Journal of Credit Risk 12(1), 43–74

Risk journals

Research Paper

Market pricing of credit linked notes: the influence of the financial crisis

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(Received October 2, 2014; revised March 11, 2015; accepted October 14, 2015)

ABSTRACT

In Germany, structured financial products already account for 6–8% of all assets invested, proving that the market for these products is still very attractive for retail investors. A question often discussed in this context is whether these products are priced fairly. One of the latest contributions in this field is the paper by Rathgeber and Wang (2011), who analyzed the pricing of credit linked notes (CLNs) in the primary market. In this paper, we significantly extend the work of Rathgeber and Wang (2011) and analyze the effect of the 2007–9 financial crisis on the pricing of CLNs: specifically, on their pricing in the secondary market. Therefore, we analyze the pricing of ninety CLNs covering 13 555 daily quoted prices. In addition to the major finding that CLNs in the secondary market are not only overpriced but also underpriced in many cases, we discover that the overpricing of CLNs significantly decreased after the financial crisis.

Keywords: credit linked notes; market pricing; fair value; financial crisis; product life cycle.

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Print ISSN 1744-6619 | Online ISSN 1755-9723

1 INTRODUCTION

In the last few years, structured financial products have increased in popularity among retail investors. In Germany, they account for 6% to 8% of all invested assets. Even in the United States, structured financial products have an annual growth rate of approximately 30%, although the local market for these products is strongly regulated (Rieger 2012). To put these relative figures into absolute terms, the gross sales of structured retail investment products accounted for €174.2 billion in Europe, US$179.8 billion in the Asia-Pacific market and US$65.1 billion in North America in 2010 (Jørgensen *et al* 2011). One such structured product is the so-called credit linked note (CLN), which allows the issuing bank to securitize its credit risk, particularly concentration risks. As explained in Rathgeber and Wang (2011), the mechanism of CLN is as follows: the buyer of the CLN receives payment for the notes only when the reference entity, another debtor of the CLN issuer, does not go into default. As a premium for taking over the risk, the buyer receives an attractive coupon. In case of the reference entities' default, the buyer receives only the recovery rate of the CLN. Although the figures mentioned above show that CLN contracts are very popular for retail investors, as they provide the opportunity for a high coupon payment, they are the subject of controversial discussions in financial research and the public. Therefore, unsurprisingly, credit default swaps (CDSs), which are similar to CLNs, were voted Europe's "most dangerous financial product" in 2013 (Greens–European Free Alliance 2013). One of the major points of criticism of such structured products is their nontransparency with regard to whether the coupon payments for and the prices of these instruments are fair and adequate compared with the related risk.

Several studies exist on the pricing of equity-linked notes, on certificates in general and the pricing of CLNs in particular. In one of the latest studies on the pricing of CLNs, Rathgeber and Wang (2011) found that they are generally overpriced to a large extent in the primary market, ie, on the date of their issue. This major finding was widely consistent with previous results in the literature. Since issuers of structured financial products are market makers, they participate in almost every transaction and, therefore, have the incentive to overprice. Further, overpricing tends to increase as products become more complex and as markets become less transparent.

As the study by Rathgeber and Wang (2011) primarily focused on the market pricing of CLNs in the primary market, this study aims to apply a similar model to test mispricing of CLNs in the secondary market. Consequently, "mispricing" (the difference between a fair price and a quoted price) does not only imply overpricing but also underpricing of CLNs, as, particularly in the secondary market, quoted CLN prices can fall below the fair value. In our study, in particular, we analyze whether the financial crisis of 2007–9 had an effect on the mispricing of CLNs. The financial crisis revealed the enormous complexity and inherent risks of structured financial products.

Thus, an investor's behavior may have changed from risk loving and only bounded-rational to more reflective (reasoned, among others, in a decrease of information asymmetry between the issuer and the investor), leaving CLN issuers less space for overpricing and inducing a decline in demand for such products. By testing the change in mispricing during the financial crisis, we simultaneously test the validity of the product life cycle hypothesis for CLN, ie, whether mispricing – in the sense of overpricing (which is higher for CLN than for other standard certificates) – decreases during the products' lifetime. Therefore, in a first step, we calculate the daily fair prices of the CLN. In a second step, we compare them with the daily quoted prices and track the daily development of price differences.

The paper is structured as follows. First, we provide an overview of the existing literature regarding the pricing of structured financial products. We then derive our hypotheses and explain the details of the methodology. Next, we explain our valuation framework and describe the widespread data sample used for our analyses, which contains ninety CLN contracts from the German retail market with a total of 13 555 historical quoted prices on a daily basis (2008–12), reflecting a significant extension of the data sample used in Rathgeber and Wang (2011). Based on our methodology and our data sample, we statistically test our hypotheses. In our test, we find statistically significant evidence that the mispricing of CLNs changed during the financial crisis.

2 LITERATURE

According to Fabozzi *et al* (2007), a CLN is a credit derivative that represents a bilateral contract under which the seller sells the credit risk of the reference entity and receives a certain premium from the protection buyer. Regarding the pricing of such credit derivatives, Rathgeber and Wang (2011) pointed out that various studies exist on the mispricing of equity-linked notes. For example, Chen *et al* (1990) and Chen and Sears (1990) were the first to find evidence of the overpricing of these products in the US market. Whereas the former focused on overpricing in the primary market, the latter found the first evidence of decreasing overpricing with decreasing maturity in the secondary market and, thus, for the life cycle hypothesis. Later, these findings regarding the primary and secondary markets were transferred to non-US markets by other studies, such as Wilkens *et al* (2003) or Gruenbichler and Wohlwend (2005).

Baule (2011) provided further evidence for the existence of a product life cycle. He found that for discount certificates on the German DAX index, the investor's demand is driven by tax benefits. Because of the high demand for certificates with a maturity of just over one year, banks anticipate a significant number of net sales and, thus, are able to charge higher premiums than for shorter maturities. According to Henderson and Pearson (2011), some structured financial products are even sold with high average margins, although they have expected negative returns. Stoimenov and Wilkens (2005) provided further evidence for the existence of life cycle effects, as banks are net sellers at the beginning of a product's lifetime and net buyers toward the end in order to increase the bank's margin.

Rathgeber and Wang (2011) provided the first comprehensive study on the mispricing of CLNs. Thereby, they focused on the primary market, in other words, on the pricing of CLNs on their date of issue. The paper provides evidence that CLN products are generally overpriced and further confirms the finding of, for example, Benet *et al* (2006) and Entrop *et al* (2009) that the coupon rate and the complexity of a contract (measured by the number of reference entities, the number of payment days and the coupon structure) have a major influence on mispricing.

To the best of our knowledge, no study is available that has analyzed the pricing of CLNs on the secondary market, as proposed by Rathgeber and Wang (2011) at the end of their paper. By analyzing pricing in the CLN secondary market, we are able to test whether the results for the primary market are transferable to the secondary market. Further, we analyze whether significant differences exist regarding the causes of mispricing in the primary and secondary markets. Moreover, we are able to test the hypothesis of the product life cycle for CLNs.

Of further interest is the question of whether the 2007–9 financial crisis had an effect on the mispricing of CLNs. This consideration is based on the idea that CLN investors often act in a risk-loving manner because they invest in a product that promises attractive coupon payments, even though it may contain a complex and nontransparent risk structure, which investors do not know in detail due to, for example, asymmetric information between the investor and the issuer. Thus, an investor's decisions are often based on biased or incomplete information. Hens and Rieger (2014) used the circumstance of incorrect beliefs (eg, probability misestimations) or behavioral utility functions (eg, prospect theory) to explain the utility gain of structured financial products and, thus, their popularity with retail investors. Breuer *et al* (2009) found evidence for such bounded rational behavior in the case of structured financial products with sports betting components, as their popularity can only be explained by the existence of inhomogeneous expectations and bounded rational, risk-loving investors. This bounded rational behavior may be intensified by very attractive coupons, which investors in structural financial products can receive. Wojtowicz (2014) showed that, for collateralized debt obligations (CDOs) in general, even fair spreads are, due to their conditions, much larger than fair spreads on similarly rated corporate bonds. This is accompanied by a high sensitivity of these instruments in the case of changes in the underlying's default probability. Bounded rational behavior may have ended during the financial crisis when investors became aware of the high risks of structured financial products. For example, tranches for high-yield CDOs were very appealing to investors before the financial crisis because they assumed that ratings represent the actual default risks. Then, this market collapsed during the financial crisis (Wojtowicz

2014). Thus, two effects of the financial crisis on the pricing of CLNs are conceivable. On the one hand, investors may increasingly be faced with the underlying risks of structured financial products (amplified by a stronger regulation) and, hence, consider them in the course of their investment decisions. On the other hand, the demand for such products may decrease. Based on theoretical considerations, both effects lead to a decrease in overpricing.

