Market makers' optimal price-setting policy for exchange-traded certificates

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ABSTRACT

This paper presents the first theoretical model of the profit maximizing price-setting policy for the issuers of exchange-traded retail certificates. Unlike previous theoretical microstructure models, the market considered is unique in that the market makers do not face significant inventory costs or risk from informed traders. The model derives the time structure of the optimal markups over a certificate's fair theoretical value and its relationship with optimal spreads, unhedgeable risk faced by the issuer and investors' buying and selling decisions. It shows that (i) the optimal markups decrease inter-temporally, (ii) issuers adjust the markups according to investors' demand, (iii) unhedgeable risk results in higher markups and influences their time structure, (iv) the markups and the spread are negatively related. Using data from the German market for leverage certificates, we find strong empirical support for the model-derived hypotheses, except for (iv). We find spreads exhibit little variation and this suggests that markups and spreads are not substitute profit sources for issuers in this market.

1. Introduction

In a relatively short period of time, the retail market for the class of structured financial products known as certificates has grown to the point where the global value of certificates under management is comparable in size to the funds under management in the hedge fund industry (Lord, 2011). This growth has attracted the attention of the academic literature and a number of interesting stylized characteristics of prices in this market have emerged. For example, Wilkens et al. (2003) examined the "fairness" of certificate prices traded on a German investor exchange and found widespread evidence of overpricing. This result has since been confirmed for a number of other European markets (see Hernández et al., 2013) and for the US (see Henderson and Pearson, 2011).[4] Subsequent research has examined this overpricing more closely and found evidence in support of a "life cycle hypothesis"[5] (issuers decrease overpricing over the certificate's lifetime, see Stoimenov and Wilkens, 2005; Baule et al., 2008;

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[4] Overpricing has also been reported in the US by Chen and Kensinger (1990), Chen and Sears (1990), Baubonis et al. (1993) and Benet et al. (2006), in Germany by Stoimenov and Wilkens (2005), Muck (2006), Wilkens and Stoimenov (2007), Baule et al. (2008), Baule (2011) and Baule and Tallau (2011), in Switzerland by Wasserfallen and Schenk (1996), Burth et al. (2001), Grünbichler and Wohlwend (2005), Wallmeier and Diethelm (2009), and in the Netherlands by Szymanowska et al. (2009).

[5] It should be noted that the term "life cycle" refers in this context to the lifetime of a specific certificate, i.e. from its issuance until its maturity, rather than the time period a certificate type exists from its invention until it disappears from the market or becomes less relevant. A comparison of the overpricing reported by studies at different points in time, such as those by Stoimenov and Wilkens (2005) and Baule (2011) implies that overpricing decreases the longer a certificate type exists. This is likely to be caused by higher economies of scale for the issuers and increasing competition over time. Whether a first mover advantage exists in the certificates market as, for example, analyzed by Schroth (2006) and Herrera and Schroth (2011) for the market for innovative corporate securities, has not been addressed yet.

Baule, 2011) and an "order flow hypothesis" (issuers anticipate investors' systematic trading patterns and adjust markups accordingly, see Wilkens et al., 2003; Baule, 2011). Other features of certificate pricing have also been documented including higher markups in more complex products (e.g., Stoimenov and Wilkens, 2005; Wilkens and Stoimenov, 2007), increased markups at the end of the day (Entrop et al., 2013) and decreased markups when competition is higher (Baule, 2011).

A related literature has considered the performance of individual investors in retail certificate markets. The general conclusion is that investors are uninformed (Schroff et al., 2013; Meyer et al., 2014), typically earn negative returns in short-term certificates (Entrop et al., 2012; Meyer et al., 2014) and show a poor risk-adjusted performance in long-term certificates (Entrop et al., 2016b). Given this poor performance, it is hardly surprising that investors' demand for certificates cannot be explained by standard preference functions (see Breuer and Perst, 2007; Branger and Breuer, 2008; Bernard et al., 2009; Hens and Rieger, 2014).

The purpose of this paper is to further our understanding of the retail market for structured financial products. Unlike the previous empirical literature, we are — to the best of our knowledge — the first to derive a theoretical model of the optimal pricing policy of certificate issuers. It is general enough to be applicable to all kinds of certificates. This model pays special attention to the market environment of exchanged-traded retail products, which is unique in that inventory costs and the presence of informed traders are less important compared to other previously considered markets. Further, a product can only be traded with its issuer and short-selling by investors is not possible (or explicitly forbidden).[6] We basically aim at two targets with the model: first, we provide theoretical foundations for empirically based, stylized facts in the form of the life cycle and order flow hypothesis; second, we reveal new insights on the time structure of optimal markups depending on extraordinary demand shifts, unhedgeable risk, investors' markup and spread sensitivity, investors' average holding period and the optimal spread as well as its determinants and its partly complex interrelations.

More specifically, we set up a multi-period monopoly pricing model where issuers are obliged to serve as market makers, i.e. to quote binding bid and ask prices for their certificates. Issuers are assumed to immediately hedge their market exposure when they sell a product, except for any unhedgeable risk where it exists. Investors' certificate demand depends negatively on both the markup above the "fair" value and the spread, and can exhibit extraordinary changes. Optimizing the resulting intertemporal profit function of the issuer with respect to the markups and the spread, leads to the optimal price-setting policy.

The model presented in this paper provides a number of key results and suggests testable hypotheses about certificate prices: (i) The "life cycle hypothesis" is theoretically justified in that it is optimal for the issuers to decrease the markups over the certificate's lifetime; (ii) the "order flow hypothesis" is theoretically justified in that issuers deviate from (i) when they anticipate extraordinary demand at a certain point in time. This impact is not necessarily contemporaneous however, as anticipated shifts in demand may also affect markups before and after this event; (iii) issuers demand compensation for unhedgeable risk in the form of higher markups. Interestingly, it is optimal for issuers to increase all markups, even where certificates are only exposed to unhedgeable risk, if they are held over a specific time horizon (such as overnight); and (iv) there is a negative relation between markups and the spread. The relative importance of these four effects depends on, amongst other things, the average holding period of certificates and investors' sensitivity to the markups and the

spread. While (i) — as already stated — is a well established effect in the literature, the remaining results, including the special structure of the order flow effect, are new.

We empirically test these hypotheses using a dataset that consists of more than 4.7 million quotes and 0.56 million trades in nearly 15,000 leverage certificates on the DAX over the time period Q2/2009 to Q3/2011. Leverage certificates are essentially one-sided barrier options and are ideally suited to the task at hand for two main reasons: first, unlike many other classes of certificates, they are frequently traded; second, they expose the issuers to unhedgeable risk in form of jump risk, which can occur randomly at any point in time but also deterministically as the difference between the closing and opening prices of the underlying on consecutive days (we refer to this as overnight gap risk). In our empirical analysis, we estimate markups via standard valuation procedures and then attempt to identify their possible determinants using a two-stage least squares (2SLS) regression procedure, which is designed to avoid endogeneity problems.

To summarize our findings: (i) the life cycle hypothesis holds and is more pronounced for leverage certificates the further away from knock-out they are; (ii) issuers adjust their pricing behavior with respect to extraordinary demand; (iii) general jump risk is priced, as is overnight gap risk and this latter effect is more pronounced for certificates that are close to knock-out and increases during the course of the day; (iv) in contrast to the predictions of the model, there is a positive relationship between markups and spread. However, as we find only little variation in the spread, this suggests that markup and spread are not substitute profit sources for the issuers. Rather, it is more likely that investors see the spread as a strong price quality signal. This would imply that investors are likely to have a much higher sensitivity to the spread, which can be observed, compared to the markup, the size of which is hard for individual investors to judge.

While the life cycle hypothesis is empirically well proven for various certificate classes, the order flow hypothesis has — to the best of our knowledge — only been shown empirically by Baule (2011) for discount certificates in a time period before 2009, when gains from financial assets held longer than one year used to be tax-free in Germany. This tax rule induced investors to buy certificates with a remaining time to maturity slightly longer than one year. This was anticipated by the issuers and therefore they increased the respective markups. We in turn analyze the effect of both extraordinarily high buy and sell volumes on an intraday basis and, thus, provide additional support for the order flow hypothesis in a different design. A detailed empirical analysis of the effect of unhedgeable risk is — again to the best of our knowledge — new to the literature on certificates. The same holds for an analysis of the relation between markup and spread.

The rest of this paper proceeds as follows. In Section 2, we present our model and derive the implied hypotheses for certificate prices. Section 3 contains the results of our empirical analysis, where Section 3.1 gives an overview of the market for leverage certificates and Section 3.2 details our dataset and the valuation procedure. In Sections 3.3 and 3.4 we present the empirical results and test the hypotheses of the model. Finally, Section 4 presents some concluding comments.

2. Market design and model

2.1. Market design

Structured retail products can either be traded on exchanges or directly via the issuers' own trading platforms. In this paper, we focus on the German market, which is one of the worlds largest, where the two main exchanges are the Stuttgart EUWAX

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[6] A detailed description of the market is provided in Section 2.1.

(European Warrant Exchange) and the Frankfurt Certificate Stock Exchange (formerly Scoach).[7]

German exchange-traded retail certificates are traded via a continuous auction, where orders are booked and executed when they arrive to the market. Issuers are obliged to serve as market makers and quote binding bid and ask prices for their certificates. As such, the market is quote-driven and the market maker takes the opposite side of every transaction.[8] This market design ensures a high level of product liquidity.

In this market, certificate issuers may be able to extract economic rents as a lack of transparency combined with investors' limited financial literacy means that it is difficult to assess the "fairness" of quoted prices. Further, investors cannot arbitrage pricing discrepancies due to explicit exchange rules (Stuttgart Stock Exchange, 2014; Frankfurter Wertpapierbörse, 2013), or physical limitations on the proprietary trading platforms that prevent short-selling.[9] The price-setting power of market makers is not without limits as investors do exhibit some degree of sensitivity to certificate prices (Baule, 2011; Baule and Blonski, 2015).[10] Further, although substitute products are available, identifying them is challenging for retail investors due to a large variety of product names and product features (see Entrop et al., 2016b, for recent empirical evidence).[11]

The unique features of the market for retail certificates mean that market frictions such as inventory costs (e.g., Garman, 1976; Stoll, 1978; Ho and Stoll, 1981, 1983; Hasbrouck and Sofianos, 1993) or the presence of informed traders (e.g., Glosten and Milgrom, 1985; Kyle, 1985) are unlikely to explain prices in the same way as they do for other more traditional markets. For example, inventory costs are unlikely to be important as market makers do not have to balance demand and supply. Rather, market makers can satisfy any demanded quantity as they simply structure the product when an order arrives and "close" the certificate when it is sold back. Informed traders are also unlikely to be important for pricing as the evidence suggests that most investors in this market segment are uninformed (Meyer et al., 2014; Schroff et al., 2013). Even if an investor was informed, the resulting risk for the market makers/issuers is negligible as they hedge each certificate when an order arrives. As such, an informed investor's profits do not impose losses on the market makers. Further, spreads in this setting can no longer be interpreted as a measure of the level of protection against informed traders as they are in a more common market setting.

2.2. General model setup

The discussion of the previous section highlighted how standard market microstructure models are not particularly relevant when explaining certificate prices. Rather, a new model is required that takes into account the specific characteristics of the certificate market. In this section of the paper, we provide such a model in which we analyze the behavior of a single issuer (i.e. market maker) for a specific certificate. The market is modelled as a discretized, inter-temporally structured continuous auction, i.e. orders are booked and executed at the quoted prices set by the issuer immediately upon arrival.[12] The issuer is the only possible trading counterpart for an investor in a given certificate. It should be noted that the model is set up generally enough to be applicable to all kind of certificates.

We focus on a finite time period, which consists of 4 discrete points in time $t_i = i$, $i = 0, 1, 2, 3$. The product is issued in t_0 and becomes due in t_3. At issuance, the issuer sets an ask price p_0^A that equals the fair value p_0 plus a markup on the ask, α_0.[13] At maturity, the issuer sets a bid price equal to the fair value, p_3, i.e. the payoff of the certificate. During the lifetime of the certificate the issuer is willing to sell and rebuy certificate units at the ask, p_i^A, and bid, p_i^B, prices which are set equal to the fair value p_i plus an ask and bid markup α_i and $\alpha_i - v$, respectively, where v denotes the bid-ask spread. Thus, the inter-temporal price structure is given by:

$$p_i^A = p_i + \alpha_i, \quad p_i^B = p_i + \alpha_i - v \quad \text{for } i = 0, 1, 2, \tag{1}$$

$$p_3^B = p_3. \tag{2}$$

It should be noted that the fair price in our model does not have to be between the bid and ask quotes, but can be above or below either of them. However, we require the spread to be non-negative, i.e. $v \geqslant 0$.

Once the product is purchased by the investor, the issuer immediately hedges the outstanding position at the fair value p_i. If the product is sold back, the issuer unwinds the hedge position at that point in time at the respective fair value.[14] However, the issuer may be exposed to some unhedgeable risk. To isolate the effect of unhedgeable risk in the model, we assume that it only exists when the product is held by the investor between t_2 and t_3. This is included in the model via opportunity costs, g, which the issuers have to bear when they unwind the hedge position in t_3.

Following Garman (1976), investors' selling decisions are assumed to be independent and poisson distributed. Assuming independence means that the poisson parameter represents a fixed fraction of certificates that are sold back when a large number of investors is considered. To reduce the number of parameters in the model, we do not allow the certificates bought by the investors in t_0 to be sold in t_2. This implies that a fraction, γ_1, of those certificates bought in t_0 is sold in t_1 and the remaining fraction, $1 - \gamma_1$, is held until maturity. Analogously, fractions γ_2 and $1 - \gamma_2$ from those certificates bought in t_1 are sold in t_2 and t_3, respectively, while, of course, all certificates bought in t_2 are sold back at maturity in t_3. Fig. 1 illustrates the model structure and the resulting cash flows.

Given demand D_i in t_i, the corresponding profit function π_i of the market maker from certificates sold in t_i is equal to the sum of the cash flows from the selling and the rebuying of certificates (i.e. the certificates portfolio) over time minus the cash flows from the related hedge positions (i.e. the hedge portfolio):

$$\pi_i = \underbrace{[p_i^A - \gamma_{i+1}p_{i+1}^B - (1 - \gamma_{i+1})p_3]D_i}_{\text{certificates portfolio}} - \underbrace{[p_i - \gamma_{i+1}p_{i+1} - (1 - \gamma_{i+1})(p_3 - g)]D_i}_{\text{hedge portfolio}}$$

for $i = 0, 1, 2,$

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[7] The descriptions that follow are also applicable to other European certificate exchanges such as Swiss SIX Structured Products Exchange, Italian Equity Derivatives Market of Borsa Italiana, London Stock Exchange Securitised Derivatives and Nordic Derivatives Exchange. All of these are based on a similar market maker system, which guarantees liquidity.

