, McKenzie, Wilkens, & Winkler, 2016; Schertler, 2016; Stoimenov and Wilkens, 2005; Wilkens et al., 2003), structured equity products in the United States (Benet, Giannetti & Pissaris, 2006; Henderson & Pearson, 2011), the Netherlands (Szymanowska et al., 2009), and Switzerland (Burth, Kraus & Wohlwend, 2001; Wallmeier & Diethelm, 2009).

²The premium is also commonly referred to as “margin” or “mark-up.”

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empirical analysis of determinants of premiums and bid/ask spreads and also the first to consider the spread at all. Briefly summarizing our key results before going into detail, we find that premiums and spreads are endogenous and negatively related but depend on different key determinants. While hedging costs are generally of minor importance for the premium (compared to standard determinants known from prior literature), initial hedging costs (IHC) are priced into the premium only in the case of large inventory changes. The key determinants of the spread are hedging cost- and risk-related—but dividends of the underlying are also relevant.

As already mentioned, several studies have analyzed the determinants of the premium, whose key results can be summarized as follows: The premium diminishes over a certificate's lifetime; this is commonly referred to as the "life cycle hypothesis" (e.g., Entrop, Scholz, & Wilkens, 2009; Stoimenov & Wilkens, 2005; Wilkens & Stoimenov, 2007; Wilkens, Erner, & Röder, 2003). Issuers adjust the premium in accordance with the order flow they expect, that is they increase (decrease) the premium in phases of positive (negative) net expected investors' buying pressure ("order flow hypothesis"; Baule, 2011; Wilkens et al., 2003). Furthermore, the premium decreases with higher competition between issuers (e.g., Baule, 2011; Entrop, Fischer, et al., 2016; Schertler, 2016), and increases with a higher issuer's credit risk (e.g., Baule, Entrop, & Wilkens, 2008; Entrop, Fischer, et al., 2016; Schertler, 2016), higher dividend yields of the underlying (e.g., Entrop, Fischer, et al., 2016), a higher volatility of the underlying (e.g., Entrop, Fischer, et al., 2016; Szymanowska, Horst, & Veld, 2009) and higher unhedgeable risk (e.g., Baller, Entrop, McKenzie, & Wilkens, 2016).

We already noted that this literature ignores the issuers' costs side and does not consider the spread at all. While the bid/ask spread usually serves as a market maker's compensation for costs (e.g., transaction costs, hedging costs) and risks (e.g., informed traders, illiquidity) in standard markets such as the equity, bond, or options markets, it can additionally serve as a further source of profit for the issuer in the market for structured products. Given its market design, described in Section 2 in more detail, the theoretical model by Baller et al. (2016) shows that there should be a substitution effect between premium and bid/ask spread.³ This implies that each determinant of the premium and the bid/ask spread, respectively, is a potential determinant of the other one.

Our analysis builds on a large quote and trade data set with 396,249 discount certificates on DAX stocks that were tradable on the Euwax between January 2006 and December 2013. From our tick data we form five time bars each day to keep the analysis numerically manageable, which still results in more than 80 million observations while most studies only observe daily quotes or quotes at issuance. For calculating the premium we use a structural model by Baule et al. (2008) that relaxes the standard Hull and White (1995) assumption of independence between the market risk of the underlying of discount certificate and issuer's credit risk. The relative bid/ask spread can be observed directly from the quotes.⁴

Our econometric design is a 2-equation system where premium and spread are the dependent variables and the potential determinants are the independent variables. We also add the spread as an explanatory variable to the premium-equation and vice versa. To account for the resulting endogeneity, we use GMM-2SLS as well as GMM-3SLS approaches to estimate our equations.

We group potential determinants into three categories. The first one is *hedging costs*. We borrow from the literature on options (see e.g., Boyle & Vorst, 1992; Huh, Lin, & Mello, 2015; Leland, 1985; Wu, Liu, Lee, & Fok, 2014) and warrants (see e.g., Petrella, 2006; Petrella & Segara, 2013), and split hedging costs into initial hedging and rebalancing costs.⁵ IHC are the costs associated with setting up and liquidating a delta-neutral position. Rebalancing costs (RC) represent the costs of rebalancing the position to keep it delta-neutral throughout the certificate's lifetime.

As delta-hedging strategies are usually carried out in discrete time for reasons of transaction costs, they are not perfect and issuers have to bear the remaining risk. Additionally, there is risk such as jump risk that cannot be hedged or only with high costs. These remaining risks also affect issuers' cost side as they result in opportunity costs. Therefore, our second category is *risks*. Here we subsume overnight gap risk and downside jump risk. We also add volatility as a broad measure for uncertainty. Additionally, we consider scalper risk, which is the risk of informed trading against the market maker. Our third category, *other variables*, captures the commonly analyzed determinants from the structured product literature, that is issuer's credit risk, order flow, competition, lifecycle effect and dividends. We also add perfect hedge opportunities via the option market.

³In contrast, Baller et al. (2016) find a positive influence of the spread on the premium in their empirical analysis. They consider highly speculative short-term knock-out products, however, and do not consider spread determinants.

⁴For simplicity, we use the term "spread" in the following instead of "relative bid/ask spread," if not stated otherwise.

⁵Issuers' price-setting behavior for warrants also exhibits overpricing, that is quoted prices above the theoretical fair value or option quotes (e.g., Bartram et al., 2008; Baule and Blonski, 2015; Horst and Veld, 2008; Li & Zhang, 2011).

Our empirical results can be summarized as follows: We find strong evidence that premium and spread are negatively related and endogenous to each other, that is premium and spread serve as substitutes. However, the respective key determinants still differ. Both dividends of the underlying and the issuer's credit risk influence the premium positively, meaning that investors are not fully compensated for the respective negative effects on the value of discounts certificates. Together with the life cycle hypothesis, that we also find support for, this reveals a clearly profit-related behavior when setting premiums. The premium is reduced by stronger competition between the issuers, which is plausible and in line with the literature. Hedging costs and risks are of less importance for the premium while, among the risk factors, the most important one is volatility, which influences the premium positively. However, IHC are also priced into the premium if there are (large) inventory changes.

Analyzing the determinants of the spread, the cost side and risks are most important. IHC, rebalancing costs, volatility, scalper risk, and overnight gap risk are all priced consistently. However, IHC are economically much more significant than rebalancing costs. Higher competition negatively affects the spread. Interestingly, we find a negative influence of the underlying's dividends. Together with its positive influence on the premium, this finding also supports the substitution effect between premiums and spreads. In fact, it is often hard for retail investors to assess the "fairness" of a quote and, thus, to judge the size of the premium while the spread can directly be observed. This may give issuers an incentive to reduce the spread and increase the premium to attract additional investors. Bartram and Fehle (2005) and in a similar vein Baller et al. (2016) argue for warrants and highly speculative knock-out products, respectively, that investors are more sensitive to the spread than overpricing as they hold these products for only a very short time and trade often. In contrast, discount certificates are much less often traded and often held until maturity (Baule, 2011). Analyzing investors' product choices from very similar discount certificates of different issuers, Entrop, Fischer, et al. (2016) find that investors turn out to be a bit more sensitive to the spread than to premiums in one of their analyses, although the main decision variables are behavioral, such as issuer and product familiarity.

The remainder of this paper is structured as follows: Section 2 describes discount certificates while Section 3 provides the potential determinants and variables of premiums and bid/ask spreads in the three categories hedging costs, risks and other variables. Section 4 presents the data set and Section 5 explains the valuation method we use. Our empirical analysis is the subject of Section 6 and Section 7 concludes.

2 | MARKET DESIGN AND DISCOUNT CERTIFICATES

Retail structured financial (investment) products are unsecured bonds issued by financial institutions whose payoff equals the payoff from a portfolio consisting of spot and derivative market components such as stocks, bonds, plain vanilla or barrier options. Germany is one of the world's largest markets for these type of products in the retail market, with a total of 460,107 outstanding products and an outstanding volume of EUR 61.2bn as of December 2017 (Deutscher Derivate Verband, 2017a). Almost all products are listed on both the Euwax (European Warrant Exchange, the trading segment of Boerse Stuttgart) and Boerse Frankfurt Zertifikate AG, which are specialized retail investor exchanges. On these exchanges, issuers are obliged to guarantee liquidity by market making and by setting binding – not indicative – quotes; a specific product can only be traded with its issuer and short selling is de facto impossible.⁶ Due to the large number of products, many products are very seldom traded; consequently, an investor usually trades with the market maker/issuer when placing an order. Issuers can extract significant economic rents from structured financial products via overpricing due to this special market design. As issuers do not bet against the investors but hedge the resulting market risk (at the "fair" prices for institutional market participants) once a product is sold, the premium is the key basis for their gains from this business. The financial institutions regularly issue—under a single base prospectus per product type—new products with differing features (e.g., with a broad range of cap-maturity-combinations in the case of discount certificates described in the following) to attract investors with different preferences. The vast majority of products are directly listed without a subscription period; only very few products are sold through banks (branches) with a fixed-price subscription period before being listed.

