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Abstract

In this paper we investigate the influence of coupon structure on the financial behavior of Individual Investors in the fixed-income market. Examining circa 26 million decisions on 204 standard putable bonds with different coupon offerings our major findings are: (i) Products with a flat coupon structure and a high duration attract fewer investors and are significantly more often exercised early, whereas financially equal products with a steeply rising coupon structure arouse more interest among investors and are less often redeemed early. (ii) The shape of the upcoming coupon structure is an important basis on which investors decide which putable bond in a portfolio to exercise early. (iii) Issuers who exploit empirical patterns related to a bond's coupon structure through "behavioral financial engineering" can benefit from a lower liquidity demand and a diminishing empirical option value.

Keywords: Individual Investors; product design; putable bond

JEL classification: G02, G11

1 Introduction

The influence of psychological factors on investors' trading and exercise decisions is attracting more and more attention in those researching market phenomena and investigating Individual Investors' financial behavior (e.g., Odean, 1998; Barber and Odean, 2011). Such psychological arguments imply that investors behave differently than ways that are assumed in standard models and that they do not act fully rationally according to theory. The literature commonly refers to this as the "cognitive biases" or "behavioral biases" of investors (see, e.g., Thaler, 2005). Prominent biases in the literature comprise among others overconfidence (e.g., Odean, 1998), mental accounting (e.g., Thaler, 1985), representativeness (e.g., Kahneman and Tversky, 1979; Shefrin and Statman, 1994) and inconsistent time preferences (e.g., Loewenstein and Prelec, 1992).[1]

While most of the mentioned concepts have been empirically researched for several investor classes and investment forms, few studies have explicitly investigated how the product design itself influences decision-making, that is how investors' decisions depend on, e.g., a product's duration, its coupon structure or the timing of coupon payments. For instance, most recent studies on exercise decisions in equity derivatives (see, e.g., Poteshman and Serbin, 2003; Pool et al., 2008; Barraclough and Whaley, 2012) do not incorporate the product structure as a dependent variable. Hence, the motivation of this paper is to extend the current behavioral finance literature by examining how the different coupon designs of putable bonds affect the decision-making of Individual Investors. Our results are of particular interest to the wide range of issuers and intermediaries who deal with fixed-income derivatives for Individual Investors, as our analyses suggest that proficient "behavioral financial engineering", i.e. optimizing and adapting the coupon structures of newly issued bonds, can lead to a higher demand and can

[1] A comprehensive overview of behavioral biases can be found in Hirshleifer (2001) and—with a focus on Individual Investors—in De Bondt (1998).

imply financial benefits for the issuer.

Several papers on investors' behavior in structured products have argued that the product structure influences investment and exercise decisions. As one of the first Hersh and Statman (1993) discuss behavioral aspects in relation to the product design and find that the attractiveness of products varies due to a different framing of cash flows by investors. More recently, Branger and Breuer (2007) derive an optimal demand for retail derivatives and argue that not only the product type but also the contract structure is of importance. Similarly, Hens and Rieger (2009) demonstrate that complicated payoff structures lead to mis-estimations by investors resulting in extra margins for banks. Changing sides, Bernard et al. (2007) develop a theoretical framework for optimally designing structured products from an issuer's perspective. They argue that products with capital protection are advantageous for issuers. Additionally, in an analysis of the optimal product design for specific discount certificates, Breuer and Perst (2007) find that issuers should prefer large stocks as underlying and aim at less competent customers to maximize profit.

However, empirical research following these mainly theoretical works is—as noted—scarce. A remarkable exception is the paper of Henderson and Pearson (2007), who examine patterns in the payoffs of publicly traded structured equity derivatives and show that investors tend to demand concave payoffs for products linked to stocks and convex payoff profiles for index products. In this paper we investigate a similar question, but focus on the fixed-income market. We analyze how the coupon structure of German governmental non-tradable putable bonds influences Individual Investors' investment, exercise and portfolio decisions and examine the financial implications of different coupon offerings. In particular, we are interested in the potential benefits to issuers who exploit empirical exercise patterns related to the coupon design of fixed-income products.