[8] In reality orders can be executed within the bid-ask spread when the market maker can match buy and sell orders of investors. However, this does not happen often due to the limited number of trades in any single product. As such, we do not consider this option in our model.

[9] Even if explicit short-selling restrictions did not exist, as it is the case for the non-German exchanges, it is still virtually impossible to arbitrage mispriced certificates (e.g., Szymanowska et al., 2009) due to a lack of short-selling opportunities.

[10] Considering warrants (Dorn, 2012) in contrast finds that investors do not compare prices but rely on suboptimal choice heuristics even if the environment is transparent.

[11] For example, at the end of November 2013 there were 1,127,838 certificates listed and 188,755 newly issued on the EUWAX.

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[12] The base structure of our model is similar to inter-temporal monopoly models and models from the field of durable goods such as Coase (1972), Stokey (1981), Bulow (1982) and Desai and Purohit (1998).

[13] For reasons of consistency, we also assume that the issuer sets a bid price like in the subsequent periods.

[14] To limit the complexity of the model we neglect transaction costs for establishing, rebalancing if necessary and closing the fair value hedge.
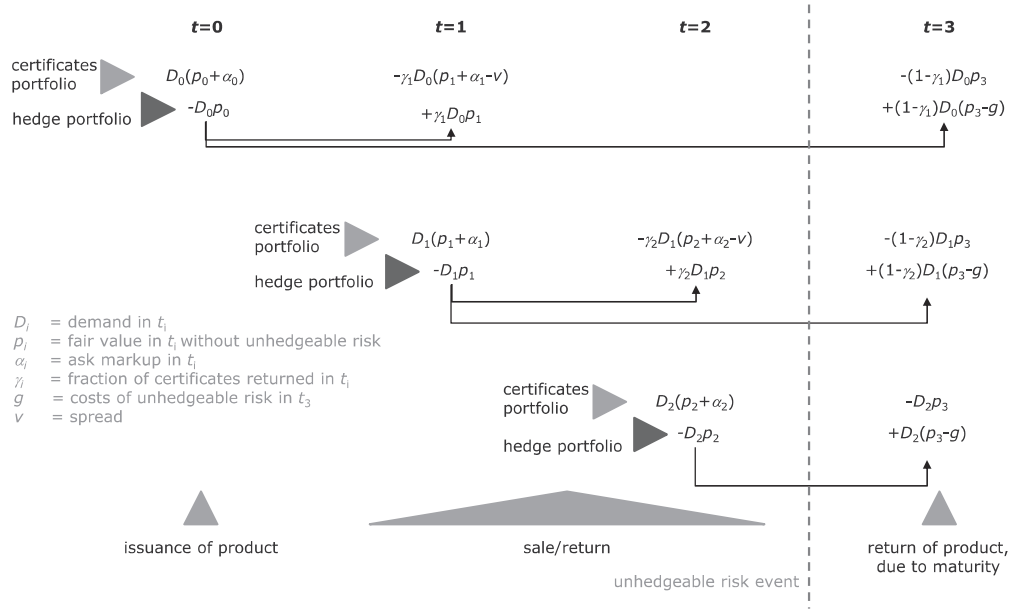
Fig. 1. General model structure and resulting cash flows. The model consists of 4 discrete points in time $t_i = i, i = 0, 1, 2, 3$. The product is issued in t_0 and becomes due in t_3. At issuance the market maker sets the fair price p_0 plus an ask markup α_0. At maturity he sets a bid price that equals the fair value p_3, i.e. the payoff of the certificate. During the lifetime of the certificate the issuer is willing to sell and rebuy certificates at ask and bid prices equal to the fair value p_i in t_i plus ask and bid markups α_i and $\alpha_i - \nu$, where ν denotes the bid-ask spread. The issuer immediately hedges the outstanding position at the fair value p_i. D_i denotes the market demand function and γ_i the immediate or accordingly $1 - \gamma_i$ the fraction of certificates returned in t_3.

where we set $\gamma_3 = 0$ for consistency and time discount factors are neglected. The aggregate profit function of the market maker over the product's lifetime, i.e. $\pi_{agg} = \pi_1 + \pi_2 + \pi_3$, may be derived by substituting (1) and (2) into (3), collecting terms and summing up, i.e.:

$$\pi_{agg} = (\alpha_0 - \gamma_1(\alpha_1 - \nu) - (1 - \gamma_1)g)D_0 + (\alpha_1 - \gamma_2(\alpha_2 - \nu)$$
$$- (1 - \gamma_2)g)D_1 + (\alpha_2 - g)D_2. \tag{4}$$

The next step is to specify the aggregated market demand functions, D_i. We assume that there exists a base demand, x, that is independent of time with $D_i'(x) > 0$. Following the empirical evidence that links demand to the time to maturity of a certificate (Baule, 2011) or the time of day (Entrop et al., 2013), we allow for demand shifts w_i in t_1 and t_2 with $D_i'(w_i) > 0$. The empirical evidence also documents investors' sensitivity towards certificate overpricing (Baule, 2011; Baule and Blonski, 2015) and we account for this in our model by including a term that accounts for the "unfairness" of the ask quotes represented by the ask markups, i.e. $D_i'(\alpha_i) < 0$. Finally, demand also depends negatively on the spread, ν, i.e. $D_i'(\nu) < 0$. In setting prices, the issuer faces a trade-off as the higher the markup and/or the spread, the higher is the expected profit, but the smaller will be demand. Further, as investors are able to observe the spread but not the markup, we expect a greater sensitivity of demand to the spread relative to the ask markup.

Taking into account each of these elements, we specify the demand functions as:

$$D_i = x + w_i - y\alpha_i - z\nu^2, \quad \text{for } i = 0, 1, 2, \tag{5}$$

where y and z represent the demand sensitivities towards markup and the spread, $x, y, z \geqslant 0$ and w_i are constants with $w_0 = 0$. We consider the squared spread, ν^2, as using the simple spread, ν, does not necessarily lead to an inner solution in the optimization problem.

We assume that the market maker knows the aggregated demand function and acts as a profit maximizer when setting the ask markups and the spread. Thus, the market maker's optimization problem is:

$$\max_{\alpha_0, \alpha_1, \alpha_2, \nu} \pi_{agg} \quad \text{s.t.} \quad D_i \geqslant 0, \nu \geqslant 0. \tag{6}$$

One might be concerned that providing the issuer with monopoly price-setting power in our model is a too strong assumption. However, as discussed in Section 2.1, market complexity, an inability to short-sell, limited investor financial literacy and the issuer acting as the sole counterparty, clearly suggest a significant degree of price-setting power. This power is limited by the price and spread sensitivities of investors, which is captured in the model by the term representing the sensitivity to the unfairness of the price-setting, y, and the spread, z. y as well as y and z together can be expected to be higher when transparency on markups and competition, respectively, is higher.

2.3. Model solution

Optimizing profit function (6) gives optimal ask markups and spread. In some special cases this can be done analytically, otherwise numerical solutions are readily obtainable. We first analyze the optimization problem when all certificates are held until maturity (Section 2.3.1) and then consider the scenario when all certificates are sold back in the period after which they are bought (Section 2.3.2). The results of the general case are then derived (Section 2.3.3), which are basically a mixture of these two special cases. Section 2.3.4 presents a number of model-derived hypotheses, which form the basis of our empirical tests.

2.3.1. Special case 1: holding until maturity

In this first special case, all investors are assumed to hold the product until maturity. This means $\gamma_1, \gamma_2 = 0$ and the aggregated profit function (4) simplifies to:

$$\pi_{agg} = (\alpha_0 - g)D_0 + (\alpha_1 - g)D_1 + (\alpha_2 - g)D_2. \tag{7}$$

We optimize this profit function with respect to the ask markups and the spread.[15] The optimal spread in this case becomes zero, because the product is never given back at the bid price before

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[15] The necessary and sufficient conditions are shown in Appendix B.

maturity and setting a positive spread would decrease the demand. The optimal ask markups are given by:

$$\alpha_0^* = \frac{x}{2y} \qquad\qquad + \frac{g}{2},$$
$$\alpha_1^* = \frac{x}{2y} + \frac{w_1}{2y} \qquad + \frac{g}{2},$$
$$\alpha_2^* = \underbrace{\frac{x}{2y}}_{1)} + \underbrace{\frac{w_2}{2y}}_{2)} + \underbrace{\frac{g}{2}}_{3)}. \tag{8}$$

Thus, the optimal markups at each point in time consist of up to three components:

(1) A higher level of base demand, x, increases the ask markups. Further, the sensitivity of demand to the markup level, y, decreases the markups. The intuitive explanation for this latter effect is obvious: demand decreases if investors are relatively more sensitive to the markup level as a higher sensitivity means a smaller markup to achieve greater product demand.

(2) The ask markups differ with respect to the demand shifting parameters, w_i, such that any extraordinary demand in t_1 or t_2, contemporaneously affects the markup. For a positive w_i, issuers exploit the extra demand by setting a higher markup, while the opposite holds for negative demand shifts.

(3) Unhedgeable risk in form of the opportunity costs, g, increases the markups. As all certificates are held until maturity, the issuer is exposed to unhedgeable risk, independent of the point in time when the certificate was bought. Thus, the issuers include their opportunity costs in all markups equally and pass them on to the investors.

2.3.2. Special case 2: selling back at the next point in time

If the fractions of certificates sold γ_1, γ_2 are equal to unity, then the product is sold back immediately in the period following its purchase. In this case, profit function (4) becomes:

$$\pi_{agg} = \alpha_0 D_0 - (\alpha_1 - v)D_0 + \alpha_1 D_1 - (\alpha_2 - v)D_1 + \alpha_2 D_2 - gD_2, \tag{9}$$

and the optimal markups, α_i^*, depend on the optimal spread v^*.[16] To explain how, we will initially ignore the indirect effects of the exogenous parameters on the markups via the spread.[17] This provides a result that is easier to understand and we return to consider these indirect effects later in this section of the paper. As such, the optimal markups are:

$$\alpha_0^* = \frac{3x}{4y} \qquad + \frac{w_1 + w_2}{4y} \qquad + \frac{g}{4} \qquad - \frac{5v^*y + 3v^{*2}z}{4y},$$
$$\alpha_1^* = \frac{2x}{4y} \qquad + \frac{2w_1 + 2w_2}{4y} \qquad + \frac{2g}{4} \qquad - \frac{6v^*y + 2v^{*2}z}{4y},$$
$$\alpha_2^* = \underbrace{\frac{x}{4y}}_{1)} + \underbrace{\frac{-w_1 + 3w_2}{4y}}_{2)} + \underbrace{\frac{3g}{4}}_{3)} - \underbrace{\frac{3v^*y + v^{*2}z}{4y}}_{4)}. \tag{10}$$

In contrast to (8) from Section 2.3.1, the optimal markups in (10) contain a fourth component that is dependent on the spread. Further, each component has a specific inter-temporal structure, i.e. it varies depending on the point in time at which it is considered. Let us consider each of these terms in order:

(1) As per the previous special case, the ask markups increase with the base demand, x, and decrease with the markup demand sensitivity, y. Over time, however, the influence of x decreases, leading to decreasing markups, ceteris paribus. This

is consistent with the "life cycle hypothesis", whereby markups are empirically observed to decrease over time (e.g., Stoimenov and Wilkens, 2005). Technically, the markups have to decrease because issuers would only earn the spread if the markups were constant. However, if the markups were reduced to zero in t_1 and t_2, this would result in a high profit from those certificates bought in t_0, but issuers would only earn the spread from those certificates bought in t_1 and t_2.[18] Hence, our model implies that it is optimal for the issuer to reduce the markups over the lifetime of the product to allow him to earn rents over that whole period.[19] Thus, our model provides a theoretical justification of the life cycle hypothesis.

(2) Again following the previous special case, positive (negative) extraordinary demand movements, w_i, have a positive (negative) influence on the ask markups at the point in time when the shift occurs. However, demand shifts also affect the markups at other points in time. For example, if $w_1 > 0$ and $w_2 = 0$, then issuers would significantly increase the ask markup in t_1 and lower the ask markup in t_2. This allows them to exploit the extraordinary demand in t_1 as the demanded products are given back in t_2 at the difference between the ask markup and the spread. Of course the lower markup in t_2 means a lower profit to the certificates bought in that period.[20] A second effect deserves attention in this context whereby the issuers increase the markup before the actual demand shift occurs, i.e. in t_0. At first glance, this may not appear to be optimal behavior for the issuers due to a resulting decrease in demand at this point in time. However, they accept this loss in demand because otherwise they would have incurred an even bigger loss due to the increased markup in t_1 at which the amount bought in t_0 is given back. Analogous considerations hold for w_2.

This discussion clearly highlights a link in our model between certificate pricing policy and anticipated demand, which is consistent with the "order flow hypothesis" (Wilkens et al., 2003; Baule, 2011). Thus, our model provides a theoretical justification for this hypothesis and highlights the various elements that come together to make up this extraordinary demand effect, i.e. the issuer increases (decreases) the markup at and before the event of the anticipated positive (negative) extraordinary demand shift and decreases (increases) it afterwards. The model also suggests that the further away we are from the demand shift event, the less the markup is influenced by this shift.

(3) The third effect also follows on from the previous special case, in that the issuer passes on the opportunity costs, g, of the unhedgeable risk to all investors through the markups. It is worth noting that the opportunity costs also have an influence on the markups in t_0 and t_1, even though the product is given back before the unhedgeable risk becomes important to the issuer. Hence, investors who bought the product in t_0 or t_1 have to pay for the unhedgeable risk even if they do not expose the issuer to that risk. Thus, our model suggests that it is optimal for the issuer to spread the opportunity costs

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[16] The necessary and sufficient conditions are shown in Appendix C.

[17] If the spread was really exogenous and not to be optimized, the optimal markups would be identical.

[18] In reality, reputation concerns might be another reason why this behavior would not be optimal for issuers. Too large and too fast markup adjustments and, thus, price changes, could prevent investors from buying certificates again, resulting in significant opportunity costs for the issuers.

[19] The effect of the life cycle hypothesis would be even more pronounced if transaction costs for establishing, rebalancing if necessary and closing the fair value hedge — that occur over the time an investor holds the certificate — were also taken into account. In this case, markups would additionally be reduced due to the amortization of these costs over time.

[20] Unlike in the previous example, the issuer here faces a significant trade-off because he can also increase the spread. However, this would be suboptimal in our setting as an increased spread decreases the demand at any point in time.

across all investors. The alternative, i.e. increasing the ask markup only in t_2, is suboptimal in our setting as such a strategy would significantly increase the bid price in t_2, which would decrease the profit from the certificates bought in t_1. The opportunity costs are not charged equally to all investors though. Rather, the charge increases the closer is the point in time when the certificate is bought to the unhedgeable risk event.