In this paper we focus on discount certificates, which are one of the most popular types of equity-linked structured financial products in Germany. They had a number and outstanding volume of 137,173 and EUR 4.4bn, respectively, as of December 2017, and the total trading volume was EUR 8.0bn on the Euwax and Boerse Frankfurt Zertifikate AG exchanges during 2017, which accounts for a 39% share in all structured financial investment products (Deutscher Derivate Verband, 2017a, 2017b).

⁶See, for example, Baule et al. (2008), Baule (2011) and Baller et al. (2016) for detailed market descriptions.

The payoff of a discount certificates DC equals the minimum of the price of an underlying asset and a fixed cap at maturity T , that is the promised payoff is given by:

$$DC_T = \alpha \min\{S_\tau; X\} \quad (1)$$

$$= \alpha (X - \max\{X - S_\tau; 0\}). \quad (2)$$

τ is the reference date on which the repayment is fixed (usually a few days before maturity, thus $\tau \leq T$), S_τ is the underlying price at date τ , X is the cap and α denotes the cover ratio, as the certificate can refer to a fraction or a multiple of the underlying. Due to the cap, the investor's upside benefits are limited for an increasing underlying price, and discount certificates will therefore trade at a discount compared to the underlying. The payoff profile is thus attractive for investors expecting sideways or slightly downward or upward price movements until maturity, as in these cases the product returns are higher compared to the returns from a direct investment in the underlying.⁷ In the case of large increasing (decreasing) underlying prices, investors would ex post have been better off with holding the underlying directly (with not being exposed to the underlying at all).

Equation (2) reveals that the payoff of a discount certificate can be duplicated by an (unsecured) long zero bond, with a face value X and maturity T , and a respective short European put option with a strike price X . Alternatively, the combination of a long position in the underlying, adjusted for intertemporal dividend payments, and a short European call option with a strike price X can be used.

3 | DETERMINANTS OF PREMIUMS AND SPREADS

In this section we consider the potential determinants of discount certificates' relative premiums and relative spreads. We divide the variables into three categories: hedging costs (Section 3.1), risks (Section 3.2) and other variables (Section 3.3), the latter including dividends, lifecycle effect, competition and perfect hedge opportunities amongst others.

3.1 | Hedging costs

Similar to Huh et al. (2015), Petrella (2006), Petrella and Segara (2013) and Wu et al. (2014), we split total hedging costs into initial hedging costs IHC_t and rebalancing costs RC_t .⁸ We can explicitly measure the dynamics of hedging costs over time because we observe the bid and ask prices throughout the lifetime of a certificate (rather than only at issuance) and also the respective bid/ask spreads in the underlying.

3.1.1 | Initial hedging costs

The IHC, that is the quantity that needs to be traded in the underlying market to establish or unwind a delta-neutral position times the relative costs, are given by:

$$IHC_t = |\Delta_t| \cdot \alpha \cdot spr_t^{UL} \quad (3)$$

with

$$spr_t^{UL} = \frac{ask_t^{UL} - bid_t^{UL}}{0.5(ask_t^{UL} + bid_t^{UL})}. \quad (4)$$

⁷However, the overpricing of certificates and investors' behavior typically result in a poor risk-adjusted performance in terms of alpha (e.g., Entrop, McKenzie, Wilkens & Winkler, 2016) and (high) investors' demand can hardly be linked to standard preferences—but can be explained under behavioral utility and/or behavioral biases (e.g., Breuer & Perst, 2007; Hens & Rieger, 2014). See Baller et al. (2016) and Henderson and Pearson (2011) for a more detailed discussion and overview.

⁸We examine the individual hedging costs for each certificate over time. Alternatively, issuers might apply netting by combining different positions and hedge the entire portfolio which can also affect the price-setting (see e.g., Pelster & Schertler, 2019).

Δ_t is the certificate's delta which is the sensitivity of its value to changes in the underlying asset price according to the Black-Scholes option pricing model (Black & Scholes, 1973) and spr_t^{UL} is the relative spread of the underlying stock. Because a discount certificate can be decomposed into a long zero bond (with a delta of zero) and a short European put option (with a positive delta) as described in Section 2, the certificate holder has a positive delta position, while the issuer has a negative one. As we measure the issuer's hedging costs, we take the absolute value $|\Delta_t|$. Analogous to the warrant literature, higher IHC can be expected to have a positive effect on the spread because the issuer increases the ask and reduces the bid price due to the higher costs of setting-up or unwinding a delta-neutral position.

As the issuer naturally holds a short position in discount certificates, any buy (sell) by an investor will increase (decrease) the issuer's negative inventory in absolute terms. As the pass-through of hedging costs into the spread might depend on the issuer's inventory (see e.g., Muravyev, 2016; Wu et al., 2014) we also interact IHC with the order flow as defined below:⁹

$$IHC \times OF_t = IHC_t \cdot OrderFlow_t \quad (5)$$

with

$$OrderFlow_t = \log(1 + Volume_t^{InvBuy}) - \log(1 + Volume_t^{InvSell}). \quad (6)$$

$Volume_t^{InvBuy}$ is the accumulated trading volume, measured in euros, of investors buying the certificate in t (in the time interval $t - 1$ to t) and $Volume_t^{InvSell}$ is the equivalent trading volume for investors selling the certificate back to the issuer.

Additionally, investors are likely to be more sensitive to the spread compared to the premium as they can observe the spread directly while it is hard for them to assess the “fairness” of the premium (Baller et al., 2016). This might give issuers an incentive to “hide” (parts of) increased IHC in the premium rather than widening the spread.

3.1.2 | Rebalancing costs

RC represent the costs of rebalancing the position to keep a delta-neutral position. In previous studies on warrants and options, rebalancing costs are measured from past or current observations via, for example, the standard deviation of the underlying (e.g., Petrella & Segara, 2013) or the current gamma (e.g., Petrella, 2006; Petrella & Segara, 2013; Wu et al., 2014), that is the sensitivity of delta with respect to changes in the underlying price. Then, for example, the empirical analysis examines how the current snapshot of rebalancing costs affects the spread.

As investors often hold discount certificates until maturity (e.g., Baule, 2011),¹⁰ issuers should include the expected RC over the certificate's lifetime in their price-setting. We proxy the RC over the certificate's lifetime by:¹¹

$$RC_t = \alpha \cdot \int_t^T \Gamma_t(s) ds, \quad (7)$$

where $\Gamma_t(t)$ is the Black-Scholes gamma in t and $\Gamma_t(s)$ with $s > t$ is calculated like the gamma in t but with a remaining time to maturity of $T - s$.

Like in the case of IHC, the pass-through of rebalancing costs may depend on the inventory which is why we also form—analogously to IHC—the interaction between rebalancing costs and the order flow:

$$RC \times OF_t = RC_t \cdot OrderFlow_t, \quad (8)$$

where $OrderFlow_t$ is defined as in Equation (6).

⁹As we do not know the level of the inventory we estimate its change via the order flow.

¹⁰This stands in contrast to warrants, which are more popular for short-term speculative investors, who reverse their position before expiration, thus making the spread more important than the relative overpricing (e.g., Bartram and Fehle, 2005).

¹¹For example, the bandwidth cost component in Whalley and Wilmott (1997) and Whalley (2011) is also a function of absolute Gamma integrated over the time to maturity of a warrant.

Like in the case of IHC, rebalancing costs can be expected to be priced in the spread. However, there are also good reasons to price RC into the premium. Clearly, the higher the expected rebalancing costs over the certificate's lifetime, the higher should be the ask price to cover future rebalancing costs. However, then, the bid price is also positively affected by RC: if the certificate is sold back to the issuer before maturity, the issuer can offer a higher bid price because future rebalancing costs cease to be relevant. All else being equal, this would induce a reduction of the premium over a certificate's lifetime. This effect is thus very similar to the standard life cycle hypothesis discussed later in Section 3.3. However, it should be noted that the life cycle hypothesis is based on a profit-maximizing argument, that is issuers set prices to optimally extract economic rents from their customers, rather than an argument of costs-pass-through as here.

3.2 | Risks

Issuers are also exposed to changes in the underlying, which cannot be hedged away or are likely to be too costly to hedge. In this case, inventory management affects the cost side of issuers because delta-hedging does not remove all risks (Stoikov & Sağlam, 2009). In the following, we consider different sources of remaining risks after having established a delta-hedge, which should be priced into issuers' spreads and/or premiums as they have a direct impact on issuers' cost side.

3.2.1 | Overnight gap risk

Overnight gap risk results from the difference between the closing and opening price of the underlying. We define overnight volatility as a proxy for the overnight gap risk in line with Baller et al. (2016). For each underlying, we generate a total return time series based on the closing and opening price (overnight). Then, we fit a GARCH(1,1) model to each time series (Bollerslev, 1986; Engle, 1982) and obtain an overnight volatility forecast for each point in time.