Hence, our research questions are concretized as follows. Are daily prices of CLN contracts fair and adequate compared with the related risk? If not, what are the reasons for the mispricing, and did the financial crisis have an effect on mispricing? Does an observable product life cycle exist for CLNs?

3 HYPOTHESES

According to Kelly and Ljungqvist (2012), asset prices are strongly driven by asymmetric information. Consequently, asymmetric information may lead to the mispricing of financial assets. For instance, with a focus on the primary market, Myers and Majluf (1984) showed that managers have strong incentives to issue overvalued equity in the case of information asymmetry. Examining the interdependence of mispricing and asymmetric information in more detail, Glosten and Milgrom (1985), among many others, showed that market makers (in terms of security markets) use mispricing (in the sense of overpricing) to compensate for the risk of trading with investors that have superior information. Another aspect contributing to information asymmetry is the complexity of a financial product. Particularly in the case of CLN contracts, it is very difficult for investors to estimate the default probabilities of the underlying assets, which can be interpreted as some kind of information asymmetry, too (Rieger 2012). Additionally, the information asymmetry and the resulting mispricing are amplified by the fact that CLNs are the only major credit derivative products available to retail investors. Thus, no adequate position exists in the retail market, making it difficult to replicate a CLN contract (particularly for multi-reference CLNs) (Rathgeber and Wang 2011).

In addition to the aforementioned general reasons of information asymmetry, in the case of CLNs, we particularly have to deal with information asymmetry in terms of bank lending. This is reasoned in the circumstance that a CLN contract is, at least from the issuer's perspective, a loan (provided to the reference entity). According to Sharpe (1990), "a bank learns more than others about its own customers", eg, about the borrower's characteristics. Consequently, the CLN issuer has a significant information advantage regarding the default probabilities compared with the investor, thus providing the possibility of mispricing the contract. Further, Wittenberg-Moeman (2008) provides evidence that loans issued by institutional investors, ie, loans that are typically issued with long maturities, are associated with higher information costs, thus leading to an increase of information asymmetry.

However, although it may be undisputed that markets for structured financial products show high information asymmetry, there is evidence for a decline of information asymmetry concerning, for example, a specific product (group) in the course of time. For instance, the recent contribution of McLean and Pontiff (2016) shows for the case of stock returns that investors learn about mispricing from academic publications, thus implying that (some) stock market anomalies become less anomalous (and instead more "normal") after being published. Thereby, the fact that the number of academic publications on the pricing of structured financial products has increased over time is undisputed. For instance, when using the search database "ScienceDirect" and searching for journal articles using the search items ("structured product" AND "pricing"), we obtain an increase of more than 68% regarding the number of related articles between 2008 and 2012. Additionally, although more difficult to express in numbers, the public coverage regarding structured financial products such as CLNs has increased in recent years, too. Therefore, coinciding with McLean and Pontiff (2016), we conclude that both academic research and public coverage have contributed to a decrease of information asymmetry. Thus, our major hypothesis is as follows:

Hypothesis H1: mispricing of CLNs in the German retail market decreases over time.

Hypothesis H1 is strongly based on the fact that the pricing of CLNs is influenced by the presence of asymmetric information within the CLN market, and that this information asymmetry generally decreases over time. Now, we want to examine the influence of the financial crisis on the mispricing of CLNs. Here, too, we use information asymmetry as our basic idea and obtain two major influences of the financial crisis. First, referring to the aforementioned development of academic research, we obtain a strong increase during (respectively, after) the financial crisis. Using the same database and search items as above, we obtain 1096 related articles for the forty-six-year period covering 1960 to 2006 and 2219 related articles for the eight-year period covering 2007 to 2015. Obviously, information asymmetry regarding the general understanding for the pricing of structured financial products decreased, thus leaving issuers less space to misprice. The second major influence of the financial crisis on information asymmetry is related to regulation aspects, above all bank regulation and financial regulation. Since the financial crisis, financial markets in general and banks in particular have been more strongly supervised by federal authorities (eg, the Federal Financial Supervisory Authority for the case of Germany). This stronger regulation of financial markets has had an impact on the market for structured financial products, too. For instance, the European Market Infrastructure Regulation (EMIR), which was developed in late 2009 as a response to the financial crisis, and which came into force in August 2012, aims to increase the stability of the over-the-counter (OTC) derivatives market (which also includes CDSs as hedging for CLNs) and includes reporting obligations for OTC derivatives, among others. To conclude, both the increased number of academic contributions after the financial crisis and the stronger regulation of financial markets led to (1) an increase in the transparency of the CLN market and (2) an increase in investors' awareness regarding the complexity of such products.

In addition to these two aspects related to a decrease of information asymmetry and, thus, to a decrease of mispricing, we assume a third aspect: how the financial crisis changed the mispricing of CLNs. During the financial crisis, the demand for structured financial products strongly decreased. For instance, the German securitization market broke down from €68.7 billion in 2006 to €7.7 billion in 2008, implying a decrease of approximately 90% (Schiller *et al* 2009). Similar evidence is provided by Wojtowicz (2014), who showed that during the climax of the financial crisis of 2008, the CDO market collapsed. Even some highly rated CDO tranches lost up to 90% of their value and were classified as "junk". Based on logical considerations, two effects could be reasonable. On the one hand, one might assume that mainly expert traders remained in the market, while (uninformed) retail investors left the market due to the unknown risk exposure. Following Glosten and Milgrom (1985), among many others, a shift toward a market "full of (informed) experts" would imply an increase in overpricing, as the CLN issuer would try to compensate for the risk of insider trading. On the other hand, the strong decrease in demand might have forced the CLN issuer to price the contract more fairly in order to increase demand.

To conclude, as both a decrease and an increase in the mispricing of CLNs due to the financial crisis is conceivable, we expect at least some effect. Thus, our second major hypothesis is as follows:

> Hypothesis H2: mispricing of CLNs in the German retail market changed after the financial crisis of 2007–9.

The hypotheses H1 and H2 are related to the temporal development of CLN mispricing on an aggregated market level, regardless of a specific contract. To extend our analysis, we want to examine the development of the mispricing of a specific CLN contract, depending on its time to maturity. Thereby, the third hypothesis is based on two (closely related) research strands.

First, taking up the already discussed strand of information asymmetry, we argue that the asymmetry of information between the CLN issuer and the CLN investor decreases with decreasing maturity. Sharpe (1990) and Berger *et al* (2005) point out that the lender (and with that the CLN issuer) has a comparative advantage over public markets in gathering information. Consequently, the CLN issuer has an information advantage regarding the reference entities' default risks at the beginning of maturity. We hypothesize that this information advantage disappears with decreasing maturity, which is also in line with Longstaff *et al* (2005), who provide evidence for a lower liquidity, ie, higher information asymmetry, of long maturity bonds, and vice versa. Thus, due to the decreasing information advantage with decreasing maturity, we expect a decrease in mispricing. Rathgeber and Wang (2011) showed that, indirectly associated with the idea of asymmetric information, the complexity of the calculation of a CLN's fair value strictly increases with the number of payment days and with the maturity of a CLN. They outlined that several days may be required to determine the fair value for a (complex) CLN product with long maturity. Consequently, a longer maturity contributes to information asymmetry and with that to higher mispricing.

Second, we take up the idea of the product life cycle. Among others, Chen and Sears (1990), Baule (2011), Henderson and Pearson (2011) and Stoimenov and Wilkens (2005) provided evidence for a product life cycle, concluding that, for multiple reasons already pointed out in Section 2, mispricing decreases with decreasing time to maturity.