Our analyses build on first findings in the studies of Eickholt et al. (2014a) and Eickholt et al. (2014b) regarding Individual Investors' behavior in putable bonds, which provide first indications that the product structure influences the probability of an early exercise. In this paper, we analyze a data set similar to that in the study of Eickholt et al. (2014b), but focus solely on empirical patterns related to the coupon structure. Our data set comprises, over a sample period of almost 13 years, circa 26 million financial decisions by Individual Investors to acquire, hold or exercise early German Federal Saving Notes (GFSN). GFSN are putable government bonds, which are very well suited for our study since they have a simple and stable structure which does not change during the whole observation period, are consistently issued every few weeks or months, cannot be traded and—most interestingly—because their coupon offerings differ steadily over time. This means that we are able to conduct consistent analyses of investors' behavior for a wide range of putable bonds with different degrees of steepness, kurtosis and levels of coupon structure.

Our main findings are threefold: first, the coupon structure influences the attractiveness of an investment ("*investment decision*"). Products with a steeply rising coupon structure and a low duration, i.e. with a short weighted average time until cash flows are paid out, attract more investors and higher overall volumes. Second, controlling for environmental changes and exogenous influences, we observe that such products are also less frequently exercised early ("*exercise decision*"), which is in line with the findings of Eickholt et al. (2014b). This implies that the average Individual Investor values bonds which promise a high final coupon in the future more highly than financially fully equivalent bonds, i.e. GFSN with the same maturity and the same financial fair value, that offer steady yearly coupons but a lower final coupon payment. Our results are robust for different time sub-samples, valuation scenarios and investor subgroups. For instance, we notice that the preference for steeper coupon structures is independent of an investor's financial sophistication or experience. Investors who very frequently invest and exercise show exercise biases similar to those of investors who invest only once.

Third, the coupon structure is also an important basis on which investors decide which bond in a portfolio of several GFSN to exercise early ("*portfolio decision*"). Consistent with our previous results, we find that the exercise probability is higher for portfolio items with a low valuation, a comparatively flat coupon structure and a high duration. A comparison of different investor groups shows again that these empirical patterns are robust and appear for almost all subsamples. Overall, we attribute the diverging decisions related to the coupon structure here and in our first analysis to a cognitive and behavioral bias of Individual Investors. Apparently, products with a higher final coupon are (irrationally) perceived as more attractive and more valuable.

Finally, we discuss which kind of coupon structure is most promising for an issuer. For this, we run several scenario analyses and examine exemplary coupon designs and interest rate environments for the difference between the financial fair value at issuance and the "empirical value". We estimate these based on the empirically observed exercise behavior of Individual Investors in our sample. Moreover, we use Monte-Carlo simulations to estimate the average empirical and theoretically optimal exercise frequency. The results suggest that issuers who exploit empirical exercise patterns related to the coupon structure can benefit in two ways. First, issuers might reduce their liquidity reserves for bonds with a steeply ascending coupon structure as the early exercise volume tends to decrease, due (among other reasons) to a preference of Individual Investors to continue holding this kind of bond. Additionally, such a lower exercise probability results in an advantage to the issuer at times when an exercise is theoretically reasonable. Second, our simulations indicate that the difference between the empirical value and the fair value widens in the case of flat or concave coupon structures, which is mainly due to the higher theoretical value placed by Individual Investors on the early exercise right for these products—a right however that they only exploit to a small extent. Obviously, such a poor utilization of a highly valuable option provides a financial advantage to issuers. Following, our main conclusion in this paper is that there is some potential for the issuers of structured fixed-income products that target Individual Investors to increase their financial benefit through proficient "behavioral financial engineering", i.e. by offering product structures designed to fit their needs.

The remainder of this paper is organized as follows. Section 2 introduces our data set. Section 3 investigates what impact upcoming coupon structure and product duration have on Individual Investors' investment (Section 3.2), on exercise (Section 3.3) and on portfolio decisions (Section 3.4). In Section 4 we investigate what kind of coupon structures can be advantageous for issuers. Section 5 concludes.