3.2.2 | Downside jump risk

The downside jump risk explicitly captures the risk of any sudden spread widenings in the underlying due to illiquidity (Chordia, Roll, & Subrahmanyam, 2001). A downside jump of the underlying price level will increase $|\Delta_t|$ and issuers need to adjust their hedging position by increasing their long position in the underlying.¹² The effect of a downside jump risk is twofold: on the one hand, if issuers fully dynamically hedge their positions at discrete time intervals throughout the certificate's lifetime, a negative expected jump will increase the costs (spreads) in the underlying, and thus increase the risk of high hedging costs. On the other hand, a downside jump in the price level reduces the required frequency of discrete time steps at which the issuer needs to buy the underlying to remain hedged, and thus avoids recurrent trading costs (spreads) in the underlying market.

The risk of a downside jump in the underlying is measured by the implied volatility slope, following Baller et al. (2016). The slope measures the difference in the implied volatility of an out-of-the-money (OTM) put and an at-the-money (ATM) call option: $SlopeSmile = \sigma_{put}^{imp}(0.98) - \sigma_{call}^{imp}(1)$, where $\sigma_{put}^{imp}(0.98)$ is the implied volatility of a put option with a time to maturity of 30 days and a fraction of strike to underlying price of 0.98, and $\sigma_{call}^{imp}(1)$ is the implied volatility of a call option with a time to maturity of 30 days where the strike equals the underlying price. The implied volatility is calculated from the Eurex options.¹³ We interpolate the implied volatility if no exact maturity and/or moneyness exist as described in Section 5.2.

¹²The payoff profile for the discount certificate buyer is concave due to the short put option component (see Section 2), whereas it is convex for the discount certificate issuer. Hence, the issuer has a downward sloping demand curve for the quantity of required shares to maintain a delta-neutral position: the discount certificate issuer has an initial long position in the underlying to neutralize the negative delta of the long put position ($\Delta_{put}^{long} < 0$) and must, for example, reduce positive delta (selling shares) if the share price rises. Hence, the issuer's demand for buying the underlying is anti-cyclical to the share price movement.

¹³The Eurex is the largest European exchange for options and futures.

3.2.3 | Scalper risk

Scalper risk is the risk of informed traders entering the market with more information about future price changes than the market makers, which is also referred to as adverse-selection risk (see e.g., Huh et al., 2015). Scalpers profit from small frequent trades and do not carry inventory overnight. Although, discount certificates are not the first choice for speculating on price trends, issuers can protect themselves against the potential of adverse selection by establishing a minimum reservation spread. Petrella (2006) defines a minimum spread, which protects the issuer by a one tick positive change in the underlying:

$$Scalper_t = \alpha \frac{Tick_t^{UL} \cdot |\Delta_t|}{0.5(ask_t^{UL} + bid_t^{UL})}, \quad (9)$$

where $Tick_t^{UL}$ is the underlying's tick size on the Xetra trading venue at time t (Xetra, 2016). It should be noted that scalpers can only profit from price increases because short selling is not possible in the market we consider.

3.2.4 | Volatility

As a more general measure of risk, we use the underlying's implied volatility level ($Vola_t$). Discount certificates are a popular way to bet on sideways movements (low volatility) and issuers might use different channels to hide increasing costs to maintain the attractiveness of discount certificates in periods of turmoil, by for example increasing the premium rather than the spread, which the retail investor is less likely to notice.

3.3 | Other variables

3.3.1 | Credit risk

Baule et al. (2008) and Entrop, Fischer, et al. (2016) find that the issuers' credit risk is a key component of premiums, as issuers do not (fully) pass the negative-value effect of credit risk to the investors when setting prices. We, therefore, follow Entrop, Fischer, et al. (2016) and include the credit risk premium (defined in Section 5.3) to control for that empirical finding.

3.3.2 | Order flow

Issuers may anticipate systematic patterns in investors' trading behavior and adjust premiums accordingly to extract higher economic rents (Baller et al., 2016; Baule, 2011; Wilkens et al., 2003). We, therefore, include the order flow as defined in Equation (6) to control for this potential effect.

3.3.3 | Perfect hedge

To account for the fact that the issuer may wish to (perfectly) hedge a certificate's position via the option market if possible, we add two dummy variables indicating such a potential hedge. Issuers can perfectly hedge their certificates' position by (a) a zero bond and shorting a put or (b) going long in the underlying and shorting a call as described in Section 2. If an Eurex option exists on a specific day for the same underlying, where the cap is identical to the option's strike and the reference date is identical to the option's maturity date, the dummy is set to 1 for the remaining lifetime of the certificate, or is otherwise 0. Separate dummies are created for American and European type options at Eurex. Of course, only European options will establish a genuine perfect hedge.

3.3.4 | Competition

A negative effect of competition on the premium of discount certificates has been examined by several studies, such as Baule (2011), Entrop, Fischer, et al. (2016), and Schertler (2016). Bartram, Fehle, and Shrider (2008) report analogous results for warrants. A respective negative effect can be expected on the spread as well, because investors can easily compare the spread of similar products by different issuers. We include a measure of competition following Baule (2011) and Entrop, Fischer, et al. (2016) with:

$$Comp_t = 1 - \frac{1}{1 + n_t}, \quad (10)$$

where n_t is the number of similar certificates offered by other issuers. Similar certificates have the same underlying, a similar cap level ($\pm 5\%$) and similar time to maturity (± 14 days). Thus, $Comp_t$ may take the value 0 (low competition) to 1 (high competition).

3.3.5 | Lifecycle effect

The lifecycle effect, that is the finding that issuers lower the premium over the certificate's lifetime, is well established and reported in many studies such as Entrop et al. (2009), Stoimenov and Wilkens (2005), Wilkens et al. (2003), and Wilkens and Stoimenov (2007). This typical structure in the price-setting allows issuers to earn economic rents from a certificate, independent of the points in time investors buy and sell the certificate back (see also Baller et al., 2016). The lifecycle hypothesis should be confirmed in a positive coefficient of the remaining time to maturity. Thus, we set:

$$TtM_t = T - t \quad (11)$$

as independent variable with T being the certificate's maturity date and t the current point in time.

3.3.6 | Dividends

As investors in discount certificates do not participate in the dividends of the underlying, higher expected dividends decrease the value of discount certificates. As investors do not have the same ability and information to assess expectations about future dividend payments and the "fairness" of prices, issuers may use dividends to increase profits and hide overpricing. In fact, Entrop, Fischer, et al. (2016) reveal that investors are not compensated enough for the level of expected dividend payments via price reduction which has a positive effect on the premium. To control for this potential effect, we include:

$$DIV_t = \frac{Div_t}{S_t} \quad (12)$$

in our analyses, where Div_t are the aggregate discounted dividend payment estimates between t and τ .

4 | DATA

4.1 | Discount certificates

Our study focuses on discount certificates written against the stocks that were included in the German DAX30 index between 2006 and 2013. The data consists of quote and trade data for 396,249 certificates on DAX stocks that were tradable on the Euwax between January 2006 and December 2013. These data as well as respective data for the stocks were sourced from Thomson Reuters Tick History (TRTH) database. The base data on discount certificates were provided by the financial data provider Deriva GmbH.

4.2 | Quote data

Discount certificates are tradable on the EUWAX between 9:00 a.m. and 8:00 p.m., resulting in 9.7bn single binding quotes (timestamp in milliseconds) in our time period. We sample each certificate's quotes in time bars where the observed close bid and ask prices correspond to the quotes at 9:30 a.m., 12:30 p.m., 3:30 p.m., 5:35 p.m., and 8:00 p.m.¹⁴ Likewise, we form bars for each underlying's Xetra quotes. We calculate the moneyness of a discount certificate as:

$$Money_t = \frac{S_t - X}{X}, \quad (13)$$

where X is the certificate's cap and S_t is the underlying's stock price at time t as above. Time to maturity is measured in years and is defined as in Equation (11). As we observe bid and ask quotes for all certificates, we are able to calculate each certificate's relative spread as:

$$Spread_t = \frac{P_t^{ask} - P_t^{bid}}{0.5(P_t^{ask} + P_t^{bid})}, \quad (14)$$

where P_t^{bid} and P_t^{ask} are the certificate's quoted bid and ask price at time bar t , respectively.

Statistics on the certificates' issuances per year, moneyness, time to maturity and spread at issuance are presented in Table 1. The number of issued discount certificates on DAX stocks on the Euwax from 2006 through 2013 increased progressively across the sample period. The number of issued certificates jumped upwards in the crises periods 2008 and 2011, whereas it fell slightly in the successive years after the crises settled down. Most discount certificates are issued with a cap below the underlying price at issuance with an average moneyness of 11.96%. The time to maturity at issuance, with an average of 1.17 years, decreased due to a change in German tax rules after 2008 (see e.g., Baule, 2011; Entrop, Fischer, et al., 2016). At the issuance day, discount certificates have an average spread of 0.19% that is larger during economic turmoil.