(4) The fourth term in (10) captures the influence of the spread on the optimal markups. To understand why a negative relationship exists, we divide the spread effect into two subeffects. First, the spread directly influences the price-setting structure of the issuer (first part containing v^*y). Recall that a higher spread means a higher profit to the issuer, ceteris paribus. Further recall that the issuer can earn a given profit by increasing either the ask markup or the spread. Therefore the spread is a substitute for the markup regarding the profit, which results in a negative relationship between those two (we refer to this as the "pure spread effect").

On the other hand, the spread has a negative influence on demand as a larger observed spread will lead to investors buying relatively fewer certificates. This negative relation between spread and demand has also an effect on the ask markup (second part containing $v^{*2}z$): If the spread is widened, the issuer will reduce the ask markup to counterbalance or rather mitigate the spread's negative impact on demand (we refer to this as the "spread signal effect").

Those direct (pure spread effect) and through demand indirect (spread signal effect) effects are the reason why the issuers do not set the spread as wide as possible.

In contrast to special case 1, the optimal spread in special case 2, v^*, is not zero but depends on g, x (and w_i) and the sensitivities y and z (see Eq. (A.1) in Appendix A). It is straightforward to show that the derivatives of v^* with respect to the parameters y, g, etc. become arbitrarily close to zero for sufficiently large z. For that reason, the direct effects of these parameters on the optimal markups via the components 1) to 3) in Eq. (10) dominate the indirect effects via the spread for large z. Recall from the beginning of this section that we chose to ignore the indirect effects of the exogenous parameters in discussing the optimal spreads for this special case. In effect, we were assuming a large z and not only is this assumption plausible (see Section 2.2), we find evidence of investors having a high sensitivity to spreads in the empirical analysis that follows. Due to its complex structure, the sensitivity of the optimal spread to its determinants can only be analyzed numerically and details are provided in Appendix A. In our empirical analysis, we find only small spreads with little variation and, therefore, refrain from empirically analyzing the determinants of the spread. Small variation in the spread is consistent with a large sensitivity of the demand function to the spread, i.e. a large z. However, for other certificate classes with larger spreads, such as discount certificates on exotic underlyings, a deeper analysis of the spread might be required.

2.3.3. General case

In reality, investors are unlikely to all hold certificates to maturity or sell all certificates at the next point in time. Rather, investors will pursue a variety of strategies and in our model this means the fraction of certificates returned will be between zero and one, i.e. $0 < \gamma_1, \gamma_2 < 1$. As this general case cannot be solved analytically, we solve the Eq. (6) numerically for various different parameter combinations. We find that the solution to this general case is essentially a mixture of the results for the

previous two special cases, where the results for special case 2 hold but are the less pronounced the smaller is γ_i. To aid the reader in understanding this point, we present Fig. 2, where the three panels show the sensitivities of the bid (dashed lines) and ask (continuous lines) markups in relation to the fraction of certificates returned (x-axis) where we set $\gamma := \gamma_1 = \gamma_2$ for ease of illustration.[21]

Panel A of Fig. 2 shows the markups when no extraordinary demand is anticipated (i.e. $w_i = 0$). For a fraction of certificates returned equal to zero, i.e. $\gamma = 0$, all markups are equal (special case 1). As γ increases, the markups diverge, meaning that the markup in t_0 is larger than in t_1, which again exceeds the markup in t_2. The differences between the markups are highest for $\gamma = 1$, i.e. special case 2. This implies that the findings on the general time structure of markups from special case 2 hold, but are less pronounced for longer average holding periods, i.e. smaller γ. Also, spreads, defined as the difference between the respective ask and bid markups, widen with increasing γ.

Panel B considers the impact of a positive demand shift in t_1, assuming $w_1 = 0.2$. Comparing the markups to those in Panel A, we find that for a given $0 < \gamma \le 1$, the positive shift leads to higher markups in t_1, and to a lesser extent also in t_0, while markups in t_2 are smaller. The differences between markups increase with increasing γ and are highest in special case 2, i.e. $\gamma = 1$.

Finally, Panel C shows the markups for different levels of opportunity costs for unhedgeable risk, $g = 0.01$ (light) and $g = 0.5$ (dark).[22] All markups are shifted up for higher levels of unhedgeable risk. For a given $\gamma > 0$, the shift is larger for the markup in t_2 than the one in t_1, which is again larger than the shift in t_0. This implies that unhedgeable risk is priced and the closer the purchase is to the unhedgeable risk event, the greater is the price effect (which is the same relation as found in special case 2).

2.3.4. Summary and hypotheses

The general case of our model produces a mixture of the results of the special cases, where the results for special case 2 hold, but are less pronounced for longer holding periods. Based on this analysis of the model, we specify the following key model-derived hypotheses on the price-setting behavior of the issuer in the market for retail exchange-traded certificates:

Hypothesis 1 (*Life cycle hypothesis*). Certificate markups decrease over the product's lifetime.

Hypothesis 2 (*Order flow hypothesis*). Product demand influences the markups set by the market maker, where a positive (negative) demand shift results in an increase (decrease) of the ask markups in the same period and, to a lesser extent, also the periods before. The effect on the subsequent period markups, however, is negative (positive).

Hypothesis 3 (*Unhedgeable risk hypothesis*). Unhedgeable risk, g, increases product markups and this effect is more pronounced the closer the buying time is to the unhedgeable risk event.

Hypothesis 4 (*Spread hypothesis*). Certificate spreads and markups are negatively related.

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[21] The necessary and sufficient conditions for a maximum of (6) if $0 < \gamma_1 = \gamma_2 < 1$ are shown in Appendix D.

[22] While a level of $g = 0.5$ is extreme, we use it to provide a better graphical illustration.
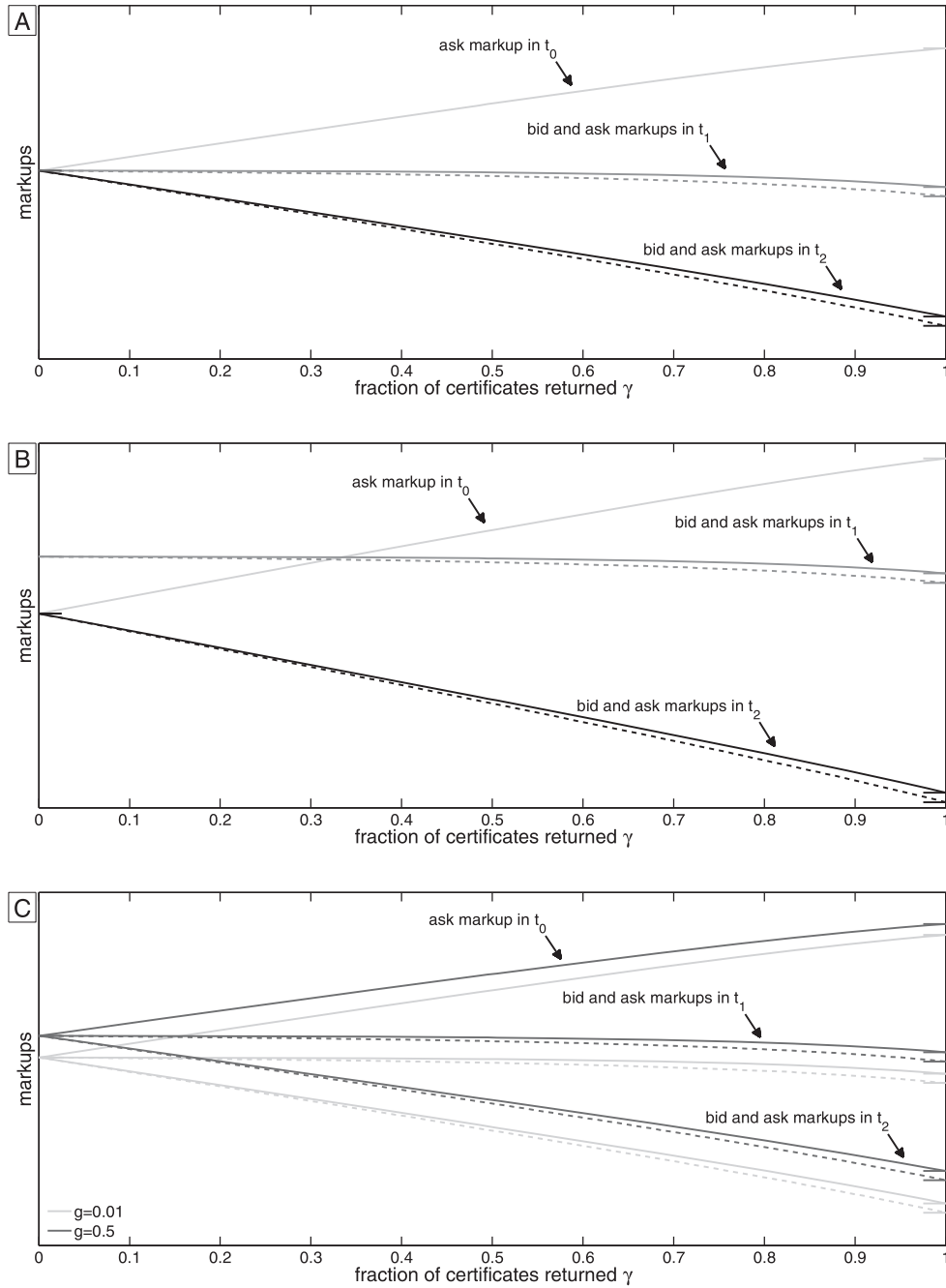
Fig. 2. Optimal markups for different fractions of certificates returned γ. For fractions equal to zero solutions are given by the special case in Section 2.3.1. For fractions equal to unity solutions are given by the special case in Section 2.3.2. As fixed values for Panel A are used $x = 1$, $w_i = 0$, $z = 0.8$, $y = z/5$ and $g = 0.01$. For Panel B we assume a positive demand shift in t_1 and additionally set $w_1 = 0.2$. For Panel C we set $w_1 = 0$ again, but assume two different levels of opportunity costs for unhedgeable risk, $g = 0.01$ or $g = 0.5$.

3. Empirical analysis

3.1. Leverage certificates

The empirical analysis in this paper focuses on long and short leverage certificates with finite maturity.[23] Long leverage certificates are equivalent to down-and-out calls, where the investor profits from increasing values of the underlying. Short leverage certificates are equivalent to up-and-out puts, where the investor profits from a decrease in the level of the underlying. The major difference to plain vanilla warrants is the knock-out feature — if the underlying crosses a predefined knock-out barrier, the product immediately expires worthless.[24] We consider leverage certificates where the barrier equals the strike as this is the most common specification traded in Germany. The certificate payoffs are:

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[23] For analyses of open-end leverage certificates see Entrop et al. (2009) and Rossetto and van Bommel (2009).

[24] Normally, there is a repayment of EUR 0.01, which is advantageous for the investors in the German tax system. We neglect this in the following.

long leverage certificate : $\quad LC_T^{long} \quad = c \max(S_T - X, 0) 1_{\{\tau^{long} > T\}}$ (11)

$$\text{with} \quad \tau^{long} \quad = \inf\{t > 0 : S_t \leqslant X\},$$

short leverage certificate : $\quad LC_T^{short} = c \max(X - S_T, 0) 1_{\{\tau^{short} > T\}}$ (12)

$$\text{with} \quad \tau^{short} = \inf\{t > 0 : X \leqslant S_t\},$$

where S denotes the value of the underlying, X the strike, T the maturity and $1_{\{\cdot\}}$ is an indicator function. τ is the time when the barrier is crossed by the underlying during the product's lifetime and c equals the conversion ratio.[25]

Leverage certificates are ideally suited to the testing of our hypotheses for a number of reasons. First, they are frequently traded and often sold prior to maturity. The same cannot be said for other products that have been the focus of this literature, such as discount certificates (Baule, 2011). This is obviously an important consideration when attempting to analyze demand effects. Second, the knock-out feature of leverage certificates naturally exposes the issuers to a de facto unhedgeable risk. The common hedging approach for issuers of these products is a static super-hedge[26] via a portfolio of European plain vanilla options, futures or forwards.[27] Normally the issuers close their position immediately if the knock-out barrier is touched. However, due to jumps in the underlying, the barrier may be overshot and the hedge may become negative. The issuers cannot pass this loss to the investor as the pay-off of leverage certificates is floored by zero. Consequently, the issuers have to bear this gap risk. Such jumps are originated by large shifts in the underlying and can randomly occur at any point in time when the underlying market is open. Most interestingly for our analysis, they also occur deterministically as the difference between the closing price of the underlying and the opening price the next day which exposes the issuer to the overnight gap risk. Clearly, this exposure is only found in those certificates that are held overnight.

3.2. Dataset and valuation

3.2.1. Dataset

The dataset considered in this paper consists of base information for all leverage certificates written against the German DAX blue chip index[28] at the time of their issue as well as quote and transaction data over their lifetime.[29] These certificates are traded on the EUWAX, which is open for trading from 9:00 a.m. to 8:00 p.m. during our observation period of Q2/2009 to Q3/2011.

The first quote is sampled at 9:30 a.m., which allows sufficient time after the open for the market to fully commence trading. Quote data is then regularly sampled on an hourly basis from 10:00 a.m. onwards. The last quotes of the day are sampled at 7:30 p.m. and again at 7:50 p.m., which is just before the market closes. We also sample quotes at 5:30 p.m, when the underlying market closes.

The time stamped transaction data provide information on the price and volume of each trade. It also includes a buy/sell-flag, which enables us to identify the direction of each trade from the investor's perspective. Finally, we know whether the executed order is a limit, market or 'other' order type[30].

On the EUWAX, a large number of DAX leverage certificates with a variety of maturity and strikes, are offered by several issuing banks. In our original dataset there are 71,338 products, although the majority (nearly 78%) are not traded during their lifetime. We exclude these products from the analysis, which leaves 15,764 traded certificates. For the sample of quote data for these certificates, we exclude stale and irregular quotes as well as quotes that would lead to problems with the estimation of markups.[31] The resulting final dataset consists of 14,847 leverage certificates and 4,703,503 quotes.

Table 1 gives an overview of our final dataset, where Panel A summarizes the base information for certificates at the time of their issue in terms of the initial time to maturity in calendar days, $T_{Initial}$, and the moneyness at issuance, MaI, divided into long and short leverage certificates at the product level. Moneyness is defined as $DAX/Strike$ for long, and $Strike/DAX$ for short leverage certificates. Summary statistics for the quote data are provided in Panel B and report the mid quote, the remaining time to maturity in calendar days, the moneyness at quote, MaQ, and the absolute bid-ask spread, i.e. the ask minus the bid quote in EUR.