2 Data

This paper aims to study the influence of different coupon structures of putable bonds on the financial behavior of Individual Investors. For this analysis we are able to utilize a unique and very detailed data set from the German Finance Agency ("Bundesrepublik Deutschland Finanzagentur GmbH")[2] that covers all investment, holding and exercise decisions of 223,117 Individual Investors in German Federal Saving Notes ("Bundesschatzbriefe", GFSN in the following), that were booked through the German Finance Agency between July 1996 and February 2009.[3]

GFSN are basically standard putable bonds issued by the German government, which are very well suited for our study for following reasons. First, GFSN have a standardized and simple product structure but differ over time regarding their coupon offerings, i.e. the steepness,

[2]The German Finance Agency is a state-owned central service agency for Germany's governmental borrowing.

[3]This data set is a randomly drawn subset that covers the transactions of circa 25% of the accounts at the German Finance Agency. Further on, we reduce the level of detail from daily to monthly observations.

kurtosis and extent of coupons vary with every new issuance. Second, new GFSN are issued every few weeks or months—whereby the former issuance is closed—after significant changes in the market interest rates, which gives us a large sample panel of investors and products. Third, commissions or transaction fees are negligible for GFSN. Fourth, GFSN are sold exclusively to Individual Investors[4] and cannot be traded on a secondary market. This restriction allows us to observe the influence of different coupon designs on investors' exercise behavior more comprehensively than in the case of products that are publicly traded and where a sale to a third party is always an alternative to early exercising. Finally, GFSN issuances have a minimum nominal value of only €50 and regularly attract a high number of Individual Investors in Germany. Even for the single least popular GFSN in our data set, we find transactions of more than 4,000 individual accounts in the German Finance Agency's debt register, which ensures some robustness of our results to, e.g., outliers.

2.1 Product statistics

Two types of GFSN (Type A and Type B) are offered at each issuance date. A Type A GFSN is a step-up bond with a maturity of 6 years that pays a yearly rising coupon. Type B products also offer yearly rising coupons over a maturity of 7 years but are issued in a zero-bond structure and pay the nominal value plus coupons and accrued interest at maturity. In addition, both Type A and Type B GFSN contain an early exercise right that gives an investor the right to redeem early his investment plus accrued interests at any point in time after the initial one-year blocking period. There are no charges for exercising early.

Investors can acquire the current issuance of a GFSN at nominal value plus accrued interest directly from the German Finance Agency via telephone or postal order or indirectly at banks.

[4]Additionally, resident institutions serving public benefit, charitable or religious purposes may also invest in GFSN. We ignore these investors in the following, as they account only for a very small share of overall investments.

Banks, however, typically charge custody fees for GFSN that are held with them, whereas the German Finance Agency offers cost-free accounts for all Individual Investors, so that a direct acquisition is in general financially more advantageous for investors. Still, investors can shift their investments between banks and the German Finance Agency at any time without fees.

Our data set comprises transactions for all 204 issued GFSN in the sample period from 1996 to 2009. Table 1 shows summary statistics on the issuances and provides an overview of the offered coupon structures over time. For comparison, we also calculate the difference between the yearly coupons and the respective spot rate at issuance.

[Table 1 about here.]

As noted above, the statistics show that the offered coupons of issued GFSN vary significantly over time with a standard deviation of about 0.8% for each year of maturity. Thus for instance, the coupons for the first year range from 1.500% (5th percentile) to 4.000% (95th percentile), with a mean payment of 2.745% and with a standard deviation of 0.812%. Similarly, we observe a wide range of offered coupons at maturity, from 3.750% (5th percentile) to 7.000% (95th percentile) for Type A GFSN (4.000% to 7.000% for Type B). Typically, the first three coupon payments of a GFSN lie below the spot rates and rise thereafter above the market rates, which indicates an non-linearly increasing coupon structure.

Going further, Table 1 provides also some consolidated information on the shape of the coupon structure at issuance. As a first proxy we compute the steepness of the coupon structure, defined as the difference between the coupon in the sixth (Type A) or seventh year (Type B) and the first year coupon. We find again a remarkable variance among the issued GFSN with an average difference of 0.02076 (0.02199), which corresponds to a relative increase of 92.061% (98.581%). There are also some products with almost flat coupon structures, where the difference between the first and last coupon amounts to only 0.00750 (0.00750) and 18.750% (18.750%)

respectively in relative terms. In contrast, this difference reaches 0.04000 (0.04250) for GFSN with the steepest rising coupon offerings.