Considering both lines of reasoning regarding the time to maturity and its predicted effect on mispricing, our third hypothesis is as follows:

> Hypothesis H3: mispricings become more significant as the time to maturity increases.

In addition to the three aforementioned main hypotheses that refer to the change in mispricing over time, we seek to control for the remaining effects examined by Rathgeber and Wang (2011). We also analyze whether the results from their paper are valid on both the product's day of issue and over its entire lifetime.

First, we adopt the notion that the number of reference entities has an effect on the mispricing of CLN contracts. Rathgeber and Wang (2011) found that the number of reference entities has a significant effect on mispricing. Among others, this finding owes to the fact that the calculation of the fair value for a multiple referenced CLN is very difficult. As Hernández *et al* (2007) showed for equity-linked notes, this nontransparency regarding default probabilities (amplified by the aforementioned problem of asymmetric information) and complexity might lead to the fact that CLN issuers overprice multi-referenced CLN contracts even more than CLN contracts with only a small number of reference entities. This paper seeks to confirm the results of Rathgeber and Wang (2011) using a significantly larger data sample:

> Hypothesis H4: mispricings become more significant as the number of underlying reference entities increases.

Analogous to Rathgeber and Wang (2011), our fifth hypothesis refers to the "first sight effect" of coupon payments, which are comparable to equity-linked bonds (Wallmeier and Diethelm 2009). The notion behind this security is that retail investors often act with bounded rationality: they only recognize a high coupon rate and, thus, the expectation of a high return instead of the hidden factors behind the high coupon rate (eg, underlyings with extremely high risk). Thus, because the size of the coupon rate might influence the attractiveness of and, with that, the demand for CLN contracts, it also affects the significance of the overpricing:

Hypothesis H5: mispricings become more significant with higher coupon rates.

The CLN contracts in our data sample also cover different coupon structures (mixed and variable). As the complexity of a CLN contract increases with increasing variability of payments, we further include the coupon structure (hereafter, coupon type) as an additional control variable. The methodology used to test our hypothesis is presented hereafter.

4 METHODOLOGY

4.1 Valuation of CLNs

Since a CLN can be interpreted as a bond with embedded CDSs, the key to the valuation of a CLN is to duplicate the CLN cashflow with the help of CDS spreads. Hence, in accordance with Rathgeber and Wang (2011), we use the CDS spreads to calculate the implied probabilities of default q. Therefore, we impose the same central assumptions: namely, that the recovery rate of a senior CDS $\mathrm{REC}_{\mathrm{CDS}}$ is given and constant. Further, there are four payment dates of the CDS in one year, each at the end of a quarter, which leads to premium payment days $T_m = \{t_{0.25}, t_{0.5}, t_{0.75}, t_1, \dots, t_m\}$ until maturity in m. In order to achieve probabilities for less than one year, we apply a natural cubic spline interpolation as our smoothing method.

In order to estimate the fair value of a CLN, our first intermediate goal is to estimate the probabilities curve of the implied default probabilities. To do so, based on the aforementioned assumptions, we (1) calculate the expected cashflows $\mathrm{CF}_{1,1}$ in the first payment year of a one-year CDS and (2) solve the resulting equation for the default probability q. The starting point of our calculation is the one-year CDS from the investor's, ie, risk buyer's, point of view. As payments occur at four payment days, these payment days have to be discounted in order to achieve the present value. By doing so, we get (4.1):

$$\mathrm{CF}_{1,1}(1 + r_{0.25})^{-0.25} + \mathrm{CF}_{1,1}(1 - q_{1|4})(1 + r_{0.5})^{-0.5} + \mathrm{CF}_{1,1}(1 - q_{1|4})^2(1 + r_{0.75})^{-0.75} + \mathrm{CF}_{1,1}(1 - q_{1|4})^3(1 + r_1)^{-1} = 0, \quad (4.1)$$

with $\mathrm{CF}_{1,1} = -(1 - \mathrm{REC}_{\mathrm{CDS}})q_{1|4} + 0.25\mathrm{CDS}_1(1 - q_{1|4})$, as one-quarter of the annual CDS spread will be paid on each of the four annual payment days. Thereby, in line with Hull and White (2003), the CDS spread CDS_1 is set in a way that the swap is priced fairly.

Based on the a priori estimated yield curve of spot rates r_t and the CDS spread CDS_1, the quarterly probability of default $q_{1|4} = 1 - \sqrt[4]{1 - q_1}$ for a one-year CDS can be solved by means of (4.1). As a result, we receive the cumulative probability of default for the end of the first year according to (4.2):

$$q_1 = 1 - (1 - q_{1|4})^4. \tag{4.2}$$

As CDS contracts with different maturities share the same underlying reference entity, they should also share the same cumulated probability of default during the same period. Therefore, we adopt the cumulated default probability q_{n-1} for the first year by calculating the quarterly probability of default $q_{n-1|4}$ for a CDS with a maturity of n years. Next, in line with Rathgeber and Wang (2011), we calculate the quarterly probability of default for CDSs with maturities of n years, as long as CDS spreads CDS_n are available. Analogous to (4.1), we receive

$$\sum_{t=1}^{4n-4} \text{CF}_{n,t} \prod_{k=1}^{t-1} (1 - q_{\lceil k/4 \rceil|4})(1 + r_{t/4})^{-t/4} + \sum_{t=4n-3}^{4n} \text{CF}_{n,t} \prod_{k=1}^{t-1} (1 - q_{\lceil k/4 \rceil|4})(1 + r_{t/4})^{-t/4} = 0, \tag{4.3}$$

with

$$\text{CF}_{n,t} = -(1 - \text{REC}_{\text{CDS}}) q_{\lceil t/4 \rceil|4} + 0.25\text{CDS}_n (1 - q_{\lceil t/4 \rceil|4})$$

representing the cashflow of the CDS with a maturity of n years at the payment date t. Further, $\lceil\ \rceil$ represents the ceiling function of Gauss. Equation (4.3) is appropriate to estimate the implied default probabilities $q_{n/4}$, as the right-hand sum has already been calculated by the past $n - 1$ applications of (4.3). Thus, (4.3) has solely to be solved for $q_{n/4}$. The cumulative probability of default is defined recursively as

$$q_n = (1 - (1 - q_{n|4})^4)(1 - q_{n-1}). \tag{4.4}$$

In our case, we receive a cumulative probability of default $q_1, q_2, \dots, q_n$ for the end of each year. Further, it can be stated that $q_0 = 0$, since, due to logical consideration, a default at the date of issue is assumed to be impossible. In a last step, and in line with Rathgeber and Wang (2011), we estimate a continuous curve of cumulated default probabilities by means of eleven data points, which consist of ten implied probabilities at ten different times of maturity as well as the origin that we have already calculated. In line with Press *et al* (2007), we used a natural cubic spline interpolation as our smoothing method. This results in a continuous isotonic function of the cumulative probability of default named $Q(t) = s(q_1, q_2, \dots, q_n)$.

After calculating these probabilities of default, we are able to price the CLN as the expected discounted cashflow under the martingale measure Q (see Jarrow and

Turnbull 1995; Jarrow *et al* 1997). In doing so, the CLN is priced arbitrage free with respect to the CDS market (see, in general, Bielecki and Rutkowski 2002).[1]

Further, because our analyses also included CLNs with multiple references, we consider the asset correlation of the underlying assets. By doing so, we are able to model multiple defaults of the reference entities. A detailed description of the calculation of the default probabilities with multiple reference entities, which extends the aforementioned valuation model by enabling the possibility to handle joint defaults, is provided by Rathgeber and Wang (2011).

Our primary goal is to price a CLN with an annual or semi-annual fixed coupon rate C_f maturing in T_m at a face value of N.[2] The price of issue is P_i. Let the date of issue be T_0 and the following payment dates be $T_1, T_2, \ldots, T_m$. On the basis of the default probabilities curve $Q(t)$ derived above, we can estimate the cumulated probability of default $Q(T_1 - T_0), Q(T_2 - T_0), \ldots, Q(T_n - T_0)$ accordingly on each of these days.