The percentage of long leverage certificates in the final base dataset is about 57%. On average, the time to maturity at issue is 72 days for long and 105 days for short certificates. The median is lower, 50% have an initial time to maturity of 54 days or less for long and 84 days or less for short certificates, which suggests the distribution is right skewed. The mean (median) moneyness at issuance for long and short leverage certificates is about 1.05 (1.03), which implies that a change in the DAX of 5% (3%) would result in a knock-out. The small moneyness at issuance of the leverage certificates traded reflects the high leverage preferences

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[25] c is usually 0.01 and scales the value of the certificate to a consumer-friendly level.

[26] A self- or over-financing portfolio strategy, which duplicates or dominates the value of the certificate. Static — sometimes also referred to as semi-static — means that a portfolio rebalancing is only necessary in the event of a knock-out.

[27] Issuers regularly prefer this hedging approach — even under the Black/Scholes-assumptions — to a Delta-hedge since the Gamma of barrier options can become extremely high when the underlying trades close to the barrier, which makes dynamic rebalancing of the hedge position difficult and costly (e.g., Carr et al., 1998). A broad strand of literature analyses static hedging or superhedging strategies built by a portfolio of liquid plain vanilla calls and puts (see, e.g., Carr and Nadtochiy, 2011, for a recent literature overview). However, allowing for jumps and stochastic volatility in the underlying makes the market incomplete and the hedges inherently imperfect (e.g., Nalholm and Poulsen, 2006b). Perfect hedging or superhedging strategies usually require strong assumptions on the underlying price process or incorporate an infinite number of options with different strikes (a strike spread portfolio) and/or different maturities (a calendar spread portfolio) leaving the issuer with unhedged risk when only a limited number of options is used. For example, Carr and Chou (2002) show how to perfectly hedge barrier options with a static portfolio of European plain vanilla options under the Black/Scholes-assumptions not incorporating jump risk. Under more general assumptions — but still requiring continuous paths of the underlying — Carr et al. (1998) derive tight upper and lower bounds built by only two plain vanilla options, which introduces simple superhedging strategies, but these are vulnerable to jump risk. Mahayni and Suchanecki (2006) and Wilkens and Stoimenov (2007) provide similar results and partly use forwards as hedge instruments. Andersen et al. (2002) on the other hand derive a perfect hedging strategy when the underlying can jump and has a deterministic volatility, but this involves a portfolio of standard options with an infinite number of both different strikes and maturities. Nalholm and Poulsen (2006a,b) briefly describe the key ideas for creating static hedge portfolios with standard options and analyze the hedging error for different dynamics of the underlying.

[28] We consider certificates with the DAX rather than single stocks as their underlying for basically two reasons: first, DAX certificates are traded more frequently than certificates written against single stocks. Second, the volatilities used to value leverage certificates are derived from the EUREX, see Section 3.2.2, where options on single stocks are American-style while options on indices are European. Extracting volatilities from American options requires estimating dividends which would imply additional parameter risk.

[29] The base data on issued certificates were provided by the financial data provider Deriva GmbH Financial IT and Consulting and the transaction data by the EUWAX. The quote data were sourced from the SIRCA Thomson Reuters Tick History (TRTH) database.

[30] For example stop-loss, stop-buy, trailing-stop-loss or one-cancels-other orders. The dataset does not contain any further information concerning the characteristics of these orders.

[31] We eliminate quotes where the ask or bid quote has not been updated within the last 30 min and quotes showing a spread larger than 1 EUR. Certificates with a cover ratio different from 0.01 are excluded as are quotes at those times where the underlying level would have to be estimated via interpolation over a time interval larger than 15 s. Bid or ask quotes which are smaller than 45 cents and quotes for certificates with a remaining time to maturity of less than 10 days are also excluded from the dataset. Last, we exclude the 1% outlying observations with the highest and lowest calculated markups.

Table 1
Certificates base data and quote data.

Panel A: Base data					
Initial time to maturity $T_{initial}$					
	P25	Mean	Median	P75	N
LC^{long}	35	72	54	94	8519
LC^{short}	48	105	84	145	6328
Total	40	86	62	117	14,847
Moneyness at issuance MaI					
	P25	Mean	Median	P75	N
LC^{long}	1.0129	1.0503	1.0260	1.0637	8519
LC^{short}	1.0165	1.0542	1.0345	1.0741	6328
Total	1.0142	1.0520	1.0296	1.0689	14,847
Panel B: Quote data					
Mid quote					
	P25	Mean	Median	P75	N
LC^{long}	3.01	5.92	5.05	7.96	2,617,056
LC^{short}	2.40	4.83	4.08	6.40	2,086,447
Total	2.71	5.43	4.59	7.24	4,703,503
Remaining time to maturity					
	P25	Mean	Median	P75	N
LC^{long}	29	67	51	93	2,617,056
LC^{short}	40	97	78	132	2,086,447
Total	33	81	62	112	4,703,503
Moneyness at quote MaQ					
	P25	Mean	Median	P75	N
LC^{long}	1.0453	1.1002	1.0805	1.1338	2,617,056
LC^{short}	1.0360	1.0775	1.0638	1.1034	2,086,447
Total	1.0407	1.0901	1.0724	1.1194	4,703,503
Spread					
	P25	Mean	Median	P75	N
LC^{long}	0.01	0.0130	0.01	0.02	2,617,056
LC^{short}	0.01	0.0140	0.01	0.02	2,086,447
Total	0.01	0.0134	0.01	0.02	4,703,503

Composition of the certificates dataset separated for base and quote data. Results are reported separately for long leverage certificates, LC^{long}, and short leverage certificates, LC^{short}. For each variable are shown the number of products or quotes, N, Mean, Median and the 25% and 75% quantiles, P25 and P75. Panel A refers to the base data of the products: Time to maturity in calendar days, $T_{Initial}$, and moneyness at issuance, MaI ($DAX/Strike$ for long and $Strike/DAX$ for short leverage certificates). Panel B refers to the quote data: Mid quote values, remaining time to maturity in calendar days, moneyness at the time of the quote, MaQ, and the absolute bid-ask spread, i.e. the ask minus the bid quote in EUR.

and the speculative investment motivation of the investors. In fact, Entrop et al. (2013) show that the mean (median) holding period is only 1.08 (0.21) trading days for a transaction dataset from an online bank. For the quote dataset, the difference between the ask and bid equals 1 or 2 cents for the majority of quotes. Thus, spreads are small and variation is limited.[32]

The transaction dataset consists of 280,010 buy and 283,057 sell transactions.[33] We aggregate traded volumes (in EUR) up to the same frequency of the quote data described above for each order

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[32] For 4173, (28.11%) of all leverage certificates in our dataset, the spread is not constant but varies over time.
[33] The data shows a (small) imbalance between the number of buy and sell transactions, which is typical for datasets like these. For example, an investor can build his position with several buys but sell it with only one trade and vice versa. Additionally, a buy does not necessarily lead to a sell as it can expire worthless if the product is knocked-out. The investor also has two possibilities to trade products, i.e. via the exchanges or the trading platform of the issuer, and, thus, can use different channels for buys and sells.

Table 2
Certificates transaction data.

	Long certificates		Short certificates		Total	
	Mean	N	Mean	N	Mean	N
Limit orders	Buys					
Volume	3383.1	58,677	4298.6	73,286	3891.5	131,963
#Transactions	1.40	58,677	1.45	73,286	1.43	131,963
Price	1.63	58,677	1.60	73,286	1.61	131,963
	Sells					
Volume	3588.6	36,984	4478.6	43,721	4070.8	80,705
#Transactions	1.22	36,984	1.28	43,721	1.25	80,705
Price	2.02	36,984	1.86	43,721	1.94	80,705
Market orders	Buys					
Volume	4087.1	28,665	5130.8	36,350	4670.6	65,015
#Transactions	1.24	28,665	1.24	36,350	1.24	65,015
Price	2.49	28,665	2.26	36,350	2.36	65,015
	Sells					
Volume	4020.6	21,571	4837.1	25,728	4464.7	47,299
#Transactions	1.19	21,571	1.21	25,728	1.20	47,299
Price	2.73	21,571	2.45	25,728	2.58	47,299
Other orders	Buys					
Volume	2177.2	4036	2256.1	5146	2221.4	9,182
#Transactions	1.14	4036	1.24	5146	1.19	9,182
Price	1.56	4036	1.45	5146	1.50	9,182
	Sells					
Volume	3204.9	41,394	3931.1	46,582	3589.4	87,976
#Transactions	1.41	41,394	1.43	46,582	1.42	87,976
Price	1.47	41,394	1.34	46,582	1.40	87,976
Total	Buys					
Volume	3964.0	81,849	5057.8	101,456	4569.4	183,305
#Transactions	1.50	81,849	1.55	101,456	1.53	183,305
Price	2.34	81,849	2.25	101,456	2.29	183,305
	Sells					
Volume	4045.7	87,034	5132.8	98,070	4621.7	185,104
#Transactions	1.48	87,034	1.57	98,070	1.53	185,104
Price	2.49	87,034	2.36	98,070	2.42	185,104

Composition of the transaction data in the certificates dataset. The average volume in EUR, the number of transactions and the average traded price are separately reported for long and short leverage certificates, market, limit and other orders and buys and sells. Volume values in EUR and the number of transactions are aggregated over the time period before the quote. The traded price is calculated as the volume weighted averaged price for the time period before a specific quote. N denotes the number of observations, for which a respective transaction was recorded beforehand.

type and trade direction. For example, the aggregated sell volume for market orders at 4:00 p.m. is the sum of all market sell order volumes in the time period from 3:00 p.m. till 4:00 p.m. (excluding 4:00 p.m.) and the respective volume at 5:30 p.m. is the accumulated market sell order volume in the time period from 5:00 p.m. till 5:30 p.m.[34] This results in 183,305 (185,104) observations, for which at least one buy (sell) was recorded before the quote. This means that roughly 3.9% of the quotes in the dataset have a transaction in the period before the quote, including the open, the two closing and the 5:30 p.m. quote. These aggregated transaction data are summarized in Table 2, which reports the average volume and number of trades in each period where a trade occurred, distinguishing between long and short leverage certificates, different order types and buys and sells. Additionally, the table contains the average

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[34] The reader might be concerned that the different lengths of the time periods considered could affect results in our following empirical analysis when analyzing the order flow hypothesis. For example, if the total sell volume was equally distributed over a day, the volume in a one-hour period would be twice the volume in a 30-min period by definition. However, the later empirical results are robust, for example to scaling the volumes in short-term intervals such as 30 min or 20 min to an hour by multiplying the volumes by 2 or 3, respectively.

traded price, where the traded price equals the volume-weighted average traded prices for the time period before a specific quote.

Table 2 reveals that the products are bought at an average price of 2.29 and sold back at a price of 2.42. Further, there are more buys than sells for limit and market orders, respectively, while sells strongly dominate orders classified as other. As we do not have detailed information on the other order type, we concentrate on market and limit orders hereafter.[35] To analyze the distribution of respective buys and sells over the course of a day, we calculate the extraordinary buy-sell relation. As a starting point, we take the hourly volume V and calculate the hourly volume fraction VF of each product i per hour h and day d:[36]

$$VF_{i,d,h}^{ot,od} = \frac{V_{i,d,h}^{ot,od}}{\sum_{h'} V_{i,d,h'}^{ot,od}}. \tag{13}$$

This is done separately for each order direction, od, i.e. buy or sell orders, and each order type, ot. Second, we compute the mean hourly buy-sell relation, BSR, as the difference between the averaged hourly buy and the sell volume fraction $BSR_h^{ot} = \overline{VF}_h^{ot,b} - \overline{VF}_h^{ot,s}$ over all days, d, and all products, i. Finally, due to the imbalance between sells and buys, we subtract the overall mean daily buy-sell relation from the hourly buy-sell relation, which leads to the mean extraordinary buy-sell volume relation, $EBSR$, for each hour, i.e. $EBSR_h^{ot} = BSR_h^{ot} - \overline{BSR}^{ot}$. Fig. 3 shows this average buy-sell relation separately for market and limit orders, and long and short leverage certificates. A positive extraordinary buy-sell relation means above-average buying activity and a negative buy-sell relation means above-average selling activity. As expected, during the first part of the day we can see higher buying-activity. This situation is reversed around 5:00 p.m. and the day closes with higher selling-activity.

3.2.2. Valuation

For each quote, the fair theoretical value of the leverage certificate (LC) is computed using the pricing model by Rubinstein and Reiner (1991) for down-and-out calls and up-and-out puts, i.e.:[37]

$$LC_0^{model,long} = S_0\Phi(x) - X\exp(-rT)\Phi(x - \sigma\sqrt{T}) - S_0\left(\frac{X}{S_0}\right)^{2\omega}\Phi(y)$$
$$+ X\exp(-rT)\left(\frac{X}{S_0}\right)^{2\omega-2}\Phi(y - \sigma\sqrt{T}), \tag{14}$$

$$LC_0^{model,short} = -S_0\Phi(-x) + X\exp(-rT)\Phi(-x + \sigma\sqrt{T})$$
$$+ S_0\left(\frac{X}{S_0}\right)^{2\omega}\Phi(-y) - X\exp(-rT)\left(\frac{X}{S_0}\right)^{2\omega-2}$$
$$\times \Phi(-y + \sigma\sqrt{T}) \tag{15}$$

with

$$x = \frac{\log\left(\frac{S_0}{X}\right)}{\sigma\sqrt{T}} + \omega\sigma\sqrt{T}, \quad y = \frac{\log\left(\frac{X}{S_0}\right)}{\sigma\sqrt{T}} + \omega\sigma\sqrt{T}, \quad \omega = \frac{r + \frac{\sigma^2}{2}}{\sigma^2},$$

---

[35] We do include the other order type in a robustness check later in the paper.

[36] Strictly speaking, hourly volume means the aggregated volume in the time period before the points in time considered as described earlier in this Section. We talk about "hour" for ease of description.

[37] It should be noted that this pricing procedure assumes that the issuer is default-free while in reality the investor is exposed to the issuer's default risk, as leverage certificates are unsecured. However, as mentioned in Section 3.2.1, the holding period of these certificates is extremely short so that the impact of default-risk is of minor relevance. Baule et al. (2008) and Entrop et al. (2009) consider different ways to incorporate credit risk when valuing discount certificates and open-end leverage certificates, respectively. When applying the procedure of Entrop et al. (2009) — open-end leverage certificates are similar to the leverage certificates in our paper — with a planned holding period of 1 to 2 days, the impact of credit risk on the value of a certificate is negligible.

where $X > S_0$ for short leverage certificates and $S_0 > X$ for long leverage certificates. Volatility is denoted by σ, r is the risk-free interest rate and $\Phi(\cdot)$ is the standard normal distribution function. As the model assumes that the underlying follows a geometric Brownian motion, which implies continuous sample paths, it does not include the effect of unhedgeable jump risk in the resulting certificate values. Consequently, if this risk is priced, it should be captured in the estimated markups, which is consistent with our theoretical model from Section 2.