4.3 | Trade data

The trade data contains the exact timestamp of executed trades as well as the volume and trade price at which the trade has been executed at the Euwax. We apply the quote rule to classify each single trade into a sale or buying decision from the perspective of a retail investor (see Chakrabarty, Li, Nguyen, & Van Ness, 2007). We match the trades with the current quote data. If there is no quote available for the day, we omit the trade. The trade is classified as a sale from the investor's perspective if the trade price is equal to or lower than the bid quote. If the trade price is equal to or higher than the ask quote, the trade is classified as a buy from the investor's perspective. We follow Baule (2011) and omit the trade if the trade price lies between the bid and ask quote or if all three values are identical.¹⁵ Figure 1 shows the development of the order flow, that is the difference between the weekly average buy and sell trading EUR volume in millions. The order flow was highly negative after the Lehman Brothers' default in 2008, while it was positive during nearly all other times. The latter indicates that many certificates are held until maturity.

5 | VALUATION

5.1 | Valuation framework

The certificate's spread and premium are taken from the sampled quote database and the end of each time bar (see Section 4.2). While the relative spread can easily be calculated using Equation (14), the fair value of discount certificates needs to be determined to quantify the premium at the end of each time bar t . We measure two theoretical fair values:

¹⁴We eliminate quote bars where bid or ask quotes are zero, contain missing values or the ask quote is less than or equal to the bid quote.

¹⁵By doing so, we refrain from classifying 9.75% of the trades to minimize the error due to classifying trades inside the quotes (Ellis, Michaely & O'Hara, 2000).

TABLE 1 Quote data set: moneyness, time to maturity and spread at issuance

Year	No. of issuances	Moneyness at issuance				Time to maturity at issuance				Spread at issuance			
		25% (%)	Mean (%)	Median (%)	75% (%)	25%	Mean	Median	75%	25% (%)	Mean (%)	Median (%)	75% (%)
2006	10,446	-9.38	6.90	1.23	15.66	1.30	1.89	1.65	2.19	0.09	0.20	0.15	0.26
2007	15,496	-9.30	9.87	4.99	23.85	1.22	1.62	1.47	1.88	0.08	0.20	0.14	0.23
2008	36,752	-9.15	15.70	10.73	35.45	0.96	1.33	1.24	1.61	0.10	0.37	0.19	0.38
2009	34,718	-6.82	15.64	9.12	33.18	0.65	1.18	1.06	1.57	0.10	0.30	0.18	0.32
2010	48,519	-6.78	11.83	5.88	25.35	0.58	1.11	1.01	1.48	0.05	0.17	0.11	0.19
2011	93,781	-6.18	13.83	8.51	28.26	0.59	1.12	1.04	1.57	0.05	0.17	0.09	0.17
2012	75,799	-8.29	12.30	5.79	27.44	0.55	1.08	1.00	1.45	0.04	0.18	0.09	0.17
2013	72,784	-7.47	6.92	2.97	16.56	0.59	1.07	1.03	1.45	0.03	0.12	0.06	0.13
2006-2013	388,295	-7.49	11.96	6.05	25.75	0.64	1.17	1.07	1.57	0.05	0.19	0.10	0.20

Notes: This table presents means, medians, and quartiles of the moneyness, time to maturity in years and spread of discount certificates at the issue date. Moneyness is defined as the underlying's stock price minus the certificate's cap level, divided by the cap. The spread is the difference between the ask and bid quote divided by the mid quote.

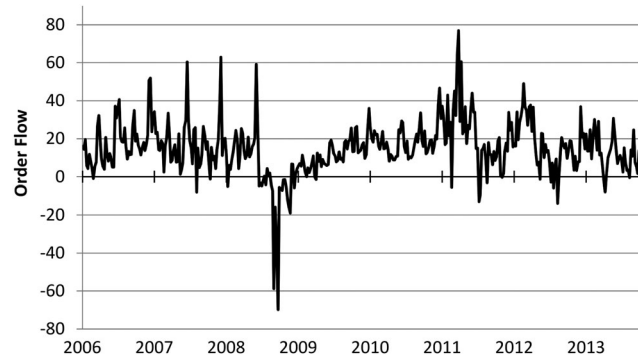


FIGURE 1 Weekly average OrderFlow. The difference between the weekly average buy and sell trading EUR volume in millions on the Euwax over the sample period

the default-free value applying the Black–Scholes option pricing model (Black & Scholes, 1973) and a structural model (Baule et al., 2008) that takes the issuer's default risk into account.

We apply the Black–Scholes formula to estimate the default-free value of a discount certificate:

$$DC_t^{df} = \alpha e^{-r(T-\tau)}(e^{-r(\tau-t)}X - p_t) = \alpha e^{-r(T-\tau)}(e^{-r(\tau-t)}X + (S_t - Div_t)N(-a_1) - e^{-r(\tau-t)}XN(-b_1)) \quad (15)$$

with

$$a_1 = \frac{\log((S_t - Div_t)/X) + (r + \sigma^2/2)(\tau - t)}{\sigma\sqrt{\tau - t}}, \quad (16)$$

$$b_1 = a_1 - \sigma\sqrt{\tau - t}, \quad (17)$$

$$Div_{t,t < \tau_1 < \tau_2 < \tau} = e^{-r(\tau_1-t)}Div_1 + e^{-r(\tau_2-t)}Div_2, \quad (18)$$

where p_t is the value of a European put option written on the certificate's underlying with maturity τ and strike price X at time t . $N(\bullet)$ represents the cumulative distribution function of the standard normal distribution. Div_t denotes the aggregate discounted dividend payment estimates (τ_1 , τ_2) between t and τ , r denotes the risk-free rate and σ the volatility of the underlying.

As certificates are unsecured securities, the fair value of certificates depends on the issuer default risk. For example, Entrop, Fischer, et al. (2016) find that the credit risk explains up to 42% and on average 39%, respectively, of discount certificate overpricing. Hull and White (1995) account for issuer credit risk by discounting the default-free value with the issuer's credit spread s , thus obtaining the value of the defaultable security. The model requires the crucial assumption that market risk (underlying price) and credit (default) risk of the issuer are independent. During periods of turmoil, the correlation between issuers' assets and underlying prices tend to increase, resulting in an overestimation of the value-impact of credit risk, that is the fair value is discounted too excessively. A more sophisticated approach to incorporate credit risk is the structural model provided by Baule et al. (2008) that assumes that the issuer's default is driven by its asset value:

$$DC_t^{SM} = \alpha e^{-r(T-\tau)}(e^{-(r+s)(\tau-t)}X - p_t^{SM}) = \alpha e^{-r(T-\tau)} \left(\begin{aligned} &e^{-r(\tau-t)}(1 + (\delta - 1)N(-b_2))X \\ &+ (S_t - Div_t)(N(-a_1, a_2, -\rho_{I,S}) + \delta N(-a_1, -a_2, \rho_{I,S})) \\ &- e^{-r(\tau-t)}X(N(-b_1, b_2, -\rho_{I,S}) + \delta N(-b_1, -b_2, \rho_{I,S})) \end{aligned} \right) \quad (19)$$

with

$$a_1 = \frac{\log((S_t - Div_t)/X) + (r + \sigma^2/2)(\tau - t)}{\sigma\sqrt{\tau - t}}, \quad (20)$$

$$b_1 = a_1 - \sigma\sqrt{\tau - t}, \quad (21)$$

$$a_2 = b_2 + \rho_{I,S}\sigma\sqrt{\tau - t}, \quad (22)$$

$$b_2 = N^{-1}\left(\frac{\delta - e^{-s(\tau-t)}}{\delta - 1}\right), \quad (23)$$

where p_t^{SM} is the value of a vulnerable put option. Compared to the default-free model above, the additional input parameters are $\rho_{I,S}$, the correlation between issuer's assets and the underlying, δ , the recovery rate of the issuer's assets in case of default, and s is the issuer's credit spread. $N(\cdot, \cdot, \rho_{I,S})$ represents the bivariate normal cumulative distribution function with correlation $\rho_{I,S}$. A positive correlation value lowers the impact of credit risk, and hence positively affects the certificate's value. If the correlation ($\rho_{I,S}$) takes the value zero, the fair value coincides with the Hull and White model. Moreover, the certificate's value of a default-free issuer, that is a recovery rate (δ) equal to one, coincides with the default-free Black–Scholes model.

5.2 | Calibration

We estimate the value of every discount certificate via standard calibration procedures. The certificate's fair value is estimated on each trading day between its issuance and maturity at 9:30 a.m., 12:30 p.m., 3:30 p.m., and 5:35 p.m. Because stock options with a time to maturity of more than 2 years are scarce and dividend forecasts are only available for two subsequent payments, we exclude discount certificates' valuation days with a remaining time to maturity of more than 2 years. For S_t , we use the certificates' underlying stock price, matched to a second with each quote, which we obtained from the TRTH database. The default-free spot rate (r) is the government spot rate curve, estimated by the Deutsche Bundesbank, using the Svensson (1994) function as an extension of the Nelson and Siegel (1987) approach. For periods of less than 1 year, we use linearly interpolated EUREPO rates. For dividend estimates, we use monthly I/B/E/S consensus analyst forecasts for the two successive dividend payments on each valuation date from Thomson Reuters.¹⁶ The expected dividend payment dates are the days after the expected shareholders' meeting dates.