If we impose a certain recovery rate $\mathrm{REC}_{\mathrm{CLN}}$, the value FV_i of the CLN can be expressed as

$$\begin{aligned}\mathrm{FV}_i = \sum_{t=1}^{m} & ((C_f N(T_t - T_{t-1}) + 1^{\mu} N)(1 - Q(T_t - T_0)) \\ & + \mathrm{REC}_{\mathrm{CLN}} N(Q(T_t - T_0) - Q(T_{t-1} - T_0)))(1 + r_{T_t - T_0})^{T_0 - T_t}, \quad (4.5)\end{aligned}$$

where $\mu = \lfloor t/m \rfloor$ is the result of the floor function and $r_{T_t - T_0}$ is the risk-adjusted discount rate. The latter is the sum of the risk-free rate and the credit spread of the issuer.

To calculate the overpricing, we evaluate the difference between the theoretical fair price FV_i and the price of issue in reality. A positive difference indicates overpricing, and vice versa. Further, we can assume the price of issue to be fair and estimate the implicit recovery rate, which fulfills this assumption:

$$\begin{aligned}\mathrm{REC}_{\mathrm{imp}} \\ = \frac{P_i - \sum_{t=1}^{m} (C_f N(T_t - T_{t-1}) + 1^{\mu} N)(1 - Q(T_t - T_0))(1 + r_{T_t - T_0})^{T_0 - T_t}}{\sum_{t=1}^{m} N(Q(T_t - T_0) - Q(T_{t-1} - T_0))(1 + r_{T_t - T_0})^{T_0 - T_t}}. \quad (4.6)\end{aligned}$$

[1] We are aware of the joint-hypothesis problem, implying that the CDS contracts may also be mispriced, and, thus, leading to a biased result regarding the mispricing of CLNs. Nevertheless, following Fama (1991) and most of the studies on capital market efficiency, we ignore this problem in our study.

[2] For a detailed description of the calculation and the specifics of the fair value of CLNs with floating coupon rates, please refer to Rathgeber and Wang (2011), as we proceed analogously.

The relative price difference and the recovery rate REC_{imp} are two major indicators to determine if a CLN product is overpriced. Thus, they will serve as dependent variables in our subsequent test.

4.2 Mispricing of CLNs

Our primary aim is to analyze the mispricing of CLN in not only the primary market, but also the secondary market. Thus, in contrast to Rathgeber and Wang (2011), we analyzed quoted prices of different CLNs not only at one point in time (date of issue), but also across the time axis. Hence, as we obtained data for different clusters i (different CLN contracts) at different points in time t, we had two different analysis dimensions. As this circumstance implies the threat of aggregation biases (Keane and Runkle 1990), we tested our data sample for the existence of panel data. Thus, we were able to analyze the effects of structurally different CLN contracts on CLN mispricing.

To determine whether the data contained fixed or random effects, we tested the panel regressions against an unweighted ordinary least squares (OLS) estimation. For the random effects model, we conducted a Lagrange multiplier test. The central idea of this test is to compare the residuals between the time series for one CLN with the residuals between the time series of different CLNs. For the fixed effects model, we conducted a simple F-test. Therefore, the F-statistic of both regressions are compared. Subsequently, we used the Hausman–Wu test to show that the random effects model dominates the fixed effects model for all cases analyzed in this paper (except for one robustness check). This test analyzes the regression coefficients of the random effects model in relation to the regression coefficients of the fixed effects model and uses the differences in relation to the standard errors as test statistic. Because the Hausman–Wu test showed the existence of random effects within our data sample, we used a random effects panel regression model to test our hypotheses regarding the mispricing of CLNs.

To test our hypothesis, in a first step we operationalize the mispricing of CLNs by means of the contract's implicit recovery rate $REC_{imp,it}$ for a CLN contract i at time t. Thereby, according to (4.6), the implicit recovery rate is calculated by means of the abovementioned multi-borrower Jarrow and Turnbull model, with a given CLN value (in this case, the market price) resolved for the recovery rate. Further, we assumed a recovery rate of 40% for the CDS, which served as the basis for the estimation of the default probabilities. This is because, according to the Standard North American Corporate CDS Converter Specification (ISDA 2009), the recovery rate of a (fair priced) senior CDS is 40%. As the recovery rate of a CLN (during the course of the financial crisis) was only 8.8%, we can assume that the higher the implicit recovery rate is, the more overpriced the CLN contract is.[3] To put it in other words, in the case of an implicit recovery rate of 100%, the CLN contract equals a risk-free investment, which a CLN in fact never is. The corresponding panel regression for the base case is shown in (4.7):

$$\mathrm{REC}_{\mathrm{imp},it} = \alpha_0 + \tau\alpha_1 + \mathrm{MAT}_{it}\alpha_2 + \mathrm{NoR}_i\alpha_3 + \mathrm{CR}_i\alpha_4 + \mathrm{CT}_i\alpha_5 + \upsilon_i + e_{it}, \quad (4.7)$$

with i indexing the different analyzed panels, ie, the different n CLN contracts. The parameter τ is a variable for the ongoing date in years since April 1, 2008, which is the earliest date with a quoted price in our data sample. CR_i is the coupon rate of the CLN and MAT_{it} is the time to maturity in t in relation to the CLNs' total time to maturity. CT_i is the coupon type of the CLN i (with $\mathrm{CT}_i = 0$ for fixed coupon payments and $\mathrm{CT}_i = 1$ for variable coupon payments), and NoR_i is the number of reference entities of the CLN i. υ_i is the CLN random coefficient. Because we have a random effects model, the random coefficient υ_i is a random variable with a fixed mean and variance. Further, to test the influence of the financial crisis, we conducted two random effects panel regressions according to (4.7). The first additional panel regression covered all points of time t with quoted prices during the financial crisis. The second additional panel regression covered all points of time t with quoted prices after the financial crisis.

We further tested the residuals for autocorrelation within the random effects model. Therefore, we used a modified Durbin–Watson test according to Bhargava *et al* (1982) in association with Baltagi *et al* (2003). The test rests on the idea that, in a panel, only autocorrelation between the residuals of the time series (length T) of every single CLN are accounted for. This circumstance reduces the number of observations in the first place. However, the modified DW statistics, as displayed in (4.8), are aggregated in the second step over all N CLNs:

$$\mathrm{DW}_{\mathrm{mod}} = \frac{\sum_{i=1}^{N}\sum_{t=2}^{T}(e_{it} - e_{it-1})^2}{\sum_{i=1}^{N}\sum_{t=1}^{T} e_{it}^2}. \quad (4.8)$$

Due to the special construction of the modified DW statistics, they cannot be analyzed with the critical values used in time series analysis. For the panel case, critical

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[3] Observing empirical recovery rates was possible for the first time during the financial crisis. According to Rathgeber and Wang (2011), four weeks after the bankruptcy of Lehman Brothers, retail investors found that the realized recovery rate for a Lehman-referenced CLN was 8.8%.

values are generated that account for this special setting and the random effects (see Bhargava 1982). To address the identified autocorrelation, we used a Prais–Winsten estimation for the panel data, because this approach does not modify the length of the time series. After one iteration, the residual's autocorrelation was reduced to a sufficient extent. For the test of heteroscedasticity, we conducted a robust Lagrange multiplier test according to Montes-Rojas and Escudero (2010). Following the idea of a Lagrange multiplier test, an auxiliary regression model has to be performed, testing for a homoscedastic covariance matrix. In this way, the test follows the well-known idea of the Breusch–Pagan test. However, due to the fact that we observe differently distributed error terms for different CLNs (random effects model), the homoscedastic covariance matrix (null hypothesis) is constructed in such a way that differently distributed error terms for the different CLN contracts exist in the covariance matrix.

In another test for the influence of the financial crisis on the mispricing of CLNs, we replaced the date parameter τ by a dummy variable for the points of time during the crisis (respectively, after the crisis).

To test the robustness of our results, we tested the panel regressions previously shown in (4.7) with alternating CDS recovery rates (8.8% and 60%) for the estimation of the default probabilities. Further, we tested our results in the case of an estimated asset correlation equal to 0.