The risk-free rate is proxied using interest rates provided by the Deutsche Bundesbank for German government bonds for any maturity longer than one year and the Eurepo rate is used for maturities of less than one year. Rates are linearly interpolated where necessary. For the underlying, we use the value of the DAX at the second of the quote. As the DAX is only available from 9:00 a.m. till 5:30 p.m., values after the physical market close are approximated by a substitute calculated from DAX-futures called the XDAX, which is again linearly interpolated where necessary.

The volatility used for calculating the fair value of a leverage certificate is the implied volatility from settlement prices of call and put options written against the DAX and traded on the EUREX. The EUREX is Europe's largest derivatives exchange for institutional investors and typically serves as the benchmark market when dealing with structured products. We follow Baule (2011) and Hentschel (2003) and use a method to calculate implied volatilities that puts more weight on out-of-the-money options. If there is no perfect match between a leverage certificate and an EUREX option with respect to time to maturity and moneyness, we use a two-dimensional interpolation scheme via maturity and strike to obtain the relevant implied volatility.

To analyze certificate price-setting behavior, we focus on the markups set by the issuer. We compare the calculated fair values LC^{model} according to (14) and (15) with the actually priced mid quotes LC^{mid}. We calculate the mid quotes from our dataset as the arithmetic mean of the bid and the ask quotes:

$$LC^{mid} = \frac{LC^{ask} + LC^{bid}}{2}. \tag{16}$$

We then calculate absolute, AP, and relative, RP, differences of the model prices and the mid quotes as:

$$AP = LC^{mid} - LC^{model}, \tag{17}$$

$$RP = \frac{LC^{mid} - LC^{model}}{LC^{model}}. \tag{18}$$

Summary statistics for the calculated markups are reported in Table 3. The results are shown separately for each moneyness at quote quintile and short and long leverage certificates. Average absolute (relative) markups over all quintiles of moneyness for long certificates are about 17 cents (5.5%), while for short certificates they are around 15 cents (6.6%). Hence, issuers charge a higher absolute (relative) premium for long (short) certificates and vice versa. The same holds when medians are considered. Moreover, we see a moneyness effect in the markups as absolute and relative markups are larger, the smaller is the moneyness at quote, and this effect is more pronounced for relative markups. Plausible explanations for this are related to demand or gap risk effects. The latter is more relevant the higher is the probability of a knock-out, i.e. the smaller the moneyness. On the other hand, certificates that are closer to knock-out are traded more often (recall we only consider traded certificates in our dataset). In the first moneyness quintile, a trade in the hour before occurred for nearly 25% of the quotes, whereas in the fifth quintile it is barely 1%.

When comparing absolute and relative markups it should be noted that relative markups can be very sensitive to small changes
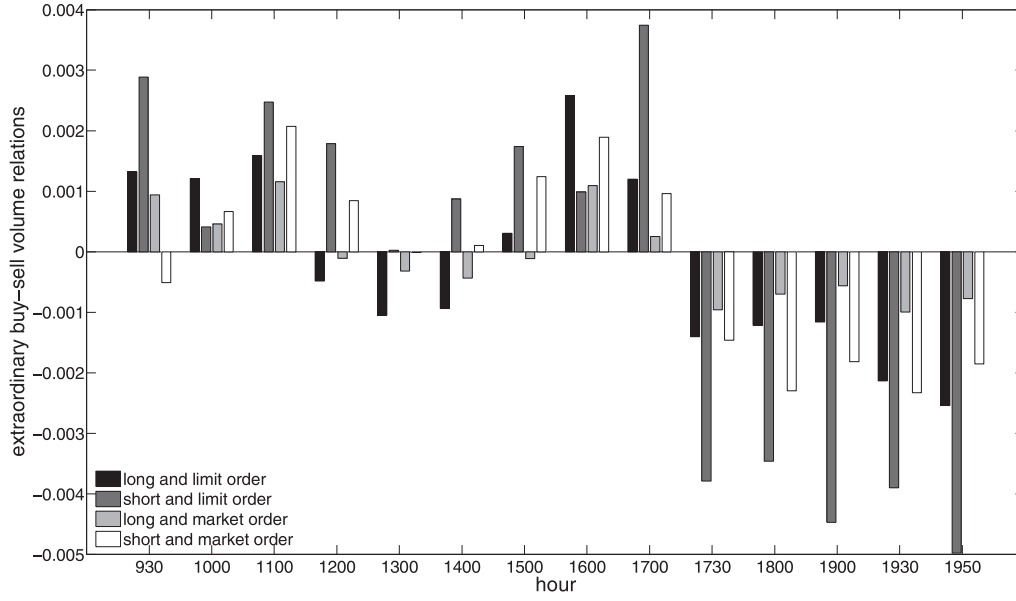
Fig. 3. Extraordinary hourly average buy-sell relation over the day. Data is reported separately for limit and market orders and short and long certificates. First, we calculate the hourly volume fraction VF of each product i per hour h and day d, $VF_{i,d,h}^{ot,od} = \frac{V_{i,d,h}^{ot,od}}{\sum_{h'} V_{i,d,h'}^{ot,od}}$, where V denotes the volume in EUR, ot the order type and od the order direction. Second, we compute the mean hourly buy-sell relation BSR as $BSR_h^{ot} = \overline{VF}_h^{ot,b} - \overline{VF}_h^{ot,s}$, where $\overline{VF}_h^{ot,od}$ denotes the hourly average over all days and products of the volume fraction for the respective order direction. Finally, the overall average daily buy-sell relation $\overline{BSR}^{ot}$ is substracted which leads to the extraordinary hourly buy-sell relation $EBSR_h^{ot} = BSR_h^{ot} - \overline{BSR}^{ot}$.

Table 3
Absolute and relative markups.

		Quintiles of moneyness at quote *MaQ*					
		1st (low)	2nd	3rd	4th	5th (high)	Total
Absolute markup							
Long	Mean	0.1822	0.1736	0.1696	0.1684	0.1705	0.1724
	Median	0.1807	0.1743	0.1714	0.1700	0.1732	0.1741
	Std	0.0571	0.0587	0.0620	0.0640	0.0660	0.0623
	N	441,266	481,663	504,715	537,288	652,124	2,617,056
Short	Mean	0.1684	0.1537	0.1451	0.1421	0.1426	0.1516
	Median	0.1672	0.1540	0.1457	0.1434	0.1447	0.1541
	Std	0.0571	0.0637	0.0702	0.0759	0.0833	0.0699
	N	499,440	459,035	435,988	403,411	288,573	2,086,447
Total	Mean	0.1749	0.1639	0.1583	0.1571	0.1619	0.1632
	Median	0.1738	0.1651	0.1606	0.1600	0.1663	0.1658
	Std	0.0575	0.0620	0.0671	0.0706	0.0729	0.0666
	N	940,706	940,698	940,703	940,699	940,697	4,703,503
Relative markup							
Long	Mean	0.1589	0.0613	0.0390	0.0268	0.0165	0.0552
	Median	0.1207	0.0583	0.0379	0.0262	0.0158	0.0340
	Std	0.1348	0.0262	0.0167	0.0116	0.0077	0.0755
	N	441,266	481,663	504,715	537,288	652,124	2,617,056
Short	Mean	0.1664	0.0556	0.0339	0.0228	0.0144	0.0656
	Median	0.1237	0.0527	0.0324	0.0220	0.0137	0.0379
	Std	0.1445	0.0280	0.0188	0.0135	0.0096	0.0932
	N	499,440	459,035	435,988	403,411	288,573	2,086,447
Total	Mean	0.1629	0.0585	0.0367	0.0251	0.0158	0.0598
	Median	0.1222	0.0558	0.0357	0.0247	0.0153	0.0356
	Std	0.1401	0.0273	0.0179	0.0126	0.0084	0.0839
	N	940,706	940,698	940,703	940,699	940,697	4,703,503

Summary statistics on markups in the certificates dataset. Markups are calculated as relative and absolute differences between priced mid quotes (arithmetic mean of ask and bid quote) and fair model values. The mean, median and the standard deviation, *Std*, are reported separately for relative (*RP*), and absolute (*AP*) markups, for long and short positions and also for different quintiles of moneyness at quote, *MaQ*. N denotes the number of observations.

in the mid quote LC^{mid} or in the model value LC^{model} when the price level, — and by this the model value — is very small (see Eq. (18)), i.e. when the moneyness is close to one. Thus, small changes in the mid quote or in the model values — for example caused by a small misestimation of an input parameter — can result in large changes of the relative markup. In contrast, the absolute markup is much more robust in this case. In fact, we find quite stable standard deviations for the absolute markups across the moneyness quintiles,

while the standard deviation for relative markup is around 0.14 in the first quintile (where the average mid quote is only 1.6 EUR) and much higher than in the remaining quintiles. That is why we focus on the more robust absolute markups in the following.[38]

3.3. Regression analysis design

To analyze the determinants of markups in more detail and to test our model-derived hypotheses, we estimate the following regression equation and several variations separately for the overall sample and each of the five moneyness at quote quintiles:

$$
\begin{aligned}
AP_i = \ & const + \beta RelTtM_i & \Big\}1 \\
& + \sum_{jkm} \delta_{jkm} \mathbf{1}_{\{Hour_i \in DayThird_j\}} OrderDummy_{ki} \times BuySellDummy_{mi} \\
& \quad \times ExtraVolumeDummy_i & \Big\}2 \\
& + \sum_n \zeta_n HourDummy_{ni} \times OvernightVolatility_i \\
& + \sum_{pq} \eta_{pq} \mathbf{1}_{\{Hour_i \in DayHalf_p\}} LongShortDummy_{qi} \times SlopeSmile_i & \Big\}3 \\
& + \theta\, Spread_i & \Big\}4 \\
& + \sum_u \lambda_u Controls_{ui} + \varepsilon_i,
\end{aligned}
$$

$$(19)$$

where the absolute markup AP_i is calculated as in (17) for each quote i in the dataset. All regressions are estimated using two-stage least squares (2SLS) to avoid endogeneity problems related to the spread as discussed below.

Hypothesis 1: Life Cycle Hypothesis

The relative time to maturity $RelTtM$ is defined as:

$$
RelTtM = \frac{Remaining\ Time\ to\ Maturity}{Initial\ Time\ to\ Maturity}. \tag{20}
$$

This variable is included to test the life cycle hypothesis and we expect a positive estimate for β if Hypothesis 1 holds as certificates that are closer to maturity should have lower markups. This effect may vary for different levels of moneyness (Entrop et al., 2013) as the life cycle hypothesis might be more pronounced for products with higher moneyness, as they are less likely to be knocked-out soon.

Hypothesis 2: Order Flow Hypothesis

Our model implies that extraordinary (positive or negative) demand shifts could impact on markups at both the point in time when the shift occurs and also before and after this event. Clearly, the way in which we identify these shifts is important and, similar to Eq. (13), we calculate for each certificate and time period, the traded volume in the respective period before the quote divided by the average daily traded volume since issuance until the day before the quote.[39] This is done separately for all combinations of market and limit orders with buys and sells. We consider a volume fraction extraordinary high if it belongs to the largest 20% in a respective combination. In this case we set the dummy $ExtraVolumeDummy$ to one and zero otherwise.

In discussing Fig. 3 in Section 3.2.1, we found that there is net buying pressure until 5 p.m. and net selling pressure thereafter. Based on this evidence, we allow for separate coefficients of the dummy in the first and second part of the day and also specify a third coefficient to individually isolate the effect at the turning point of 5:00 p.m.[40]

In the equity literature, the volume-return relation is known to suffer from endogeneity (e.g., Chen, 2012; Dorn et al., 2008) and the reader may have similar concerns in our setting. To allay such fears, recall that we do not examine returns but the markups of the issuer. In our data, the correlation between markups and mid-quotes is −5%, and so, the return to a product does not correlate with the markup of the issuer. There is another potential endogeneity concern as investors are sensitive to the level of the markups in our model in which case markups could have an influence on order flow. To address this concern, recall that limit orders are placed at some point prior to the time of execution and they are based on conditions and expectations at the point in time when the order is placed, not at the point in time it is executed. For market orders however, this relation does not hold. It is for this reason that we distinguish between market and limit orders in our analysis. Further, we consider aggregated trade volumes that summarize the period immediately prior to the time of the quote. In effect, we are using lagged volume data to explain the markup, which cannot be influenced by unknown future markups.

Hypothesis 3: Unhedgeable Risk Hypothesis

As described in Section 3.1, unhedgeable risk in the form of jumps in the underlying can materialize at random points in time and also deterministically, i.e. in the overnight interval. We proxy the influence of these two types of risks separately.

(**a**) *OvernightVolatility*.

As a proxy for the overnight gap risk we use overnight DAX volatility forecasts. More specifically, we calculate the overnight returns based on the last XDAX level and the opening DAX the next day and fit a GARCH(1,1) model according to Engle (1982) and Bollerslev (1986) to the resulting time series. The development of the forecasts is shown in Fig. 4.

As our model implies that the relevance of unhedgeable risk on the markups increases with proximity of the point in time at which this risk can occur, we estimate separate coefficients, ζ_n, of the overnight volatility for each hour. We expect them to be positive and to increase during the course of the day.

(**b**) *SlopeSmile*.

Following Arisoy (2014), we use the implied volatility slope calculated from out-of-the-money (OTM) puts as a proxy for the overall downside jump risk of the DAX and the resulting gap risk for the issuer. Compared to stock portfolios, which have been used in earlier studies (e.g., Ang et al., 2006), the implied volatility skew is a more precise measure of the systematic jump risk at the individual stock level (Yan, 2011) and also in the cross-section (Cremers et al., 2013). We use settlement prices of EUREX options with a maturity of 1 month and the respective implied volatilities calculated as discussed in Section 3.2. If options with an exact maturity of 30 days are not available, we interpolate. The measure of the slope is calculated as the difference between the implied volatility of out-of-the-money puts with moneyness of $m = 0.98$ and at-the-money calls, i.e. the $SlopeSmile = \sigma_{put}^{imp}(m) - \sigma_{call}^{imp}(1)$. To aid the reader in understanding this measure, Fig. 4 includes a time series plot of this slope measure.

We measure the effect of the overall downside jump risk separately for long and short certificates and the first and second part of the day. The respective coefficients, η_{pq}, are supposed to be

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[38] However, using relative markups would not change our results, with the exception of some extraordinary buy and sell dummies that all turn positive in the lowest moneyness at quote quintile. Results for relative markups are available on request.

[39] We do not divide by the volume of the day of the quote to avoid a forward looking bias in our regression. If a trade occurs exactly at the point in time we consider a quote, its volume is assigned to the period before the next quote to avoid endogeneity problems. On the first day a certificate is traded all fractions are set to zero as we cannot divide by 0.