The volatility σ of the underlying stocks is estimated by extracting the implied volatilities from daily settlement prices of stock options listed at Eurex, that were provided by the Karlsruher Kapitalmarktdatenbank of the Karlsruhe Institute of Technology. As Eurex stock options are of American type, we estimate the implied volatility by using the Leisen-Reimer binomial tree model (Leisen & Reimer, 1996). The model improves the convergence in comparison to the Cox, Ross and Rubinstein (1979). We apply a daily discretization and allow for two discrete dividend payments. The implied volatility is the volatility that equates the option's binomial tree price with the Eurex option settlement price by applying a root-searching algorithm (Brent, 1973). We estimate the implied volatility for American put (with and without dividend payments) and call options (with dividend payments); for call options without dividend payments, we apply the Black-Scholes formula. Moreover, as we estimated the implied volatility from Eurex option chains, only the volatility of out-of-the-money Eurex options is used, which is common practice (e.g., Taleb, 1997, p. 164). The implied volatility is assigned to each discount certificate, matching the same underlying, strike (cap) and maturity. If we do not find an exact match, we bilinearly interpolate the estimated implied volatility from the four options with the same underlying, the nearest (lower and higher) strikes and (shorter and longer) maturities to the certificate (see e.g., Baule, 2011; Horst & Veld, 2008).

The structural model additionally requires the issuer's credit spread as an input. We obtain issuer-specific one- and two-year CDS spreads for senior debt from Datastream. For each day and each issuer, a spread curve is interpolated for a time to maturity of up to 2 years. For each trading day, the credit spread with the congruent time to maturity and issuer is used for each certificate. As a proxy for the correlation ($\rho_{I,S}$) between the asset returns of the issuers and the returns of the underlying, we use the equity correlation between issuer and underlying firms from historical continuously compounded daily stock returns over a 125-day period. Consequently, we only consider public issuers in the following. The recovery rate (δ) takes the default value of 0.4.

¹⁶ Recall that German stocks pay dividends yearly.

TABLE 2 Average Spreads and Total Premiums per Year

Year	N	Spread (%)	Default-free Premium (<i>DFP</i> , %)	Credit Risk Premium (<i>CRP</i> , %)	Total Premium (<i>TP</i> , %)	<i>CRP/TP</i> (%)
2006	6,894,692	0.21	0.23	0.02	0.25	7
2007	10,606,424	0.19	0.15	0.09	0.24	37
2008	25,107,751	0.33	0.45	0.43	0.89	49
2009	30,708,473	0.44	0.51	0.55	1.07	51
2010	30,448,320	0.22	0.14	0.34	0.49	70
2011	52,376,131	0.16	0.30	0.63	0.94	67
2012	67,399,864	0.17	0.21	0.60	0.82	73
2013	55,646,023	0.13	0.38	0.23	0.60	38
2006–2013	279,187,678	0.16	0.30	0.37	0.66	56

Notes: The table reports average spreads and premiums of discount certificates from listed issuers at 9:30 a.m., 12:30 p.m., 3:30 p.m., and 5:35 p.m. written on DAX stocks in the secondary market from 01/2006 to 12/2013. *N* is the sample size per year. The spread is defined in Equation (14). Premium definitions for default-free (*DFP*), credit risk (*CRP*), and total premium (*TP*) are given in Equations (24), (25), and (26), respectively. *CRP/TP* is the fraction of the average credit risk premium on the average total premium. To correct for data and valuation errors, we truncated the lowest and highest 1% of the *DFP* distribution.

5.3 | Premiums of discount certificates

Based on the fair theoretical values, the default-free premium DFP_t , the credit risk premium CRP_t , and the total premium TP_t are defined as in Baule et al. (2008):

$$DFP_t = \frac{DC_t^{mid} - DC_t^{df}}{DC_t^{df}}, \quad (24)$$

$$CRP_t = \frac{DC_t^{df} - DC_t^{SM}}{DC_t^{SM}}, \quad (25)$$

$$TP_t = \frac{DC_t^{mid} - DC_t^{SM}}{DC_t^{SM}}, \quad (26)$$

where DC_t^{mid} is the certificate's mid quote (average of bid and ask quotes) at 9:30 a.m., 12:30 p.m., 3:30 p.m., and 5:35 p.m. on the Euwax.

Table 2 depicts the average yearly spreads (see Equation (14)) and premiums for 317,062 discount certificates and more than 279 million observations. The table contains all certificates of issuers listed on the stock exchange and observations were truncated at a 1% level regarding the default-free premium.¹⁷ The number of outstanding certificates and issuers from which investors could choose increased steadily over the sample period 2006–2013. The average spread is 0.16% for the whole sample period. The spread was the highest in 2008 and 2009, after the Lehman Brothers default occurred, with 0.33% and 0.44%, respectively. For listed issuers, discount certificates are priced 0.66% above the fair value. The average credit risk premium accounts for 56% of the structural model's total premium with an average default-free premium of 30 basis points.¹⁸ Table 3 shows the average spreads and premiums for each issuer; these vary substantially across issuers.

Figure 2 shows the development of the weekly average total premiums (*TP*) and spreads over the sample period. Interestingly, the overpricing of discount certificates surged during both economic crises (2008/09 and 2011/12), whereas spreads were only raised during the global financial crisis in 2008/09.

¹⁷Table 3 displays the issuers we consider. We do not include the issuers BayernLB, BHF-Bank, BW-Bank, Dresdner Bank, DZ Bank, Interactive Brokers Financial Products, LBB, LBBW, Lang & Schwarz, Sal. Oppenheim, Vontobel, WestLB, WZG Bank. These issuers are not listed or CDS spreads are not available in our sample period.

¹⁸For comparison, when calculating the total premium by the method of Hull and White (1995), we find that the average estimated credit risk premium (and consequently the total premium) for the structural model is 0.11 percentage points lower than in the Hull and White model. As expected, the difference between both models is higher (e.g., 23 basis points in 2009) when market risk, and thus correlations and spreads, increases.

TABLE 3 Average spreads and total premiums per issuer

Issuer	N	Spread (%)	Default-free Premium (DFP, %)	Credit risk Premium (CRP, %)	Total Premium (TP, %)	CRP/TP (%)
Barclays	2,889,837	0.13	0.02	0.45	0.48	96
BNP	28,391,251	0.25	0.22	0.29	0.51	56
Citibank	25,207,212	0.16	0.42	0.46	0.88	52
Commerzbank	81,447,930	0.17	0.24	0.53	0.78	68
Deutsche Bank	23,322,072	0.31	0.34	0.23	0.57	40
Goldman Sachs	15,461,596	0.32	0.22	0.55	0.77	71
HSBC Trinkaus	21,535,096	0.24	0.42	0.23	0.65	35
ING	660,691	0.23	0.20	0.01	0.21	6
Macquarie	3,612,595	0.14	0.31	0.53	0.84	63
Merrill Lynch	3,309,037	0.31	0.26	0.91	1.17	78
Morgan Stanley	3,491,635	0.26	0.30	0.90	1.20	75
RBS	10,992,586	0.25	0.30	0.64	0.94	68
Société Générale	4,569,689	0.25	0.49	0.17	0.66	26
UBS	48,815,771	0.18	0.40	0.44	0.84	52
UniCredit	5,480,680	0.16	0.32	0.87	1.19	73
Total	279,187,678	0.16	0.30	0.37	0.66	56

Notes: The table reports average spreads and premiums of discount certificates from listed issuers at 9:30 a.m., 12:30 p.m., 3:30 p.m., and 5:35 p.m. written on DAX stocks in the secondary market from 01/2006 to 12/2013. *N* is the sample size per issuer. The spread is defined in Equation (14). Premium definitions for default-free (*DFP*), credit risk (*CRP*), and total premium (*TP*) are given in Equations (24), (25), and (26), respectively. *CRP/TP* is the fraction of the average credit risk premium on the average total premium. To correct for data and valuation errors, we truncated the lowest and highest 1% of the *DFP* distribution.

6 | EMPIRICAL ANALYSIS

6.1 | Empirical design

To empirically analyze the determinants of the total premium *TP* (see Equation (26)) and of the spread as defined in Equation (14), respectively, we estimate the following two equations in several variants and methodological settings:

$$TP_{ijt} = \mu + \beta Spread_{ijt} + \sum_k \gamma_k HedgingCosts_{kijt} + \sum_l \theta_l Risks_{lijt} + \sum_m \xi_m OtherVariables_{mijt} + \sum_n \phi_n Controls_{nijt} + \epsilon_{ijt}, \quad (27)$$

$$Spread_{ijt} = \mu' + \beta' TP_{ijt} + \sum_k \gamma'_k HedgingCosts_{kijt} + \sum_l \theta'_l Risks_{lijt} + \sum_m \xi'_m OtherVariables_{mijt} + \sum_n \phi'_n Controls_{nijt} + \epsilon'_{ijt}, \quad (28)$$

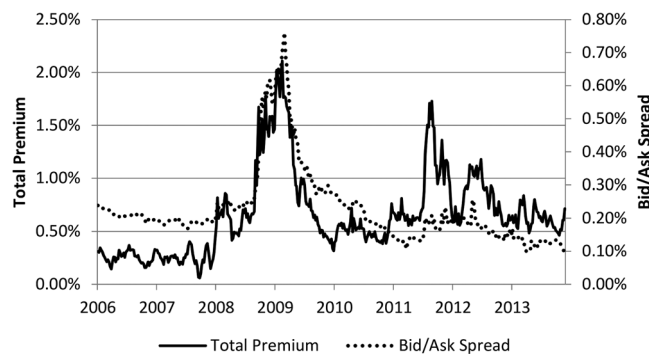


FIGURE 2 Weekly average total premiums and spreads. The weekly average total premiums (total premium, see Equation (26)) and spreads over the sample period are shown. The spread is the difference between the ask and bid quote divided by the mid quote

where TP_{ijt} denotes the total premium of discount certificate i of issuer j in t and the other variables are indexed analogously. As the total premium and the spread are likely to be substitutes as mentioned in the introduction, we add the spread and the total premium as first variable in Equations (27) and (28), respectively. The remaining independent variables are those defined in Sections 3.1–3.3.