Additionally, we repeated the panel regression shown in (4.7) with the relative mispricing ΔCLN_{it} as dependent variable. Thereby, ΔCLN_{it} is calculated using (4.9):

$$\Delta\text{CLN}_{it} = \frac{P_t}{\text{FV}_t} - 1, \tag{4.9}$$

with the relative deviation $(P_t/\text{FV}_t) - 1$ of the market price P_t from the theoretical fair value FV_t of a CLN in t. The corresponding panel regression is shown in (4.10):

$$\Delta\text{CLN}_{it} = \beta_0 + \tau\beta_1 + \text{MAT}_{it}\beta_2 + \text{NoR}_i\beta_3 + \text{CR}_i\beta_4 + \text{CT}_i\beta_5 + v_i + e_{it}. \tag{4.10}$$

For the calculation of the theoretical fair value FV_t, we used recovery rates of 40% and 8.8%, respectively, for both the CLN contracts and the CDSs, which served as the basis for the estimation of the default probabilities. Finally, we repeated the robustness check with a recovery rate of 40% and an estimated asset correlation equal to 0.

The next section presents the data sources for testing the panel regression models.

5 DATA SOURCES

For our analysis, we identified six major German CLN issuers (two issuers more than in the paper of Rathgeber and Wang (2011)):[4]

- Commerzbank AG (analogous to Rathgeber and Wang);
- Deutsche Bank AG (additional issuer);
- DZ Bank AG (analogous to Rathgeber and Wang);
- Landesbank Baden-Württemberg (analogous to Rathgeber and Wang);
- Landesbank Berlin (additional issuer);
- UniCredit Group (analogous to Rathgeber and Wang).

The following data had to be obtained from each CLN contract to meet the requirements of our model:

- payment dates, including the final payment day;
- coupon rate, coupon type and payment structure;
- issue price and issuer;
- underlying reference entities;
- market prices of trading days with positive trading volume.

Except for the different product names given by the specific issuers, all of these CLN products are constructed similarly. They only differ from one another in the following aspects:

- number of reference entities, single or multiple;
- type of reference entities, corporate or national sovereign;
- coupon type, fixed rate or variable rate (floating rate or a mix of fixed and variable);
- payment structure, periodic or only at maturity;
- issue price and final payment at, under or over par.

[4] Analogous to Rathgeber and Wang (2011), we used dummy variables to evaluate possible differences among the credit risk of the issuers.

Altogether, we observed ninety CLN products issued from April 1, 2008 to February 27, 2012, covering 13 555 quoted market prices on a daily basis and correlated to a positive trading volume (we excluded some of the 136 CLN products from Rathgeber and Wang (2011) because the data required for our model was not available). Prices for days that had a trading volume equal to 0 were ex ante excluded and are not part of our 13 555 quoted prices spanning the data sample. The CLN data of the different CLNs were obtained from the individual product descriptions, which were retrieved from the issuers' homepages. The daily market prices and the corresponding trading volumes were retrieved from the European Warrant Exchange Stuttgart (EUWAX).[5] Table 1 on the facing page shows the descriptive statistics on the ninety different CLN contracts used in our analysis. At the same time, the descriptive statistics show that the composition of the data sample used in the paper at hand is comparable to that used by Rathgeber and Wang (2011).

The descriptive statistics (Table 2 on page 61) of the implicit recovery rates of the CLNs show that 4021 of the quoted prices (which is 29.66% of the entire data sample) implied a recovery rate of 40% or higher. In comparison, the recovery rate of a (fair priced) senior CDS is 40%, and the recovery rate of a Lehman-referenced CLN during the financial crisis was only 8.8%. The highest implicit recovery rate in the sample was 163.72%. Besides these rather high implicit recovery rates, we also observed 6041 quoted prices (44.57%), implying negative recovery rates, with the lowest implicit recovery rate being −3115.30%. On average, we observed an implicit recovery rate of −36.98%.

Further, the descriptive statistics regarding the quoted prices of the CLN and the relative mispricing ΔCLN_t calculated using (4.4) and a recovery rate of 8.8% show that none of the quoted prices were priced with their fair values. In fact, 8199 of the quoted prices (which is 60.5% of the entire data sample) showed a deviation between market price and fair value of more than 5%. Only 1396 quoted prices showed a deviation of less than 1% (which is 10.3% of the entire data sample). In total, 6876 (50.73%) of the quoted prices were overpriced, and 6679 (49.27%) of the quoted prices where underpriced. The largest overpricing within the sample was 70.14% (observed for a CLN issued by Commerzbank), and the largest underpricing was 30.76% (observed for a CLN issued by Landesbank Baden-Württemberg). The average relative mispricing ΔCLN_t in absolute terms within the observation period was 9.38%, ie, CLNs were on average 9.38% overpriced. Separated by issuers, Commerzbank, DZ Bank AG and Landesbank Berlin showed the largest average mispricing at more than 10%.

In addition to the CLN data, input parameters are also needed to calculate values in accordance with our model. To discount the estimated cashflows for each date, we needed the risk-free spot rate on a daily basis. The required parameters for the

[5] We gratefully acknowledge the data provided to us by the EUWAX.

TABLE 1 *Descriptive statistics of analyzed CLNs.*

Issuer	Frequency	Date of issue	Frequency	Maturity	Frequency	Number of reference entities	Frequency
Commerzbank AG	20	2006	2	< 1 year	0	1	51
Deutsche Bank AG	21	2007	3	1–3 years	3	2–5	47
DZ Bank AG	26	2008	22	> 3 years	97	6–10	1
Landesbank BW	22	2009	31			> 10	1
Landesbank Berlin	1	2010	22				
UniCredit Group	10	2011	19				

Coupon type	Frequency	Type of references	Frequency	Number of payment days	Frequency	Coupon rate	Frequency
Floating	23	Sovereign	16	1–10	64	< 3	8
Mixed	12	Corporate	84	> 10	36	3–6	78
Fixed	64					> 6	14

All values in percent.

calculation of the spot rates and discount factors were estimated by the German Central Bank using the Svensson method (Svensson 1994).

The CDS spreads of the reference entities were retrieved through Thomson Reuters Datastream, which uses historical data from Credit Market Analysis (CMA) as a source. We used daily quoted closing rates of senior CDSs with maturities from one to ten years, which were available for most of our required reference entities since 2008.

To calculate the joint default probabilities for CLNs with multiple underlying reference entities, we needed their asset correlation. Therefore, for each underlying corporation, we used its daily stock return within the observation period of April 1, 2008 to February 27, 2012 (or shorter, if data was not available for the entire period). As a proxy for the correlations of national sovereigns, we took the major stock index of each underlying country and calculated the daily stock return. Following Rathgeber and Wang (2011), we applied Merton's model, because the credit risk of a sovereign is closely related to its economic development, which is represented by the sovereign's stock index.

6 TESTS AND RESULTS

6.1 Mispricing in the German CLN secondary market: base case

Table 3 on page 62 presents the test results for the entire observation period based on the panel regression model from (4.7).

The parameter values were negative for date and coupon rate. According to the regression model, this result indicates that the implicit recovery rate decreased with an increasing coupon rate (H5) and during the entire observation period (H1). For the maturity (H3), the number of reference entities (H4) and the control variable "coupon type" values were positive. Therefore, according to the regression model, this means that the longer the maturity, the larger the number of reference entities, or the more complex the coupon type, the larger the implicit recovery rate. In all cases except the coupon rate, we observed highly significant results. The explanatory power of the CLN contract panel regression was 0.229.

Further, the Hausman–Wu test statistic reported in Table 3 on page 62 distinctly shows that a random effects model is more appropriate than a fixed effects model. This is unsurprising for several reasons. First, we are inspecting the time series of different CLNs, as different CLNs have different characteristics; this is not accounted for in the regression model according to (4.7), eg, asymmetric information regarding default probabilities between the issuer (respectively, investor) and the reference entities (loan borrowers). Consequently, this leads to different mispricings of different CLNs. At the same time, we expect to observe the same dependence structure on the independent

TABLE 2 Descriptive statistics of quoted market prices, implicit recovery rate (calculated by means of a multi-borrower Jarrow and Turnbull model with the quoted market price as CLN value, resolved for the recovery rate) and the relative mispricing (calculated by means of (4.4)).