[40] An inclusion into the first or second part of the day would have distorted the respective coefficients.
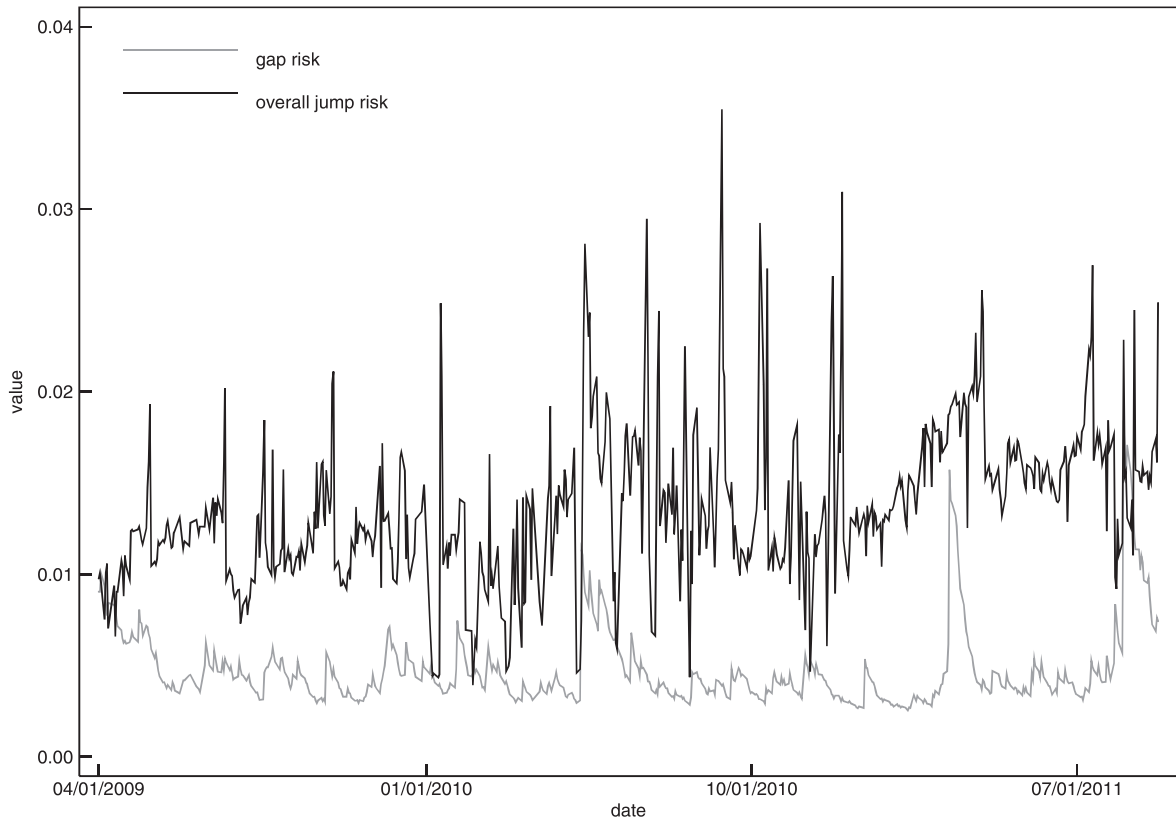
Fig. 4. Development of the overall jump risk and the overnight gap risk proxies. For the overnight gap risk we use overnight DAX volatility forecasts, calculated via a Garch (1,1) approach according to Engle (1982) and Bollerslev (1986). For the overall gap risk we use the implied volatility slope calculated from OTM puts. The measure of the slope is calculated as the difference between the implied volatility using the method according to Section 3.2 of out-of-the-money puts with moneyness $m = 0.98$ and at-the-money calls, $sl \equiv \sigma_{put}^{imp}(m) - \sigma_{call}^{imp}(1)$.

positive for long certificates and negative for short certificates because a knock-out is only possible for long leverage certificates if a negative jump occurs. Therefore, a higher jump risk should increase the markups for long, and decrease the markups for short leverage certificates.

Hypothesis 4: Spread Hypothesis

According to our model, the spread should have a negative effect on the markup, due to compensation effects that occur with respect to the profit and the demand function of the issuer, i.e. a negative θ. Since we are only interested in explaining the issuers price-setting behavior, we use a 2SLS approach to control for the possible endogeneity between spread and markup. Specifically, we use two instruments for the spread:

(i) The average spread over all products of the prior day,
(ii) 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.

To understand the first instrument, recall that, due to the signal effect of the spread, the issuer is under a certain pressure to set the spread around the general average level in the market. Hence, the daily average spread should be a good proxy for the spread. As we use the lagged variable, there should be no reverse causality. The second instrument is based on the ratio between the spread of the most similar product of a different issuer and the average spread of the same day. Due to competition effects, the spread of the most similar product of the same day and the spread of interest can be expected to be similar, however, it also may suffer from endogeneity. This holds also, but less so, for the average spread,

as all spreads are set around an average level. But taking the respective fraction and the first difference is likely to cancel out a potential reverse causality, which is also supported by the later tests.

To identify the most similar product, we choose a product listed at the same time in the market as the reference quote issued by a different issuer. We measure the similarity between all relevant products and the reference quote along the dimensions of relative time to maturity and moneyness at quote. We first transform the moneyness and the time to maturity in the Euclidean space according to Torgerson (1958). Then we calculate the Euclidean distance between the reference observation and the other quotes according to the following formula:

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2},$$ (21)

where p_i and q_i are the transformed moneyness at quote and relative time to maturity for the two compared observations. The spread of the product with the smallest distance is then used as part of the instrument. If several products with the same distance existed, we use the arithmetic mean of the spreads.

For each of the following 2SLS-regressions we test the instruments' validity via Wooldrige's score based test of overidentifying restrictions (Wooldridge, 1995) and an F-test for the joint significance of the first stage instruments' coefficients. Moreover, we test for endogeneity of the spread using the approach of Hausman (1978) and Wooldridge's score based test for endogeneity (Wooldridge, 1995). The tests of overidentifying restrictions cannot be rejected at a reasonable level as the p-values range from

15% to 84%.[41] The null hypothesis of the relevance and endogeneity tests can always be rejected at a 0.1% significance level. Stock et al. (2002) suggest that the *F*-statistic should exceed a level of 10, which holds in our tests. Hence, the instruments are valid and the spread is indeed endogenous. The regression tables in Section 3.4 contain respective details.

Controls

In addition to the variables included in the regression model that are designed to test our four key hypotheses, we also include a number of control variables. Specifically, we include a dummy for long leverage certificates to capture any differences in pricing policies for long and short certificates. As we use different products from different issuers over a time period of two and a half years, we also need to control for fixed effects. These fixed effects are unlikely to be product specific, because the same issuer would not set different markup levels for their products without a reason. Rather, we assume issuer and quarter specific level differences in the markups meaning we include quarter and issuer dummies in the regression model. Moreover, the original time to maturity divided into quintiles is used as a control variable as the markups might be related to the term of the products at issue. We additionally include dummies for quintiles of moneyness at quote, because the moneyness might have an influence on the price-setting policy.

To calculate the implied volatility used in the valuation of the products, we used settlement prices of EUREX options rather than prices at the time of the quote. According to Wallmeier (2015), 95% of the intraday variation of implied volatility can be explained by changes in the index level. Therefore, we use the DAX return from the quote time until the settlement time of the day as a control variable for intraday changes of the volatility. Further, on Fridays, the markups could be higher due to the longer trading break and risk of information arrival during the weekend. This means that the gap risk faced by the issuer might be higher on Fridays, which might have consequences for the price-setting. As such, we control for this effect via a Friday dummy.

3.4. Regression results

In order to remedy multicollinearity doubts we first conduct a correlation analysis. Table 4 shows Pearson correlations and the corresponding *p*-values of a two-tailed test between the absolute markup and the main independent variables.

The correlations of the independent variables are small. This reveals that there should be no multicollinearity issues in our analysis. The reader might wonder about the fact that the correlations between the dependent and the independent variables are also small. As we particularly examine interactions in our regression analyses, for which we often expect opposite influences, the effects are partly cancelled out in the overall correlation analysis. However, we note that the signs are consistent with the findings in our regression analyses.

The results of the regression Eq. (19) are presented in Table 5 in column (1). As predicted, the coefficient of the **relative time to maturity** is positive and highly significant. This evidence provides support for Hypothesis 1, i.e. products with a higher remaining time to maturity have larger markups.

Turning to consider the **volume** effects in our equation, we find that for both the first (930–1600) and the latter (1730–1950) part of the day, the coefficients of market and limit orders are positive

for buys and significant. This implies that extraordinarily high buy volume leads to issuers increasing their markups, which is consistent with Hypothesis 2. When we consider the intervening time period at 1700, we find counter-intuitive evidence of significantly negative coefficients which cannot be explained by our model.

When we consider the effect of extraordinary high sells, we find negative coefficients for 930–1600 and positive coefficients for 1730–1950. This implies that in the first part of the day issuers decrease markups when extraordinarily high sell volume occurs to pay less for the returned products, which is plausible. Remembering that the buy-sell relation (see Section 3.2.1) is negative in the second part of the day, a strongly above-average sell pressure in a specific period might lead to issuers increasing the markups afterwards as more certificates than expected have been redeemed and so fewer certificates than expected are outstanding and likely to be sold back in a subsequent period. Therefore, issuers can exploit the next buyers via higher markups. All in all, these empirical results suggest that issuers adjust their markups as a reaction to extraordinary demand shifts. This is evidence in support of Hypothesis 2, i.e. the order flow hypothesis.

The coefficients associated with the **overnight gap risk** variable are positive and mostly significant at the 0.1% level. This implies that overnight gap risk is priced. In addition, comparing the coefficients over the course of the day, we find that the coefficients increase during the second part of the day. This suggests that the importance of this risk increases with its proximity to the overnight gap risk event. All in all, this evidence supports Hypothesis 3. The coefficients of the **overall jump risk**, measured by the slope smile, are negative for short and positive for long certificates. As the slope smile proxies the downside jump risk, the positive sign for long certificates is consistent with Hypothesis 3, i.e. unhedgeable risk is priced.

The effect of the **spread** is positive and significant at the 0.1% level. Hence, there is a positive relationship between the spread and the markup. This contradicts Hypothesis 4, as our model suggests that the spread and the markup are substitute profit sources. As we find only a little variation in the spread, this suggests that investors see the spread as a strong price quality signal, which would imply a much higher sensitivity to the spread than to the markup. This makes sense as the first can be observed and is easily comparable, but it is hard for individual investors to judge on the size of the second. If the issuer had to increase the spread, the demand could decrease substantially. The issuer could be compensated for the resulting loss of profit through an increase in the markups.

Columns (2) to (5) of Table 5 report variations of (1) including different subgroups of independent variables in the regression. All models show similar results, although in model (3) some coefficients lose significance. An exception is the full model without controls (2). Here, the spread effect is much more pronounced, and we now find nearly all volume coefficients positive and highly significant. However, we do not put too much emphasis on this because — as already mentioned in Section 3.3 — the validity test of the instruments is rejected in this case which hints at a misspecification of the structural equation when leaving out the control variables.

As already discussed in Section 3.3, the relevance of the life cycle hypothesis and of the gap risk effect can be expected to depend on how close a certificate trades to the barrier, i.e. its moneyness. Therefore we rerun the full regression (19) for different quintiles of moneyness at quote, *MaQ*. The results are shown in Table 6.

The effect of the coefficient of the **relative time to maturity** becomes larger with increasing quintiles of moneyness. Hence, the less likely the product is to be the knocked out, the stronger is the support for the life cycle hypothesis. Regarding the **volume**

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[41] The only exception is the overall regression without control variables. In this case we have to reject the overidentifying restrictions test, which indicates either correlated instruments with the error term or a misspecification of the regression model. For the sake of completeness we still report the results, assuming that a misspecification of the model is the reason for the rejected validity as including control variables leads to no rejection. See Section 3.4 for details.

Table 4
Correlations of independent variables and absolute markups.

| | | Correlations | | | | | | | | |
| | | | Limit order | | Market order | | Gap | Overall | | |
		rel.TtM	Buy	Sell	Buy	Sell	Risk	Jump risk	Spread	*AP*
rel.TtM	Pearson correlation	1								
	p-value									
Limit order Buy	Pearson correlation	−0.01	1							
	p-value	0.00								
Limit order Sell	Pearson correlation	−0.01	0.06	1						
	p-value	0.00	0.00							
Market order Buy	Pearson correlation	−0.01	0.05	0.03	1					
	p-value	0.00	0.00	0.00						
Market order Sell	Pearson correlation	−0.01	0.03	0.03	0.05	1				
	p-value	0.00	0.00	0.00	0.00					
Gap risk	Pearson correlation	0.00	0.00	0.00	0.00	0.00	1			
	p-value	0.00	0.00	0.00	0.00	0.14				
Overall Jump risk	Pearson correlation	−0.03	−0.01	−0.01	−0.01	−0.01	0.07	1		
	p-value	0.00	0.00	0.00	0.00	0.00	0.00			
Spread	Pearson correlation	0.05	0.00	0.00	0.00	0.00	0.12	−0.14	1	
	p-value	0.00	0.00	0.00	0.00	0.09	0.00	0.00		
AP	Pearson correlation	0.14	0.01	0.01	0.01	0.01	0.04	−0.03	0.00	1
	p-value	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	

Correlations between independent variables and absolute markups. For the overall sample are shown the pearson correlation and the *p*-value of a 2-tailed significance test. Results are computed for the relative time to maturity, extraordinary volume dummies for limit and market orders and buys and sells, the proxies for the overnight gap and the overall jump risk and the spread.

effects, we find that the coefficients of market and limit orders in the first moneyness quintile are equivalent to the overall regression results and, interestingly, more significant for limit orders. In the higher moneyness quintiles, the coefficients often lose significance. However, as roughly 50% of all trades belong to the first moneyness quintile, while only 1% occur in the last quintile, finding significant coefficients in the upper quintiles was always going to be more challenging.

The coefficients associated with the **overnight gap risk** variable are similar to the overall consideration, with the exception of the last quintile. Moreover, the effect is more pronounced for certificates closer to knock-out, which is plausible as the importance of gap risk increases with decreasing moneyness. Additionally, comparing the coefficients over the course of the day, the coefficients increase most in the first quintile which is also consistent with our expectations. The overnight gap risk for these certificates is more relevant when the risk event gets nearer. The coefficients of the **overall jump risk**, measured by the slope smile, are negative for short and positive for long certificates over all moneyness quintiles. The effect of the **spread** does not differ much across moneyness quintiles and is positive significant.

To summarize, our empirical analysis provides a set of results that are largely consistent with our theoretical model on the issuers' optimal price-setting. The only exception is the result for the spread effect.