We also add some controls. As premiums and spreads might be influenced by the moneyness (defined as in Equation (13)), we include the moneyness at quotes and its square root in the model (Baule, 2011; Baule & Blonski, 2015; Jameson & Wilhelm, 1992). Furthermore, the implied volatility was calculated by using daily settlement prices of Eurex options rather than intraday prices. Wallmeier (2015) shows that 95% of the implied volatility intraday variations are explained by changes in the underlying level. To control for intraday changes of the volatility, we follow Baller et al. (2016) and include the return of the underlying prices from the quote time until the settlement time of the same day in our model. Furthermore, we include issuer-fixed effects, underlying-fixed effects and monthly time-fixed effects.

In Sections 6.2 we estimate the regression equations above separately and include the interaction terms. We at first use the high-dimensional fixed effects estimator of Correia (2016) and Newey-West heteroskedasticity- and autocorrelation-consistent (HAC) standard errors (Newey & West, 1987). However, the results may be biased due to the endogeneity between the premium and the spread.

To account for this, we additionally re-estimate the regressions by applying a GMM-2SLS approach. As instruments for the spread in Equation (27), we follow Baller et al. (2016) and utilize (a) the average spread over all products with the same underlying of the prior day and (b) the first difference of the ratio between the spread of the most similar product of a different issuer and the average spread of the same day for the same underlying. The most similar certificate is the product, which has the same underlying, the same time bar, and the smallest Euclidean distance with regard to time to maturity and moneyness. This procedure is applied analogously to the total premiums in Equation (28). For each instrumental variables (IV) regression, we report validity tests for underidentification, weak identification, and overidentification (Hansen, 1982; Kleibergen & Paap, 2006). The test statistics indicate that the instruments are correlated with endogenous regressors, are not weak instruments and are uncorrelated with the error term as well as correctly excluded from the estimated equation.

Finally, the previous single equation models are also estimated simultaneously (Section 6.3). We follow Roll, Schwartz, and Subrahmanyam (2010) and examine average premiums, spreads and certificate characteristics, where the average is taken over all certificates with the same underlying and issuer per day, that is we have one observation per each underlying-issuer combination per day. The reason for using daily time periods is twofold: first, the size of our data set makes it numerical challenging to apply a GMM estimator in a 3SLS-setting. Secondly, it allows us to examine average, “representative” discount certificates, which should reduce the impact of noise on the single-certificate level. As additional instruments to the exogenous explanatory variables common to all equations, we include the previously used instruments from the individual IV regressions. The system is estimated by using the GMM-3SLS estimator which allows for HAC standard errors and different instruments in different equations (Schmidt, 1990; Wooldridge, 2010).

6.2 | Determinants of issuers' total premiums and spreads

The results for the first regressions are presented in Table 5. We examine the magnitude of issuers' hedging costs, risks and the other variables on either total premium or spread by comparing the standardized coefficients. We measure the effect of a one-standard-deviation increase in the independent variable on the unit change in the total premium or spread by multiplying the standardized coefficients in Table 5 with the standard deviation of the dependent variable. Table 4 thus presents summary statistics for the main variables used in the regressions in Table 5. The standard deviation of the premium is 1.124%, and the standard deviation of the spread equals 0.518%.

Columns (1) to (3) show the estimated coefficients with total premium as the dependent variable and columns (4) to (6) with the spread as the dependent variable. Columns (2) and (3) as well as (5) and (6) are IV regressions described above.

Columns (1) and (4) neglect the endogeneity between premiums and spreads, and both coefficients for *Total Premium* and *Spread* are positive. However, the coefficients are negative for IV regressions (columns (2), (3), (5) and (6)), that is premiums tend to be lower when spreads are higher and vice versa. If the spread (premium) increases by one standard deviation, the premium (spread) decreases by $0.0609 \times 1.124\% = 6.85$ basis points ($0.1139 \times 0.518\% = 5.90$ basis points), based on the coefficients reported in columns (3) and (6). This supports our conjecture regarding a substitution effect between spreads and premiums, and is our first important result that is stable across all our analyses.

TABLE 4 Summary statistics

Variable	Unit	Mean	SD	P25	P75
Total Premium	%	0.6220	1.124	0.0108	0.8571
Spread	%	0.2278	0.518	0.0669	0.2410
IHC	%	0.0314	0.059	0.0048	0.0369
RC		0.0328	0.068	0.0024	0.0347
GapRisk		0.0122	0.009	0.0079	0.0130
JumpRisk	%	0.1069	4.467	−1.6601	2.0542
ScalperRisk	%	0.0089	0.010	0.0026	0.0117
Vola		0.3811	0.228	0.2684	0.4156
CreditRiskPremium	%	0.3850	0.586	0.0365	0.4830
OrderFlow		0.0133	0.693	0.0000	0.0000
PerfectHedge A		0.1491	0.356	0.0000	0.0000
PerfectHedge E		0.0271	0.162	0.0000	0.0000
Comp		0.5490	0.374	0.0000	0.8571
TtM		0.7960	0.507	0.3671	1.1562
DIV		0.0281	0.031	0.0000	0.0455

Notes: This table presents summary statistics for the main variables used in the regressions in Section 6.2. Total Premium is defined as TP (see Equation (26)). Spread is the certificate's relative spread, based on the close bid and the close ask price (see Equation (14)). IHC is the certificate's initial hedging costs at time t . RC is the certificate's rebalancing costs at time t . GapRisk is the overnight gap risk measured through a GARCH(1,1)-forecast of the overnight volatility, JumpRisk measures the downside jump risk via the implicit volatility skew slope, ScalperRisk is the risk of informed traders entering the market and is measured by the reservation spread. Vola stands for the implied volatility level of the underlying asset. CreditRiskPremium is the credit risk premium (Equation (25)). OrderFlow is the net accumulated trading volume measured in euros within the time interval. PerfectHedge A and PerfectHedge E are dummy variables which are 1 if an American and European option, respectively, exists for the same date, underlying, strike and maturity date, and 0 otherwise. Comp is a measure of competition, proxied by the number of similar certificates. TtM stands for time to maturity in years. DIV is the relative size of the expected dividend payments. Explanatory variables are described in more detail in Section 3. $N = 83,152,248$.

6.2.1 | Hedging costs

Initial hedging- and rebalancing costs have a positive effect on total premiums, whereas the effect on premiums is slightly more pronounced for RC than IHC (columns (1) and (3)). However, looking at the standardized coefficients, the economic magnitude is minuscule for both hedging costs. In fact, an increase in IHC (RC) by one standard deviation increases the premium by only $0.0063 \times 1.124\% = 0.71$ ($0.0089 \times 0.518\% = 1.00$) basis points (based on column (3)). This especially implies issuers do not seem to incorporate future (expected) rebalancing costs in the premiums in the way supposed in Section 3.1.

Examining the determinants of the spread, the coefficients for IHC and RC are positive and much higher. IHC , in turn, are more important than rebalancing costs in explaining certificate spreads, which is consistent with the warrant market (Petrella, 2006). Hence, issuers adjust the spread when the initial hedging becomes costlier. Interestingly, IHC is the determinant with the highest influence on spreads across all variables: a one-standard-deviation increase in IHC raises the spread by $0.1842 \times 0.518\% = 9.54$ basis points (based on column (6)). This indicates that issuers dynamically delta-hedge their positions and that certificates' trading costs are linked to the trading costs in the stock market, because the certificate's delta and the underlying's spread are both components of IHC .

6.2.2 | Hedging costs and changes in inventory

We examine the simultaneous impact of hedging costs and changes in issuers' inventory, by examining the two interaction terms in our regressions: first, the interaction between IHC and the order flow (see Equation (5)), and secondly, the interaction between rebalancing costs and the order flow (see Equation (8)).