	% of quoted prices	Implicit recovery rate					Relative mispricing ΔCLN_t (recovery rate 8.8%)							
		Average	Min	Max	< 0	> 0.4	> 5%	< 1%	Average	Average, absolute value	Med	Min	Max	SD
Overall	13 555	−0.3698	−31.1530	1.6372	6041	4021	8199	1396	−0.0282	0.0938	0.0013	−0.3076	0.7014	0.1340
Issuer 1: Commerzbank AG	2362	−0.1215	−10.6463	1.0853	987	761	1721	122	0.0392	0.1138	0.0128	−0.2401	0.7014	0.1583
Issuer 2: Deutsche Bank AG	12	−0.4498	−1.8454	0.2670	7	0	5	0	−0.0656	0.0702	−0.0190	−0.2274	0.0277	0.0801
Issuer 3: DZ Bank AG	4355	−0.2062	−16.1531	1.6372	1892	1449	2976	330	0.0572	0.1232	0.0054	−0.2821	0.5863	0.1635
Issuer 4: Landesbank Baden-Württemberg	5087	−0.3776	−31.1530	1.0350	2269	1266	2512	762	0.0073	0.0624	0.0009	−0.3076	0.5406	0.0859
Issuer 5: Landesbank Berlin	540	−0.1040	−10.8750	1.3718	112	419	474	7	0.1108	0.1369	0.1373	−0.1462	0.4673	0.1160
Issuer 6: UniCredit Group	1199	−1.5386	−26.4323	1.1863	774	126	510	171	−0.0467	0.0616	−0.0232	−0.2785	0.1034	0.0726

The average relative mispricing in absolute values only takes into account the extent of the relative mispricing, not its sign. Med denotes median. SD denotes standard deviation.

TABLE 3 Results for the panel regression for the entire observation period.

	Entire observation period
α_0	−1.222***
	(−1093.200)
α_1 (τ)	−2.000***
	(−213.400)
α_2 (MAT)	13.993***
	(98.400)
α_3 (NoR)	4.130***
	(822.200)
α_4 (CR)	−191.968
	(−1.300)
α_5 (CT)	17.229***
	(211.800)
Durbin–Watson	0.215
Hausman–Wu	7.804
Adjusted R^2	0.229

Values are for regression coefficients α_0, α_1, α_2, α_3, α_4, α_5, Durbin–Watson test statistic (before Prais–Winsten estimation), Hausman–Wu test statistic and explanatory power R^2 (values in brackets are t-values; ***significance at the 0.1% level; **significance at the 1% level; *significance at the 5% level).

variables, which are stationary in time but at different levels. Interestingly, these levels are not fixed but random instead. The latter can be explained by the fact that these characteristics resulting in different levels are uncorrelated with the independent variables and not constant in time.

To account for dynamic effects, we also tried to estimate a panel regression with yearly effects. However, the CLN specific effects clearly dominated the model. In addition to that, due to the autocorrelation and the applied Prais–Winsten estimation, we estimated the equations in differences, which additionally reduced the potential influences of lagged variables.

6.2 Mispricing during and after the financial crisis

To test hypothesis H2 and, thus, CLN mispricing during and after the financial crisis, our first step was to conduct two further panel regressions: one with CLN data before May 8, 2009 and one after May 8, 2009. This date was selected because the European Central Bank performed the last reduction of the key interest rate with respect to the financial crisis on May 7, 2009. Table 4 on the facing page presents the results of this regression.

TABLE 4 Results for the panel regressions regarding the implicit recovery rate during and after the financial crisis.

	During financial crisis (April 1, 2008–May 7, 2009)	After financial crisis (May 8, 2009–February 27, 2012)
α_0	0.169***	−1.379***
	(53.215)	(−1022.400)
α_1 (τ)	0.030	−2.106***
	(0.068)	(−151.300)
α_2 (MAT)	6.896*	14.073***
	(1.679)	(101.000)
α_3 (NoR)	1.045***	4.610***
	(32.997)	(798.300)
α_4 (CR)	−222.543	−194.226
	(−0.112)	(−1.200)
α_5 (CT)	9.501***	17.691***
	(12.041)	(203.900)
Durbin–Watson	0.149	0.227
Hausman–Wu	0.321	5.044
Adjusted R^2	0.287	0.225

Values are for the regression coefficients $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$, Durbin–Watson test statistic (before Prais–Winsten estimation), Hausman–Wu test statistic and explanatory power R^2 (values in brackets are t-values; ***significance at the 0.1% level; **significance at the 1% level; *significance at the 5% level).

Highly significant results were obtained, particularly after the financial crisis, at least at the 0.1% level, in all cases except for the coupon rate. For the maturity, the number of reference entities and the control variable coupon type, we observed positive values during and after the financial crisis, indicating an increasing implicit recovery rate with an increasing maturity, increasing number of reference entities and increasing complexity of the CLN. We observed negative values for the coupon rate during and after the financial crisis, indicating that in both periods the implicit recovery rate decreased with increasing coupon rate. These findings are in line with the CLN panel regression previously shown in Table 3 on the facing page. The parameter values had different signs during and after the financial crisis only for the date, indicating that the implicit recovery rate increased (statistically not significant) during the financial crisis but decreased (statistically significant) afterwards. The explanatory power during the financial crisis was 0.287 and, thus, higher than in the CLN contract panel regression previously shown in Table 3. After the financial crisis, the explanatory power was 0.225 and was therefore almost on the level of the CLN contract panel regression from Table 3.

TABLE 5 Results for the panel regression with a dummy for the period after the financial crisis.

	Dummy regression
α_0	−1.545***
	−1744.900
α_1 (post-crisis dummy)	−0.343***
	(−639.200)
α_2 (MAT)	15.588***
	(119.700)
α_3 (NoR)	3.998***
	(806.200)
α_4 (CR)	−223.814
	(−1.200)
α_5 (CT)	17.130***
	(208.500)
Durbin–Watson	0.208
Hausman–Wu	3.198
Adjusted R^2	0.224

Values are for the regression coefficients α_0, α_1, α_2, α_3, α_4, α_5, Durbin–Watson test statistic (before Prais–Winsten estimation), Hausman–Wu test statistic and explanatory power R^2 (values in brackets are t-value; ***significance at the 0.1% level; **significance at the 1% level; *significance at the 5% level).

In a second step, we tested whether the mispricing of CLNs was significantly different during and after the financial crisis by conducting a Chow test, according to Chow (1960). The null hypothesis was that the mispricing of CLNs during the financial crisis was equal to the mispricing of CLNs after the financial crisis. The results of the Chow test at a 0.99 confidence level rejected the null hypothesis. Hence, the Chow test is an indicator that the mispricing of CLNs did significantly change through the financial crisis.

Because only thirty-five of the ninety CLNs in our data sample contain quoted prices during the financial crisis (2545 out of 13 555 quoted prices), the Chow test may only be convincing to a limited extent. Thus, our third step involved conducting a further panel regression including a dummy variable for the financial crisis, whereby the dummy was equal to 1 for dates after the financial crisis and 0 otherwise. The date variable had to be excluded, given high autocorrelation with the dummy variable. In this case, we (once again) obtained highly significant results for all variables except the coupon rate. The explanatory power was 0.224.

The financial crisis dummy parameter showed a highly significant negative sign, indicating that the implicit recovery rate decreased to a highly significant extent after the financial crisis. In line with the positive result of the Chow test, this result provides further evidence for the existence of two structurally different regimes: one during the financial crisis and one after the financial crisis. The remaining parameters indicated the same sign as in the CLN panel regression, previously shown in Table 3 on page 62, ie, the implicit recovery rate and, thus, the mispricing of CLNs decreased with an increasing coupon rate but increased with increasing maturity, an increasing number of reference entities and an increasing CLN complexity.

6.3 Robustness check

To check the robustness of these results, we conducted six robustness checks. For three of the robustness checks, we applied the same procedure as previously described with alternative recovery rates of 8.8% and 60% for the CDSs, which served as a basis for the estimation of the default probabilities. (As mentioned above, in the base case, we assumed a CDS recovery rate of 40%.) In another robustness check, we applied the same procedure as previously shown but assumed an asset correlation of 0 (and a CDS recovery rate of 40% analogous to the base case). During the remaining three robustness checks, we repeated the aforementioned regression with the relative mispricing according to (4.4) as dependent variable and different recovery rates (respectively, an asset correlation equal to 0). Table 6 on the next page shows the results for the robustness checks with alternating recovery rates and an asset correlation equal to 0.