To further test the informational content of the full regression model, we follow Gigerenzer and Brighton (2009) and Woodside (2013) and conduct two predictive validity tests for random subsamples on the issuer and certificates level, respectively. First, the data set is randomly split in half according to the issuers. Then we run regression (19) on the resulting two subsamples. The coefficients and the constants of subsample one are then used to predict the absolute markups in subsample two using the respective variables in this subsample two and vice versa. Finally the respective actual values of the markup and the predicted values are compared via correlation tests. Both correlations are above 0.23 and significant at the 0.1% level. When analogously splitting the data set randomly on the certificates level, we find significant correlations

above 0.45. These tests imply that the regression model used delivers information on the absolute markups.

With various other robustness checks, such as excluding all insignificant independent variables, analyzing relative rather than absolute markups, using time to maturity measured as days scaled by days per year instead of relative time to maturity, using out-of-the-money puts with different moneynesses for the calculation of the overall jump risk and higher order GARCH models to proxy the overnight gap risk, adding the other order types[42] in the regression, using net order flow instead of extraordinary buys and sells, or using the 50% highest volume fractions to specify extraordinary buys and sells, the basic tenor of our findings is maintained. The results of these robustness checks are not presented to preserve space and are available on request.

4. Conclusion

In this paper, we consider the issuers profit maximizing price-setting policy in the market for retail certificates. We present the first theoretical model that derives the inter-temporal structure of the optimal markups and analyzes their determinants. In doing so, we provide a theoretical justification for a number of previously reported empirical findings and also uncover some new expected relations. Specifically, the model implies that issuers deliberately (i) decrease their markups inter-temporally (referred to as the life cycle hypothesis), (ii) adjust the markups according to investors' demand (the order flow hypothesis), (iii) include unhedgeable risk in their markups and increase the risk's influence with closer proximity to an unhedgeable risk event (the unhedgeable risk hypothesis), and (iv) decrease the markups if the spread is increased (the spread hypothesis).

We use a combined dataset of quotes and trades in finite maturity DAX leverage certificates on the German market from Q2/2009 till Q3/2011 to empirically examine these hypotheses.

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[42] While adding the other order types analogously to the limit and market orders, the latter do not change their coefficients significantly.

Table 5
Regression results.

			(1) Overall	(2) Without controls	(3) Volume	(4) Jump & gap risk	(5) *rel.Ttm* & spread
		rel.TtM	0.0232***	0.0342***			0.0235***
Limit order	Buy dummy	930–1600	0.0011*	0.0120***	−0.0007		
		1700	−0.0216***	−0.0088***	−0.0249***		
		1730–1950	0.0061***	0.0210***	0.0043***		
	Sell dummy	930–1600	−0.0033***	0.0075***	−0.0043***		
		1700	0.0110***	0.0226***	0.0065*		
		1730–1950	0.0052***	0.0195***	−0.0003		
Market order	Buy dummy	930–1600	0.0016*	0.0147***	−0.0008		
		1700	−0.0065	0.0068*	−0.0111***		
		1730–1950	0.0047**	0.0187***	0.0031		
	Sell dummy	930–1600	−0.0023**	0.0098***	−0.0042***		
		1700	0.0187***	0.0299***	0.0128***		
		1730–1950	0.0023	0.0178***	−0.0005		
Hour dummy # gap risk		Hour 930	1.5991*	−1.2209		0.9744***	
		Hour 1000	0.9045***	0.5846***		0.8312***	
		Hour 1100	0.7775***	0.4343***		0.7275***	
		Hour 1200	0.8683***	0.5518***		0.7912***	
		Hour 1300	0.8513***	0.5531***		0.7898***	
		Hour 1400	0.8404***	0.5295***		0.7541***	
		Hour 1500	0.9791***	0.6828***		0.9007***	
		Hour 1600	0.9906***	0.7665***		0.9159***	
		Hour 1700	0.2584***	−0.0065		0.2591***	
		Hour 1730	1.3819***	0.9906***		1.6223***	
		Hour 1800	1.2061***	0.7969***		1.3708***	
		Hour 1900	1.1978***	0.6971***		1.3710***	
		Hour 1930	1.1765***	0.6416***		1.3552***	
		Hour 1950	1.3012***	0.1579**		1.4285***	
Overall jump risk	Short	930–1700	−0.7363***	−0.8404***		−0.7511***	
		1730–1950	−0.7441***	−0.8294***		−0.8383***	
	Long	930–1700	1.0554***	1.4625***		1.1448***	
		1730–1950	0.6903***	1.1291***		0.7176***	
Spread			1.0275***	4.9532***			1.4117***
Controls		Long dummy	Yes	No	Yes	Yes	Yes
		Issuer dummy	Yes	No	Yes	Yes	Yes
		Quarter dummy	Yes	No	Yes	Yes	Yes
		Quintiles *MaQ*	Yes	No	Yes	Yes	Yes
		Quintiles $T_{Initial}$	Yes	No	Yes	Yes	Yes
		Friday dummy	Yes	No	Yes	Yes	Yes
		Intraday DAX return	Yes	No	Yes	Yes	Yes
Constant			0.1576***	0.0687***	0.1993***	0.2052***	0.1420***
GR^2			21.50	7.78	21.10	21.05	20.79
N			4,056,370	4,056,370	4,655,290	4,655,290	4,056,370
Wooldrige's score based test of overidentifying restrictions (*p*-value)			1.2598 (0.2617)	13.1762 (0.0003)			1.2888 (0.2563)
F-test on first stage regression (*p*-value)			34,519 (0.0000)	516,053 (0.0000)			31,769 (0.0000)
Wooldrige's score based test for endogeneity (*p*-value)			206.08 (0.0000)	97,918 (0.0000)			425.74 (0.0000)

Results of regression (19) for absolute markups. A 2SLS approach with instrumented spread is conducted for various variations on the overall sample. As spread instruments are used (i) the average spread over all products of the prior day and (ii) the first difference of the ratio between the spread of the most similar product and the average spread of the same day. Regressors are the relative time to maturity, *rel.TtM*, the order flow measured as extraordinary buy and sell dummies separately for buys and sells and limit and market orders and three parts of the day, the overnight gap risk measured through a Garch(1,1)-forecast of the overnight DAX volatility, the overall jump risk measured via the implicit volatility skew slope separately for long and short certificates and for two parts of the day and the instrumented spread. As controls are used dummies for long leverage certificates, issuers, quarters and Fridays, moneyness quintiles, Q-*MaQ*, initial time to maturity, $T_{Initial}$, quintile dummies and the intraday DAX return from time of quote till DAX market closure. Validity is tested via Wooldrige's score test of overidentifying restrictions (Wooldridge, 1995) and an *F*-test for the joint significance of the first stage coefficients of the instruments. Endogeneity is tested via a regression based approach following Hausman (1978) and Wooldrige's score test for endogeneity (Wooldridge, 1995). In the table are only reported the results of the latter though. N denotes the number of observations. GR^2 is the generalized criterion proposed by Pesaran and Smith (1994). Significance at the 5% level is indicated with *, at the 1% level with ** and at the 0.1% level with ***. All statistics are estimated using heteroskedasticity robust standard errors (White, 1980).

Carefully dealing with endogeneity issues in a 2SLS-approach, we find that the issuers, (i) decrease the markups over the product's lifetime and this effect is more pronounced for products with higher probabilities of knock-outs. (ii) Moreover, the issuers adjust their markups as a reaction to extraordinary demand shifts, especially in the cases of limit orders and buys. (iii) The overnight gap risk is included in the markups and this effect is more pronounced with closer proximity to the overnight gap and products with smaller probabilities of knock-outs. Moreover, overall unhedgeable risk events in form of the downside jump risk are priced. (iv) We did find evidence to suggest that the spread and markup are not substitute profit sources for the issuers, which runs counter to the prediction of our model. Further, our results suggest that investors are not able to effectively judge the "unfairness" of the prices and see the spread as a strong price quality signal, which prevents the issuers from

Table 6
Regression results for moneyness quintiles.

			Quintiles of Moneyness at Quote *MaQ*				
			(1) 1st (low)	(2) 2nd	(3) 3rd	(4) 4th	(5) 5th (high)
		rel.TtM	0.0201***	0.0256***	0.0256***	0.0245***	0.0278***
Limit order	Buy dummy	930–1600	0.0026***	0.0007	−0.0006	0.0020	−0.0039
		1700	−0.0104***	−0.0254***	−0.0275***	−0.0133	−0.0585***
		1730–1950	0.0055***	0.0053*	0.0087**	0.0115*	0.0144
	Sell dummy	930–1600	−0.0018*	−0.0023*	−0.0042**	0.0032	−0.0046
		1700	0.0121**	0.0159**	0.0120	0.0301**	0.0244
		1730–1950	0.0085***	0.0028	0.0050	0.0004	0.0056
Market order	Buy dummy	930–1600	0.0020*	0.0038**	0.0054**	0.0025	−0.0005
		1700	−0.0026	0.0083	−0.0234**	0.0005	0.0119
		1730–1950	0.0031	0.0032	0.0124**	0.0145*	0.0011
	Sell dummy	930–1600	−0.0009	−0.0006	−0.0034	−0.0007	−0.0043
		1700	0.0215***	0.0302***	0.0163	0.0328*	−0.0078
		1730–1950	0.0035	0.0041	0.0042	−0.0023	−0.0110
Hour dummy # Gap risk		Hour 930	2.5677	9.2281***	4.6716*	2.0626	−3.0312***
		Hour 1000	2.4915***	2.3798***	2.2763***	1.4738***	−0.8844***
		Hour 1100	2.5116***	2.1135***	1.8476***	1.3754***	−0.7849***
		Hour 1200	2.4062***	2.1396***	2.1475***	1.5315***	−0.7082***
		Hour 1300	2.4950***	2.1979***	2.1197***	1.4628***	−0.8267***
		Hour 1400	2.5050***	2.1001***	2.0647***	1.4124***	−0.7305***
		Hour 1500	2.3444***	2.2025***	2.1963***	1.6407***	−0.4339***
		Hour 1600	2.2243***	2.2706***	2.3342***	1.6908***	−0.6011***
		Hour 1700	−0.2832*	1.2715***	1.7340***	1.9922***	−0.7540***
		Hour 1730	3.0711***	2.7901***	2.8326***	2.3336***	−0.1502
		Hour 1800	4.0474***	2.6068***	2.3411***	1.8400***	−0.6485***
		Hour 1900	4.2568***	2.6627***	2.3482***	1.7492***	−0.6070***
		Hour 1930	4.0407***	2.6674***	2.4347***	1.9524***	−0.7628***
		Hour 1950	4.5467***	2.8573***	2.5746***	2.1120***	−0.7339***
Overall jump risk	Short	930–1700	−0.2016***	−0.5773***	−0.6873***	−0.8699***	−1.0973***
		1730–1950	−0.2440***	−0.5335***	−0.6948***	−1.0671***	−1.4098***
	Long	930–1700	0.7029***	0.9668***	1.0362***	1.0688***	1.2166***
		1730–1950	0.0133	0.5743***	0.6859***	0.6567***	0.8718***
Spread			1.5998***	2.4772***	2.1011***	3.0520***	1.8520***
Controls		Long dummy	Yes	Yes	Yes	Yes	Yes
		Issuer dummy	Yes	Yes	Yes	Yes	Yes
		Quarter dummy	Yes	Yes	Yes	Yes	Yes
		Quintiles $T_{Initial}$	Yes	Yes	Yes	Yes	Yes
		Friday dummy	Yes	Yes	Yes	Yes	Yes
		Intraday DAX return	Yes	Yes	Yes	Yes	Yes
Constant			0.1605***	0.1018***	0.0889***	0.0539***	0.1115***
GR^2			15.11	20.86	26.46	27.19	25.52
N			809,724	814,898	813,002	810,786	807,960
Wooldrige's score based test of overidentifying restrictions (*p*-value)			0.0399 (0.8416)	2.0712 (0.1501)	1.2431 (0.2649)	0.6188 (0.4315)	1.9297 (0.1648)
F-test on first stage regression (*p*-value)			6844 (0.0000)	6508 (0.0000)	7302 (0.0000)	6999 (0.0000)	8322 (0.0000)
Wooldrige's score based test for endogeneity (*p*-value)			99.72 (0.0000)	208.82 (0.0000)	171.92 (0.0000)	558.01 (0.0000)	405.37 (0.0000)

Results of regression (19) for absolute markups. A 2SLS approach with instrumented spread is conducted separately on subgroups of quotes formed by quintiles of moneyness at quote, Q-MaQ. As spread instruments are used (i) the average spread over all products of the prior day and (ii) the first difference of the ratio between the spread of the most similar product and the average spread of the same day. Regressors are the relative time to maturity, *rel.TtM*, the order flow measured as extraordinary buy and sell dummies separately for buys and sells and limit and market orders and three parts of the day, the overnight gap risk measured through a Garch(1,1)-forecast of the overnight DAX volatility, the overall jump risk measured via the implicit volatility skew slope separately for long and short certificates and for two parts of the day and the instrumented spread. As controls are used dummies for long leverage certificates, issuers, quarters and Fridays, initial time to maturity, $T_{Initial}$, quintile dummies and the intraday DAX return from time of quote till DAX market closure. Validity is tested via Wooldrige's score test of overidentifying restrictions (Wooldridge, 1995) and an *F*-test for the joint significance of the first stage coefficients of the instruments. Endogeneity is tested via a regression based approach following Hausman (1978) and Wooldrige's score test for endogeneity (Wooldridge, 1995). In the table are only reported the results of the latter though. *N* denotes the number of observations. GR^2 is the generalized criterion proposed by Pesaran and Smith (1994). Significance at the 5% level is indicated with *, at the 1% level with ** and at the 0.1% level with ***. All statistics are estimated using heteroskedasticity robust standard errors (White, 1980).

substantially varying the spread. Instead issuers optimize their profits by setting higher markups.

As the model is set up in a very general manner, it does not focus on a specific certificate class, but is applicable to all kinds of certificates traded on retail exchanges. However, the empirical relevance of the derived hypotheses can be expected to vary among different certificate classes, compared to leverage certificates which we look at in our empirical part. For example, investment certificates such as reverse convertibles and discount certificates with standard underlyings can often easily be hedged as they only include plain vanilla options as derivatives components. Therefore, unhedgeable risk and a respective premium in

the markups should be of minor importance. On the other hand, if the underlying is highly illiquid or more exotic, such as a commodity, or if the certificate includes more complex derivatives components such as a barrier option in the case of bonus certificates or basket options, unhedgeable risk becomes relevant again. Additionally, these investment certificates are much less often traded than short-term leverage certificates, which is why empirically analyzing volume effects is quite a challenge in this case. Moreover, one usually finds much larger time-varying spreads for these certificates compared to leverage certificates, especially for exotic underlyings. This would allow one to test empirically the determinants of the optimal spread that we derive with our model. It would also be interesting in this case to analyze whether there is a negative relationship between markup and spread as predicted by our model.