TABLE 5 Determinants of total premium and spreads

	Total Premium			Spread		
	No IV	IV		No IV	IV	
	(1)	(2)	(3)	(4)	(5)	(6)
Total Premium				+0.0201*** (26.18)	−0.0992*** (−37.81)	−0.1139*** (−40.79)
Spread	+0.0145*** (26.09)	−0.0546*** (−44.98)	−0.0609*** (−49.22)			
IHC	+0.0013** (2.21)	+0.0154*** (25.54)	+0.0063*** (10.40)	+0.2048*** (96.66)	+0.2053*** (97.16)	+0.1842*** (92.30)
IHC × OF	+0.0051*** (13.91)	+0.0052*** (14.45)	+0.0052*** (14.34)	+0.0008 (1.17)	+0.0014** (2.06)	+0.0020*** (3.02)
RC	+0.0082*** (24.28)	+0.0097*** (28.44)	+0.0089*** (25.14)	+0.0226*** (41.16)	+0.0236*** (42.56)	+0.0296*** (53.52)
RC × OF	−0.0007*** (−3.43)	−0.0006*** (−3.21)	−0.0011*** (−5.39)	+0.0006** (2.10)	+0.0005* (1.79)	+0.0003 (1.28)
GapRisk	+0.0435*** (59.06)	+0.0530*** (71.29)	+0.0427*** (58.17)	+0.1366*** (68.70)	+0.1421*** (69.47)	+0.1156*** (57.51)
JumpRisk	−0.0178*** (−55.95)	−0.0174*** (−54.02)	−0.0110*** (−34.83)	+0.0067*** (8.87)	+0.0046*** (6.05)	+0.0035*** (4.56)
ScalperRisk	+0.0272*** (26.91)	+0.0388*** (37.29)	+0.0252*** (24.02)	+0.1668*** (105.88)	+0.1704*** (107.72)	+0.1526*** (101.91)
Vola			+0.0757*** (176.26)			+0.1657*** (83.79)
CreditRiskPremium	+0.4731*** (936.70)	+0.4722*** (929.61)	+0.4485*** (853.59)	−0.0220*** (−40.32)	+0.0344*** (25.47)	+0.0377*** (27.70)
OrderFlow	−0.0028*** (−20.27)	−0.0028*** (−20.27)	−0.0028*** (−19.88)	+0.0003* (1.69)	−0.0000 (−0.25)	+0.0002 (1.06)
PerfectHedge A	−0.0074*** (−33.01)	−0.0061*** (−27.09)	−0.0099*** (−44.43)	+0.0189*** (52.54)	+0.0180*** (49.98)	+0.0139*** (38.56)
PerfectHedge E	−0.0050*** (−28.46)	−0.0054*** (−30.19)	−0.0043*** (−24.37)	−0.0051*** (−23.63)	−0.0057*** (−25.98)	−0.0042*** (−19.37)
Comp	−0.0197*** (−85.40)	−0.0211*** (−90.86)	−0.0219*** (−95.80)	−0.0202*** (−81.16)	−0.0225*** (−90.69)	−0.0159*** (−63.78)
TtM	+0.1320*** (363.02)	+0.1326*** (363.46)	+0.0447*** (108.32)	+0.0048*** (13.33)	+0.0206*** (45.96)	+0.0706*** (120.22)
DIV			+0.1987*** (470.49)			−0.0132*** (−22.03)
Moneyness	Yes	Yes	Yes	Yes	Yes	Yes
Intraday Return	Yes	Yes	Yes	Yes	Yes	Yes
Issuer FE	Yes	Yes	Yes	Yes	Yes	Yes
Underlying FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
p-value of KP rk LM statistic		0.000	0.000		0.000	0.000

(Continues)

TABLE 5 (Continued)

	Total Premium			Spread		
	No IV	IV		No IV	IV	
	(1)	(2)	(3)	(4)	(5)	(6)
KP rk Wald <i>F</i> statistic		9,471	9,246		257,342	234,378
<i>p</i> -value of Hansen <i>J</i> statistic		0.217	0.221		0.872	0.764
Adj. <i>R</i> ²	0.468	0.465	0.482	0.263	0.256	0.270
Obs.	83,152,248	83,152,248	83,152,248	83,152,248	83,152,248	83,152,248

Notes: This table reports estimated standardized coefficients of regressions described in Section 6.1 with either *TP* or *Spread* as the dependent variable. Total Premium is defined as *TP* (see Equation (26)); the variable is instrumented in columns (5) and (6). Spread is the certificate's relative spread, based on the close bid and the close ask price (see Equation (14)); the variable is instrumented in columns (2) and (3). *IHC* is the certificate's initial hedging costs at time *t*, *IHC* × *OF* is an interaction variable between the initial hedging costs and the order flow (Equation (6)). *RC* is the certificate's rebalancing costs at time *t*, *RC* × *OF* is an interaction variable between the rebalancing costs and the order flow. *GapRisk* is the overnight gap risk measured through a GARCH(1,1)-forecast of the overnight volatility, *JumpRisk* measures the downside jump risk via the implicit volatility skew slope, *ScalperRisk* is the risk of informed traders entering the market and is measured by the reservation spread. *Vola* stands for the implied volatility level of the underlying asset. *CreditRiskPremium* is the credit risk premium (Equation (25)). *OrderFlow* is the net accumulated trading volume measured in euros within the time interval. *PerfectHedge A* and *PerfectHedge E* are dummy variables which are 1 if an American and European option, respectively, exists for the same date, underlying, strike and maturity date, and 0 otherwise. *Comp* is a measure of competition, proxied by the number of similar certificates. *TiM* stands for time to maturity in years. *DIV* is the relative size of the expected dividend payments. Explanatory variables are described in more detail in Section 3. The controls used are: moneyness at quotes, the moneyness's square root, and the intraday return from the time of the quote until the underlying's market closure. All regressions are estimated with issuer-, underlying- and monthly time-fixed effects. Validity of the instrumental variables (IV) regressions is tested via the robust Kleibergen-Paap rk LM statistic of underidentification, Kleibergen-Paap rk Wald *F* statistic of weak identification (Kleibergen & Paap, 2006) and Hansen *J* statistic of overidentification (Hansen, 1982). Obs. denotes the number of observations. Standardized beta coefficients for all models, that is all variables are standardized. The interaction terms are the product of the standardized variables. HAC *t* statistics in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

If there are high *IHC* and asymmetric order flows, the positive coefficient of *IHC* × *OF* reveals that issuers adjust the premium according to the order flow, that is, investor's buying pressure leads to increases and selling pressure to decreases in premiums. For example, in column (3), the coefficient for *IHC* is 0.0063 and for *IHC* × *OF* is 0.0052. For high buying or selling pressure the overall effect is economically meaningful. The interaction term for rebalancing costs *RC* × *OF* shows a negative relationship with total premiums. However, the effect is very small. Thus, the interaction effect is less pronounced for rebalancing costs than *IHC*.

The effect of the interaction terms on the spread are shown in columns (4) to (6). *IHC* × *OF* shows a significant positive relationship with the spread at a 1% level only in column (6), while none of the interaction terms for rebalancing costs are statistically significant at a 1% level.

All in all, our results imply that issuers price *IHC* not only into the spread but also into the premium if there are large changes in the inventory.

6.2.3 | Risks

GapRisk, *ScalperRisk*, and *Vola* increase the total premium, with *Vola* and *GapRisk* having the largest economic impact on total premiums within the risk determinants. A one-standard-deviation increase in *Vola* (*GapRisk*) raises the premium by $0.0757 \times 1.124\% = 8.51$ ($0.0427 \times 1.124\% = 4.80$) basis points (based on column (3)). *JumpRisk* has a significant and negative coefficient. A downside jump in the underlying price increases the certificate's delta $|\Delta_t|$ and issuers need to adjust their hedging position by increasing their long position in the underlying. Consequently, a downside jump in the price level reduces the required frequency of discrete time steps at which the issuer needs to buy the underlying to remain hedged, and thus avoids recurrent trading costs through spreads in the underlying market as discussed in Section 3.1.

The risk factors have an economically much higher impact on spreads than premiums: *GapRisk*, *JumpRisk*, *ScalperRisk*, and *Vola* increase the spread, with *Vola* and *ScalperRisk* being one of the most economically significant determinants of spreads. If *Vola* (*ScalperRisk*) increases by one standard deviation, the spread changes by $0.1657 \times 0.518\% = 8.58$ ($0.1526 \times 0.518\% = 7.90$) basis points (based on column (6)). Hence, issuers protect themselves

against adverse-selection risk, albeit the fact that discount certificates are not the first choice for informed traders. *JumpRisk* has a positive and economically insignificant relationship with the spread.¹⁹ *Vola* is the economically most significant risk determinant for premiums as well as spreads. This variable reflects uncertainty in periods of turmoil, which is consequently transferred to retail investors.

6.2.4 | Other variables

In line with the results from Section 5.3, the credit risk premium has the largest impact on total premiums. *CRP* has also a positive, but small relationship with the spread for model (5) and (6). The *OrderFlow*—although statistically significant—has an economically irrelevant impact on the total premium. This stands in contrast to the order flow hypothesis (e.g., Baule, 2011), that is issuers anticipate systematics in the order flow and increase the premium in phases of positive expected net purchases by investors and vice versa. However, limited evidence for the order flow hypothesis is also found by Entrop, Fischer, et al. (2016). Still, order flow becomes relevant when we interact it with the hedging costs. Moreover, our empirical finding is consistent with the hypothesis that order processing costs decrease if trading volume increases (Petrella & Segara, 2013). The *OrderFlow* is statistically and economically insignificant when explaining the spread.