Table 6 on the next page shows that almost all of the results of the base case were robust against changes within the assumed recovery rate: regarding the CLN panel regression and the regression with the crisis dummy, all results from the base case were confirmed within these three robustness checks. The results of the base case were also confirmed during and after the financial crisis for an alternating CDS recovery rate of 8.8%. For a recovery rate of 60% as well as an asset correlation equal 0, all parameters were analogous to the base case except for the date variable during the crisis. In both cases, in contrast to the base case, the implicit recovery rate also decreased during the crisis and not only after the crisis. Further, the robustness checks had no impact on the significance of the results from the base case.

Additionally, we repeated the aforementioned regression with the relative mispricing as dependent variable (4.10). Thereby, the relative mispricing was calculated according to (4.9). We further considered different recovery rates of 8.8% (respectively, 40%) for the calculation of the CLN as well as CDS for the estimation of the default probability. In a separate robustness check, we further assumed an asset correlation equal 0. Table 7 on page 68 shows the results of these three robustness checks.

Table 7 on page 68 shows that the robustness checks with the relative mispricing as dependent variable confirms the results of the aforementioned regressions in almost all cases. The two major differences are the reversed signs for the coupon rate and the

TABLE 6 Results for the robustness checks with alternating CDS recovery rates for the estimation of the default probabilities and an asset correlation equal to 0. [Table continues on next page.]

(a) Recovery rate 8.8%

	Entire period	During crisis	After crisis	Dummy regression
α_0	−2.024***	0.071***	−2.247***	−2.563***
	(−1769.4)	(22.892)	(−1626.6)	(−2838.6)
α_1 (τ/post-crisis dummy)	−3.228***	0.276	−3.618***	−0.496***
	(−359.6)	(0.621)	(−268.900)	(−923.4)
α_2 (MAT)	23.443***	7.488*	24.151***	26.198***
	(172.2)	(1.772)	(180.6)	(209.0)
α_3 (NoR)	5.128***	1.174***	5.696***	4.904***
	(1079.5)	(35.944)	(1040.0)	(1046.5)
α_4 (CR)	−255.385	−253.580	−249.029	−305.243
	(−1.3)	(−0.124)	(−1.4)	(−1.5)
α_5 (CT)	23.024***	11.368***	24.227***	22.972***
	(299.4)	(13.939)	(294.7)	(296.0)
Durbin–Watson	0.208	0.147	0.219	0.200
Hausman–Wu	24.988	1.493	15.096	9.172
Adjusted R^2	0.216	0.291	0.211	0.208

(b) Recovery rate 60%

	Entire period	During crisis	After crisis	Dummy regression
α_0	−0.722***	0.217***	−0.842***	−0.913***
	(−686.724)	(66.216)	(−665.247)	(−1085.3)
α_1 (τ/post-crisis dummy)	−1.282***	−0.148	−1.165***	−0.263***
	(−122.472)	(−0.346)	(−76.694)	(−491.6)
α_2 (MAT)	7.946***	6.502*	7.605***	8.850***
	(49.928)	(1.649)	(48.909)	(61.5)
α_3 (NoR)	3.735***	0.975***	4.184***	3.664***
	(643.017)	(32.170)	(630.315)	(636.7)
α_4 (CR)	−163.120*	−203.115	−172.654*	−185.648
	(−1.721)	(−0.107)	(−1.933)	(−1.2)
α_5 (CT)	14.362***	8.388***	14.274***	14.219***
	(152.445)	(11.149)	(142.679)	(148.900)
Durbin–Watson	0.210	0.152	0.224	0.208
Hausman–Wu	2.003	0.135	1.516	1.773
Adjusted R^2	0.230	0.282	0.230	0.229

TABLE 6 Continued.

(c) Asset correlation = 0

	Entire period	During crisis	After crisis	Dummy regression
α_0	−1.171***	0.222***	−1.332***	−1.509***
	(−1056.1)	(72.978)	(−994.916)	(−1715.3)
α_1 (τ/post-crisis dummy)	−2.115***	−0.350	−2.211***	−0.355***
	(−222.3)	(−0.769)	(−157.152)	(−663.3)
α_2 (MAT)	13.764***	5.255	13.922***	15.486***
	(95.3)	(1.194)	(98.582)	(117.3)
α_3 (NoR)	4.343***	1.203***	4.805***	4.202***
	(847.800)	(35.243)	(818.346)	(831.1)
α_4 (CR)	−195.127	−201.182	−196.940**	−229.260*
	(−1.3)	(−0.094)	(−2.488)	(−1.8)
α_5 (CT)	16.972***	9.001***	17.447***	16.869***
	(204.500)	(10.529)	(197.669)	(201.3)
Durbin–Watson	0.215	0.150	0.227	0.208
Hausman–Wu	8.350	0.177	5.602	3.767
Adjusted R^2	0.229	0.251	0.226	0.222

Values are for the regression coefficients α_0, α_1, α_2, α_3, α_4, α_5, Durbin–Watson test statistic (before Prais–Winsten estimation), Hausman–Wu test statistic and explanatory power R^2 (values in brackets are t-values; ***significance at the 0.1% level; **significance at the 1% level; *significance at the 5% level).

maturity: in the case of the coupon rate, we observe positive signs in each case except the relative mispricing during the crisis in the case of a recovery rate of 40%, indicating an increasing mispricing with increasing coupon rate. In the case of maturity, we observed negative signs in each case, indicating an increasing mispricing with decreasing maturity. We further observed smaller explanatory powers than in the base case, especially in the case of a recovery rate of 40%.

6.4 Discussion of results

Overall, consolidating the base case and the robustness checks leads to the conclusion that all of our hypotheses except H5 (regarding the first sight effect) are verified statistically.

Our first hypothesis H1 is based on the idea that CLN markets are characterized by strong information asymmetry, not least due to the fact that banks have a significant information advantage regarding borrower's, ie, reference entity's, characteristics (Sharpe 1990). These information asymmetries and the resulting overpricing of CLN contracts on an overall market level ought to decrease over the course of time due to

TABLE 7 Results for the robustness checks with the relative mispricing as dependent variable, using different recovery rates as well as an asset correlation equal to 0. [Table continues on next page.]

(a) Relative mispricing as dependent variable (recovery rate 8.8%)

	Entire period	During crisis	After crisis	Dummy regression
β_0	0.020***	−0.003	−0.020***	−0.056***
	(12.423)	(−0.744)	(−46.478)	(−121.002)
β_1 (τ/post-crisis dummy)	−0.441	−0.072	−0.411***	0.014***
	(−0.418)	(−0.171)	(−6.298)	(27.212)
β_2 (MAT)	−0.730	−0.374**	−0.356***	−0.118***
	(−1.149)	(−2.670)	(−6.198)	(−6.145)
β_3 (NoR)	0.460***	0.248***	0.747***	0.646***
	(4.329)	(11.251)	(12.577)	(20.193)
β_4 (CR)	19.311	12.065	35.122	21.161
	(0.003)	(0.009)	(0.043)	(0.054)
β_5 (CT)	3.433	1.712***	1.095	1.512**
	(1.345)	(3.601)	(1.126)	(2.768)
Durbin–Watson	0.100	0.196	0.082	0.104
Hausman–Wu	5.916	0.840	4.735	2.548
Adjusted R^2	0.230	0.320	0.094	0.125

(b) Relative mispricing as dependent variable (recovery rate 40%)

	Entire period	During crisis	After crisis	Dummy regression
β_0	−0.089***	−0.069	−0.054***	−0.085***
	(−122.607)	(−13.832)	(−90.531)	(−142.776)
β_1 (τ/post-crisis dummy)	−0.004	−0.277	−0.129***	−0.017***
	(−0.171)	(−0.739)	(−3.128)	(−30.936)
β_2 (MAT)	−0.107***	−0.077	−0.168***	−0.082***
	(−5.674)	(−0.649)	(−5.127)	(−5.835)
β_3 (NoR)	0.358***	0.165***	0.468***	0.368***
	(25.539)	(8.999)	(14.967)	(23.933)
β_4 (CR)	9.422	−3.797	4.836	8.265
	(0.042)	(−0.003)	(0.012)	(0.038)
β_5 (CT)	1.516***	1.491***	1.487**	1.613***
	(6.650)	(3.786)	(2.960)	(6.172)
Durbin–Watson	0.131	0.234	0.109	0.134
Hausman–Wu	2.761	2.166	6.246	1.534
Adjusted R^2	0.154	0.273	0.108	0.154

TABLE 7 Continued.