When judging the empirical size of issuers' markups in the literature, it should be borne in mind that these do not represent the net earnings of the issuers, as they must cover cost components such as hedging and taking unhedgeable risk, and operational and marketing costs. However, given the following key evidence on structured financial products and other certificates, and individual investors, there is an ongoing discussion in many countries regarding whether investors should be better protected from these products, for example by greater (self-) regulation and disclosure. First, the demand for structured financial products can hardly be justified under standard preferences but requires behavioral utility and/or cognitive biases (Breuer and Perst, 2007; Branger and Breuer, 2008; Bernard et al., 2009; Das and Statman, 2013; Hens and Rieger, 2014). Second, investor performance is poor, primarily due to the overpricing (Henderson and Pearson, 2011; Entrop et al., 2012, 2016b; Meyer et al., 2014). Third, investors suffer from product and market complexity in their product selection (Entrop et al., 2016a,b).

In fact, first steps have been made in the direction of greater (self-) regulation and disclosure. For example, in the U.S. in 2012, the SEC advised issuers of exchange-traded structured financial products to disclose fair value estimates side-by-side with the public offering price in the prospectus (see U.S. Securities and Exchange Commission, 2012), which the issuers now do. However, SEC staff is still concerned about product complexity, especially about complex payoff structure and intransparent underlyings such as non-common indices (see Starr, 2015). In late 2013, the German Derivatives Association[43] introduced the "Fairness Code", a voluntary undertaking with respect to structuring, issuing, marketing and trading these products (see Deutscher Derivate Verband). Under these rules, issuers are obliged to state in the prospectus the issuer-estimated value for structured products (not for warrants and leverage certificates) at the point in time the product conditions are determined.[44] The Belgian Financial Services and Markets Authority (FSMA) in turn introduced a voluntary moratorium in 2011 on the distribution of "particularly complex" structured products (see Financial Services and Market Authority, 2011) that most issuers and distributors joined.

The first two initiatives aim at increasing value transparency for each individual product, which can be expected to result in better priced products. However, this effect could certainly be extended by continually and prominently disclosing fair values over a product's lifetime, as a large part is not bought at issuance but later via the exchanges or issuers' trading platforms. The Belgian

initiative in turn is primarily meant to reduce product and market complexity. Its aim is to prevent issuers from exploiting higher economic rents from a larger number of uninformed investors by simply increasing complexity — a phenomenon, for example, analyzed by Carlin (2009) and Kalayci and Potters (2011). However, even if both "regulations" were to be combined, they still might not be sufficient if investors' financial literacy is not increased. On the other hand, merely increasing investors' financial literacy could be outweighed by issuers increasing complexity (see Carlin and Manso, 2011).

In summary, if authorities do hope to protect retail investors from the "dark side of financial innovation" (a phrase used by Henderson and Pearson, 2011, in the case of structured financial products), the most likely means of doing so would be through a combination of increasing value transparency, reducing market and product complexity as well as increasing investors' financial literacy.

Acknowledgements

Appendix A. Optimal spread in special case 2

The optimal spread v^* in special case 2 is given by:

$$v^* = \frac{y}{2z} + \frac{1}{2}\left(A - \sqrt{A^2 - B^3}\right)^{\frac{1}{3}} + \frac{B}{2\left(A - \sqrt{A^2 - B^3}\right)^{\frac{1}{3}}} \tag{A.1}$$

where

$$A = \frac{y^3}{8z^3} - \frac{3xy + w_1 y - 3w_2 y - 3gy^2}{12z^2}$$
$$+ \frac{6xyz + 2w_1 yz + 2w_2 yz - 6gzy^2 - 11y^3}{24z^3}, \tag{A.2}$$

$$B = \frac{y^2}{4z^2} + \frac{6xz + 2w_1 z + 2w_2 z - 6gzy - 11y^2}{18z^2}. \tag{A.3}$$

The optimal spread is mainly determined by the variables g, x (and w_i) and the sensitivities y and z. Obviously, it converges to zero for a large spread sensitivity z. This is natural as, for a given spread, a higher z reduces the demand and, so, the issuer's profit. Therefore, the spread is reduced to stabilize demand. Additionally, it is straightforward to show that the derivatives of v^* with respect to the parameters y, g, etc. become arbitrarily close to zero for sufficiently large z, which is plausible as discussed in Section 2.3.2. For that reason the direct effects of these parameters on the optimal markups via the components 1) to 3) in (10) dominate the indirect effects via the spread.

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[43] The German Derivatives Association (Deutscher Derivate Verband) represents the vast majority of issuers of structured financial products in Germany.

[44] It is quite obvious that such industry self-regulation is meant to forestall impended governmental regulation. Additionally, the issuers of structured financial products had grave concerns regarding their reputation after the collapse of Lehman, an important issuer in Europe until 2008.
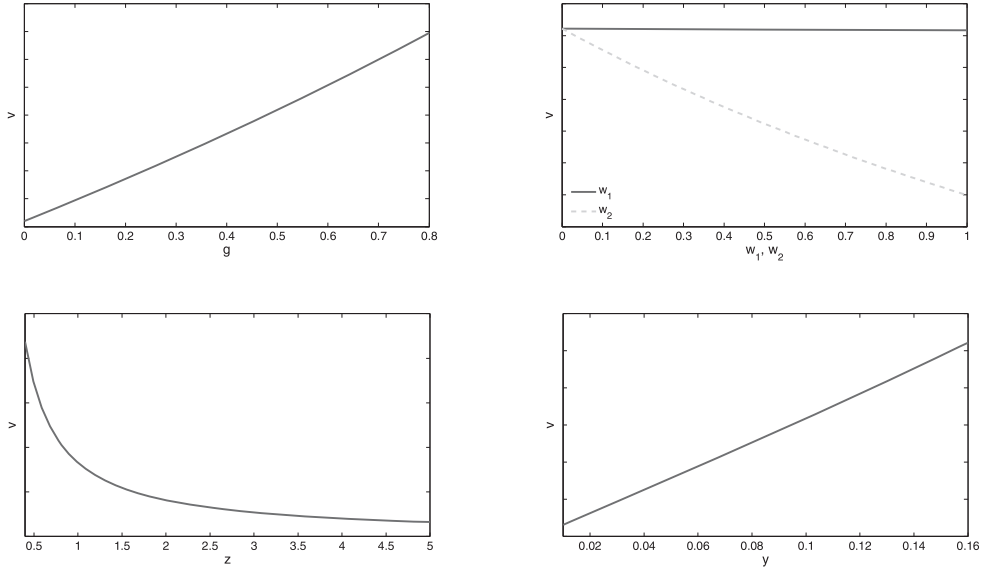
Fig. 5. Comparative statics of the spread v according to the markup and spread sensitivities y and z, the opportunity costs of unhedgeable risk g and exogenous demand shifts w_i. As base values are used $x = 1$, $w_i = 0$, $z = 0.8$, $y = z/5$ and $g = 0.01$.

Due to the complexity of Eq. (A.1), we show comparative statics of key variables in Fig. 5 where parameters are set at realistic values from an economic point of view.[45]

The spread is an increasing function of the unhedgeable risk g. If the issuer faces increasing unhedgeable risk, the spread is widened, which serves to protect the issuer and the bid markup is set smaller with respect to the ask markup. The spread decreases with higher positive demand shifts in t_2 and decreases only modestly with a higher positive demand shift in t_1. A positive demand shift in t_1 increases demand in t_1 and more is demanded. But the issuer has to consider that there is a subsequent period where a higher amount has to be given back. These effects even out nearly completely. If a positive demand shift occurs in t_2, the dealer has not to consider how much of the product is sold back. Hence the spread is decreased to sell a higher amount of the product. The reverse is true for negative demand shifts.

The spread sensitivity z of the demand has an overall negative impact on the spread. If it is high, this has a negative influence on the demand. To offset this effect up to a certain level, the spread is decreased. For very high z the spread converges to zero, as previously mentioned. If the markup sensitivity of the demand, y, is high the spread is increased. The issuer compensates the higher demand sensitivity to the ask markup level and the equivalent lower level of ask markups by an increase in the spread.

Appendix B. Special case 1: holding until maturity

The optimization problem is given by:

$$\max_{\alpha_0,\alpha_1,\alpha_2,v} \pi = (\alpha_0 - g)D_0 + (\alpha_1 - g)D_1 + (\alpha_2 - g)D_2 \quad \text{s.t.} \quad D_i \geqslant 0, v \geqslant 0 \tag{B.1}$$

First order conditions are given by:

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[45] As for the range of the variables, it is assumed that the demand at the fair value x is at a sufficiently high level to guarantee a positive demand. Therefore x is held fixed and only the demand shifts w_i are varied. Also due to the positive demand constraint, the opportunity costs of the unhedgeable risk g and the sensitivity y must be sufficiently small. Moreover, it is reasonable that the ratio $\frac{z}{y}$ is larger than unity. The reason is that, in contrast to the ask markup level, the spread can be observed directly by the investor. Therefore the investor should react more sensitive to the spread than to the ask markup level.

$$\frac{\partial \pi}{\partial \alpha_0} = x - v^2 z - 2\alpha_0 y + gy \overset{!}{=} 0 \tag{B.2}$$

$$\frac{\partial \pi}{\partial \alpha_1} = x + w_1 - v^2 z - 2\alpha_1 y + gy \overset{!}{=} 0 \tag{B.3}$$

$$\frac{\partial \pi}{\partial \alpha_2} = x + w_2 - v^2 z - 2\alpha_2 y + gy \overset{!}{=} 0 \tag{B.4}$$

$$\frac{\partial \pi}{\partial v} = -2vz(\alpha_0 + \alpha_1 + \alpha_2 - 3g) \overset{!}{=} 0 \tag{B.5}$$

These equations can easily be solved. The sufficient second order condition for $\pi(\alpha_0^*, \alpha_1^*, \alpha_2^*, v^*)$ being a local maximum is a negative definite Hessian H_π. The Hessian reads

$$H_\pi(\alpha_0^*, \alpha_1^*, \alpha_2^*, v^*) = \begin{Bmatrix} -2y & 0 & 0 & -2v^*z \\ 0 & -2y & 0 & -2v^*z \\ 0 & 0 & -2y & -2v^*z \\ -2v^*z & -2v^*z & -2v^*z & -2z(a_0^* + a_1^* + a_2^* - 3g) \end{Bmatrix} \tag{B.6}$$

which is always negative definite for the in the model assumed sufficiently large x, which can be derived from Sylvester's criterion based on the leading principal minors.

Appendix C. Special case 2: selling back at the next point in time

The optimization problem is given by:

$$\max_{\alpha_0,\alpha_1,\alpha_2,v} \pi = (\alpha_0 - \alpha_1 + v)D_0 + (\alpha_1 - \alpha_2 + v)D_1 + (\alpha_2 - g)D_2$$

$$\text{s.t.} \quad D_i \geqslant 0, \ v \geqslant 0 \tag{C.1}$$

First order conditions are given by:

$$\frac{\partial \pi}{\partial \alpha_0} = x - v^2 z + y(\alpha_1 - 2\alpha_0 - v) \overset{!}{=} 0 \tag{C.2}$$

$$\frac{\partial \pi}{\partial \alpha_1} = w_1 + y(\alpha_0 + \alpha_2 - 2\alpha_1 - v) \overset{!}{=} 0 \tag{C.3}$$

$$\frac{\partial \pi}{\partial \alpha_2} = w_2 - w_1 + y(\alpha_1 - 2\alpha_2 + g) \overset{!}{=} 0 \tag{C.4}$$

$$\frac{\partial \pi}{\partial v} = 2x + w_1 - \alpha_0 y - \alpha_1 y - 2v^2 z - 2vz(\alpha_0 + 2v - g) \overset{!}{=} 0 \tag{C.5}$$

The Hessian reads:

$$H_\pi(\alpha_0^*, \alpha_1^*, \alpha_2^*, v^*) = \left\{ \begin{array}{cccc} -2y & y & 0 & -y-2v^*z \\ y & -2y & y & -y \\ 0 & y & -2y & 0 \\ -y-2v^*z & -y & 0 & -2z(a_0^*+6v^*-g) \end{array} \right\}$$

(C.6)

which is negative definite if the above solutions hold due to the assumption of x being sufficiently large, which can be derived from Sylvester's criterion based on the leading principal minors.

Appendix D. General case

The optimization problem is given by:

$$\max_{\alpha_0, \alpha_1, \alpha_2, v} \pi_{agg} = (\alpha_0 - \gamma_1(\alpha_1 - v) - (1-\gamma_1)g)D_0 + (\alpha_1 - \gamma_2(\alpha_2 - v))$$
$$- (1-\gamma_2)g)D_1 + (\alpha_2 - g)D_2 \quad \text{s.t.} \quad D_i \geq 0, \ v \geq 0$$

(D.1)

First order conditions are given by:

$$\frac{\partial \pi}{\partial \alpha_0} = x - v^2 z - 2\alpha_0 y + gy + \gamma(\alpha_1 y - vy - gy) \stackrel{!}{=} 0$$

(D.2)

$$\frac{\partial \pi}{\partial \alpha_1} = w_1 - 2\alpha_1 y + \gamma(\alpha_0 y + \alpha_2 y - vy) + (1-\gamma)(x + gy - v^2 z) \stackrel{!}{=} 0$$

(D.3)

$$\frac{\partial \pi}{\partial \alpha_2} = w_2 - 2\alpha_2 y + gy + \gamma(\alpha_1 y - w_1) + (1-\gamma)(x - v^2 z) \stackrel{!}{=} 0$$

(D.4)

$$\frac{\partial \pi}{\partial v} = 2vz(g - \alpha_0) + \gamma(2x + w_1 - \alpha_0 y - \alpha_1 y - 6v^2 z)$$
$$+ 2vz(1-\gamma)(2g - \alpha_1 - \alpha_2) \stackrel{!}{=} 0$$

(D.5)

The Hessian reads:

$$H_\pi(\alpha_0^*, \alpha_1^*, \alpha_2^*, v^*) = \left\{ \begin{array}{cccc} -2y & \gamma y & 0 & -2v^*z - \gamma y \\ \gamma y & -2y & \gamma y & -2v^*z(1-\gamma) - \gamma y \\ 0 & \gamma y & -2y & -2v^*z(1-\gamma) \\ -2v^*z - \gamma y & -2v^*z(1-\gamma) - \gamma y & -2v^*z(1-\gamma) & \begin{array}{c} -12v^*yz - 2z(a_0^* - g) - \\ -2z\gamma(\alpha_0^* - \alpha_2^*) - \\ -2z(1-\gamma)(\alpha_0^* + \alpha_1^* - 2g) \end{array} \end{array} \right\}$$

(D.6)

which is negative definite if the above solutions hold due to the assumption of x being sufficiently large, which can be derived from Sylvester's criterion based on the leading principal minors.

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