(Perfect) hedge opportunities, through available Eurex options with the same underlying asset, strike, and time to maturity as the discount certificate, reduce issuers' total premiums although the effect is small. For the spread, the perfect hedge variables show mixed results. While the coefficient is negative in the case of a European type option that allows for a real perfect hedge, the hedge opportunity with American type options exhibits a positive relationship with the spread. As expected, the competition among issuers *Comp* has a negative influence throughout all models, implying lower total premiums (spreads) when there is higher competition while controlling for the spread (premiums).

Time to maturity is positive and significant for the premium supporting the “lifecycle hypothesis.” It also has a positive relationship with the spread, however, the economic influence on spreads is not as significant as on total premiums, where the lifecycle effect is a crucial component. We argued in Section 3.1 that decreasing premiums over time could also be explained by hedging costs. However, as rebalancing cost turned out to be of minor importance for the premium, our results imply that the phenomenon of decreasing premiums is indeed primarily profit-related.

When examining the effect on the total premium, the dividend variable *DIV* is positive (column (3)), supporting previous findings from Entrop, Fischer, et al. (2016). This implies that issuers do not pass the negative-value effect of dividends fully to the investor. Dividends turn out to have the second largest influence on the total premium after the credit risk premium. In contrast, the spread exhibits a negative sensitivity to *DIV* (column (6)), that is, small but will become more relevant in the subsequent simultaneous equation model. This implies that issuers increase the premium and decrease the spread. This is plausible if investors are more sensitive to the easily comparable spreads than to the less transparent premiums, as they can hardly assess the financial fair value of a discount certificate.

To summarize our results, premiums and spreads serve as substitutes. In descending order, the credit risk premium, dividends, volatility, time to maturity and gap risk are the most economically important determinants of total premium. *IHC* are priced into the premium in the case of large changes in the inventory. The economically most significant determinants of spreads are, in descending order, *IHC*, volatility, scalper risk, and gap risk—but also the dividends of the underlying influence the spread.

6.3 | Simultaneous equations model

The standardized coefficients of the simultaneous equations model are reported in Table 6. Model (1) presents the GMM-3SLS estimates without fixed effects, whereas model (2) includes issuer dummies. Most findings are in line with the empirical results from the previous analyses, for example, premiums and spreads are significantly negatively related. Hence, we discuss only deviations from previous results and stress some distinctive features.

The effect of *IHC* and *RC* remain the same when either explaining premiums or spreads. However, the economic significance of rebalancing costs on spreads is more distinctive than the results from Section 6.2; *RC* is now the fourth most influential determinant.

¹⁹However, the relationship becomes positive when applying a simultaneous equations model (see Section 6.3).

TABLE 6 Simultaneous equations model

	(1)		(2)	
	Total Premium	Spread	Total Premium	Spread
Total Premium		−0.0304*** (−5.53)		−0.0554*** (−8.92)
Spread	−0.0466*** (−3.95)		−0.0538*** (−4.54)	
IHC	+0.0088 (1.51)	+0.3207*** (17.96)	+0.0117** (2.02)	+0.3187*** (17.94)
RC	+0.0281*** (8.21)	+0.0753*** (20.31)	+0.0227*** (6.62)	+0.0690*** (18.64)
GapRisk	+0.0362*** (9.43)	+0.0155 (1.36)	+0.0373*** (9.83)	+0.0183 (1.62)
JumpRisk	−0.0261*** (−8.32)	−0.0234*** (−6.41)	−0.0248*** (−8.04)	−0.0236*** (−6.58)
ScalperRisk		+0.1442*** (17.14)		+0.1476*** (17.76)
Vola	+0.1339*** (25.98)	+0.2927*** (21.48)	+0.1359*** (25.68)	+0.2996*** (21.75)
CreditRiskPremium	+0.6116*** (190.74)		+0.5968*** (163.69)	
OrderFlow	−0.0107*** (−12.11)	−0.0000 (−0.02)	−0.0095*** (−11.09)	+0.0009 (0.93)
PerfectHedge A	+0.0458*** (22.55)	+0.0158*** (6.05)	+0.0272*** (11.28)	−0.0012 (−0.34)
PerfectHedge E	−0.0120*** (−8.41)	+0.0026* (1.70)	−0.0051*** (−3.57)	+0.0077*** (4.81)
Comp	−0.0381*** (−17.32)	−0.0276*** (−8.90)	−0.0653*** (−25.61)	−0.0614*** (−19.58)
TtM	+0.0501*** (22.31)	+0.0253*** (6.49)	+0.0541*** (21.72)	+0.0422*** (9.96)
DIV	+0.0678*** (30.19)	−0.0407*** (−15.99)	+0.0766*** (34.39)	−0.0337*** (−13.09)
Moneyness	Yes	Yes	Yes	Yes
Intraday Return	Yes	Yes	Yes	Yes
Issuer FE	No	No	Yes	Yes
Underlying FE	No	No	No	No
Adj. R^2	0.513	0.359	0.531	0.367
Obs.	596,681		596,681	

Notes: This table reports the simultaneous estimated standardized coefficients of regressions described in Section 6.3 with TP (see Equation (26)) and $Spread$ (see Equation (14)) as dependent and independent variables. IHC is the certificate's initial hedging costs at time t . RC is the certificate's rebalancing costs at time t . $GapRisk$ is the overnight gap risk measured through a GARCH(1,1)-forecast of the overnight volatility, $JumpRisk$ measures the downside jump risk via the implicit volatility skew slope, $ScalperRisk$ is the risk of informed traders entering the market and is measured by the reservation spread. $Vola$ stands for the implied volatility level of the underlying asset. $CreditRiskPremium$ is the credit risk premium (Equation (25)). $OrderFlow$ is the net accumulated trading volume measured in euros within the time interval. $PerfectHedge A$ and $PerfectHedge E$ are dummy variables which are 1 if an American and European option, respectively, exists for the same date, underlying, strike and maturity date, and 0 otherwise. $Comp$ is a measure of competition, proxied by the number of similar certificates. TtM stands for time to maturity in years. DIV is the relative size of the expected dividend payments. Explanatory variables are described in more detail in Section 3. The controls used are: moneyness at quotes, the moneyness's square root, and the intraday return from the time of the quote until the underlying's market closure. Model (1) presents the GMM-3SLS estimates without fixed effects, whereas Model (2) includes issuer dummies. Obs. denotes the number of observations. Standardized beta coefficients are reported; HAC t statistics in parentheses. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

The influence of *GapRisk* on spreads is still positive but loses significance. *JumpRisk* is now negative throughout all coefficients, and thus issuers do not perceive downside jump risk as an additional cost factor. In Section 6.2, it had a significant positive relationship with spreads. The proxies for perfect hedge opportunities had mostly a significant negative effect on premiums and spreads in Section 6.2. The relationship was only significantly positive for American type options on spreads. Now, perfect hedge variables show mixed results; this can hardly be interpreted but all effects are still economically insignificant.

The competition variable *Comp* is still significant and negative through all coefficients; however, the economic significance on spreads increased. The same holds for the dividend *DIV* as already mentioned in Section 6.2.

7 | CONCLUSION

This paper examines the joint determinants of premiums and spreads, focusing on various new pricing components of structured financial products. The focus of this paper is on issuer's price-setting behavior and how it is affected by hedging costs. We examine a large discount certificate data set on DAX stocks that were tradable on the Euwax between January 2006 and December 2013. The fair theoretical value is calculated using a structural model, which relaxes the assumption of market risk (underlying price) and issuer's credit (default) risk being independent.

We find strong evidence for a negative relation between premium and spread and vice versa (substitution effect). However, the respective key determinants still differ. The main economic factors significantly explaining the premium of discount certificates are profit-related, like dividends, credit risk, lifecycle effect, and competition. While hedging costs and risks play a subordinate role in explaining the premium, there is clear evidence that IHC are also priced into the premium if there are large inventory changes. The economically significant determinants for the spread are mainly hedging costs and non-hedgeable risks. We find that hedging costs are positively related to the spread, with IHC being economically the most significant determinant. Scalping risk leads to a higher minimum reservation spread—thus, issuers protect themselves from scalpers. Furthermore, competition plays an important role in reducing the spread for certificates. In contrast to the premium, we find a negative influence of the underlying's dividends on the spread.

We conclude that issuers predominantly use certificate's premiums to manually adjust to changes in the market, which are profit and inventory cost related, whereas the spread is mainly used for issuer's cost side management.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study are obtained from several sources. Quote and trade data, and other market data were obtained from Refinitiv (formerly Thomson Reuters), that is, TRTH, Datastream. Base data of certificates were obtained from Deriva GmbH, option data were provided by Karlsruher Kapitalmarktdatenbank. Restrictions apply to the availability of these data, which were used under license. Other data are obtained from public sources (Deutscher Derivate Verband, 2017a, 2017b; Xetra, 2016) and are available on request.

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