(c) Relative mispricing as dependent variable (asset correlation = 0)

	Entire period	**During crisis**	**After crisis**	**Dummy regression**
β_0	−0.032***	−0.046***	−0.046***	−0.084***
	(−14.648)	(−9.243)	(−84.260)	(−147.143)
β_1 (τ/post-crisis dummy)	−0.545	−0.392	−0.238***	−0.008***
	(−0.690)	(−1.035)	(−5.173)	(−14.431)
β_2 (MAT)	−0.437	−0.233*	−0.248***	−0.113***
	(−1.088)	(−1.937)	(−6.624)	(−7.476)
β_3 (NoR)	0.375***	0.226***	0.607***	0.505***
	(5.653)	(12.049)	(16.576)	(28.600)
β_4 (CR)	7.531	5.689	10.535	9.103
	(0.002)	(0.005)	(0.021)	(0.038)
β_5 (CT)	2.545*	1.399***	1.551**	1.1635***
	(1.668)	(3.484)	(2.622)	(5.444)
Durbin–Watson	0.124	0.223	0.101	0.127
Hausman–Wu	3.405	1.562	6.727	1.677
Adjusted R^2	0.230	0.291	0.123	0.171

Values are for the regression coefficients β_0, β_1, β_2, β_3, β_4, β_5, Durbin–Watson test statistic (before Prais–Winsten estimation); Hausman–Wu test statistic, and explanatory power R^2 (values in brackets are t-values; ***significance at the 0.1% level; **significance at the 1% level; *significance at the 5% level).

an increasing "body of knowledge". We can confirm H1 during the entire observation period from 2008 to 2012, using the implicit recovery rate as proxy for the extent of mispricing. Accordingly, irrespective of the maturity of single CLN contracts, the overpricing of CLNs decreased in our data sample. This perception coincides with the recent evidence of McLean and Pontiff (2016), who postulate that academic research contributes to decrease market anomalies.

In a second step, hypothesis H2 examined the influence of the 2007–9 financial crisis on the mispricing of CLNs in more detail. In essence, we argued that due to a tremendous increase in the number of research papers dealing with the pricing of structured financial products after 2007, and due to a stronger regulation of the financial market, especially for credit derivatives, information asymmetry within the CLN market declined. We operationalized H2 by separately analyzing the implicit recovery rate (respectively, the mispricing) during and after the financial crisis. In doing so, we observe a statistically significant decrease of mispricing after the financial crisis. In contrast, during the crisis, we observe a (statistically not significant) increase in mispricing. This finding is basically in line with, for example, Wojtowicz (2014), who stated that, as of today, bounded rational investors are increasingly aware of the underlying risks of structured financial products; thus, issuers are no longer able to overprice their products to the same extent as they did before or during the crisis. Hence, although it may also be conceivable that mispricing increased due to the financial crisis because of a shift toward a market full of "informed experts", we obtain the result that we ex ante consider to be logical. Moreover, our finding regarding the effect of the financial crisis is robust as both a Chow test and a further regression with a dummy variable for the time after the financial crisis confirm the result that mispricing decreased to a significant extent after the financial crisis. This provides evidence for a structural break due to the crisis.

The third key hypothesis in our study, H3, examined the pricing of CLNs not on an aggregated market level but on a contract level instead. In particular, we analyzed whether the mispricing is correlated to the time to maturity. We confirm H3 for the entire observation period from 2008 to 2012 as well as in the cases of two identified regimes (during and after the crisis). In all cases, we observed an increase in overpricing with decreasing maturity. This result strengthens the assumption that information asymmetry between the issuer and the investor decreases with decreasing time to maturity, which is basically in line with Longstaff *et al* (2005). Further, this result is in line with the findings of, for example, Chen and Sears (1990), Stoimenov and Wilkens (2005) or Baule (2011), thus providing evidence for the existence of a product life cycle. Our results not only confirm existing contributions in this field of research but also put them on a broader basis, as the data sample for this paper covers many more data points (13 555) and a longer period (eg, Baule (2011) only analyzed the period from November 2006 to December 2007). As a restriction, we have to point out that in the case of relative mispricing as the dependent variable, we observed an inverse product life cycle with an increase in mispricing with decreasing maturity.

Regarding the complexity of CLN products (which in turn also contributes to information asymmetry), we confirm hypothesis H4: the overpricing increases with an increasing number of reference entities. The same result is observed for the control variable coupon type, ie, the complexity of the coupon structure. Thus, the two cases confirm the findings of Rathgeber and Wang (2011).

Surprisingly, Hypothesis H5 regarding the first sight effect has to be rejected in almost all of our tests (except the robustness checks with the relative mispricing as the dependent variable). We hypothesized that the overpricing increases with higher coupons. In fact, our finding contrasts the findings of Rathgeber and Wang (2011) and Wallmeier and Diethelm (2009). One reason for this contradictory and unpredicted result may be the aforementioned higher awareness of investors of the high underlying risks of structured financial products after the financial crisis, which is amplified by the high number of academic and public coverage. Thus, a high coupon might no longer induce a positive first sight effect but rather put the investor on alert for the inherent risk structure.

To summarize, our results provide evidence that the CLN market generally shows a decrease in overpricing over the course of time. In particular, the overpricing of CLN during and after the financial crisis changed significantly, to the effect that the overpricing decreased to a more significant extent after the crisis, which is in line with our expectations based on existing literature. Another interesting contribution to the literature is the fact that Rathgeber and Wang (2011) only observed overpricing on the date of issue. We have now identified that the majority of the 13 555 quoted prices were actually underpriced instead of overpriced, showing (highly) negative implied recovery rates.

7 CONCLUSION AND OUTLOOK

The market for structured financial products has grown in the past few years. Hence, a significant number of studies have analyzed the pricing of these products. This paper significantly extended the contribution of Rathgeber and Wang (2011): we analyzed whether CLN contracts are priced with their fair value not only on their date of issue but also during their life cycle. Thereby, our analysis was based on a widespread data sample covering 13 555 daily quoted prices of ninety CLN contracts from five major issuers in the German market. This is also a significant extension of Rathgeber and Wang (2011). Analogous to Rathgeber and Wang (2011), we applied a market-based valuation model for the calculation of the fair value of CLNs. This approach is based on the reduced model by Jarrow and Turnbull (1995) and Jarrow *et al* (1997), extended by the single-factor Merton model to estimate the joint default probabilities by means of asset correlations. For the derivation of the default probabilities, we used the CDS spreads of the underlying entities.

One of the major findings of this paper is that CLNs are not only overpriced in the secondary market but also often underpriced to a large extent. This result is rather surprising in view of the fact that Rathgeber and Wang (2011) only observed overpriced CLN products on their issue date. Further, we discovered that overpricing CLNs significantly decreased after the 2007–9 financial crisis due to a decrease in information asymmetry, although CLN markets are gradually recovering, and demand for structured products is still high. This result is also robust for changes in recovery rates or correlation coefficients. The theory of the product life cycle, ie, decreasing overpricing with decreasing maturity, was confirmed as well as the positive correlation between the complexity of the CLN product and the mispricing. The latter finding not only confirms but also strengthens the corresponding finding of Rathgeber and Wang (2011) because of the extended and widespread data sample used in this paper. Surprisingly, the common theory of the first sight effect, ie, an investor's focus on a high coupon rate in expectation of a high return instead of the hidden factors behind the high coupon rate, had to be rejected.

Based on the results of our paper, a few possibilities exist to extend our work. Although our data sample is quite large, with 13 555 quoted prices, it does not begin until April 2008. Thus, the data sample contains data during the financial crisis and after the financial crisis, but not prior to the financial crisis. By extending the data sample with data prior to the financial crisis, we would also be able to analyze CLN mispricing before the crisis. Moreover, the change in interest rates is modeled more specifically to more accurately calculate fair prices for CLNs with floating coupon payments. Further, the valuation framework may be used for CLN products issued on CLN markets other than the German market to test whether these hypotheses are universally valid.

DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the writing of this work.

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