As a second proxy for the shape of the coupon structure we calculate for Type A GFSN the Fisher-Weil duration (see Fisher and Weil, 1971) based on the coupon offerings and spot rates at issuance, whereby we focus on the duration of the bond component and omit the option right. For Type B GFSN, the duration always equals maturity due to the zero-bond structure, hence we do not further analyze the values for this product type at this stage. In general, we interpret the duration as the weighted average time until all payouts (coupons and nominal value) have been made to the investor. The statistics reveal that the average value over all bonds is circa 5.539 years. The 5th percentile is 5.403 years for a bond with a comparatively flat coupon structure, whereas the longest (95th percentile) weighted average time until payout lies closer to the respective bond's maturity at 5.712 years.

2.2 Investor statistics

Our data set contains circa 31 million decisions by 223,017 Individual Investors to acquire, hold or exercise early one of the above-mentioned 204 GFSN on an individual account and monthly basis. However, we exclude in our following analyses all decisions in the last year of a product's maturity, as we suspect that at this time investors' decision criteria on holding or exercising a GFSN differ from the criteria for products with a longer remaining lifetime.[5] For example, the question of coupon structure is presumably negligible if the product matures in one month, whereas coupon structure is probably more important if the investment is still bound for several years. This leaves us with circa 26 million decisions, which is—compared to most studies on Individual Investors' behavior in equity derivatives such as Bauer et al. (2009),

[5] In addition, we exclude accounts with an average transaction volume below €300 since for such small volumes the early exercise right seems to be of comparatively low importance.

Schmitz and Weber (2012) or Liao et al. (2013)—still a comparatively large sample. Table 2 provides summary statistics on the selected investor base and on their activities in GFSN.

[Table 2 about here.]

Overall, we note that the investor base in GFSN is quite heterogeneous. Male (33.47% for Type A, 38.41% for Type B GFSN) and female (38.36%, 38.00%) investors of any age invest in GFSN (we have no information for the remaining share of investors). The average investor is 44.09 years (31.15 years) old. Further, the data shows that about 4.15% (3.50%) of investors hold a doctoral degree or professorship. Regarding the distribution channel, we note that Individual Investors slightly prefer to acquire GFSN at a bank and to transfer their accounts later to the German Finance Agency (59.18%, 54.01%). A smaller proportion (40.82%, 45.99%) chooses the direct distribution channel.

Looking at the financial statistics, we find that a large share of the investor base invests only rarely, i.e. has a low investment frequency. Obviously, this is due to the restriction of our sample to Individual Investors, who are typically less active in financial markets than professional investors or funds. An investor in our sample acquires on average only 3.147 (2.790) GFSN throughout the whole observation period of almost 13 years. Similarly, the mean investment volume is small, with circa €8,818 (€5,085). Nevertheless, Individual Investors make regular use of the exercise option. Almost every second investor redeems an investment early at least once before maturity, which totals overall circa 82,787 (47,900) early exercise decisions in our data set. A separate analysis—not reported here—shows that these early exercises occur for all GFSN in our sample, the share of investments exercise early per GFSN ranging from 9% to 52% (13% to 48%).[6]

[6]For comparability, we consider in this analysis only GFSN that mature before the end of our sample period.

We note only a few differences in the average investment behavior of the presented investor subgroups (see Table 2), which we mainly attribute to personal characteristics or environmental circumstances. For instance, the results reveal that older investors and investors holding a doctoral degree put higher volumes in GFSN, which is presumably due to greater personal wealth. In addition, investors who prefer to invest in GFSN via direct distribution show greater investment activity than Individual Investors, who mainly invest through banks, which might be due, for example, to a generally more conservative strategy of indirect investors. A third example is the lower (absolute and relative) exercise activity of female investors. This pattern seems to be an analogy to Individual Investors' behavior on the equity market, where the increased trading activity of men is typically ascribed to a higher confidence of male investors in their financial competency (see, e.g., Barber and Odean, 2001).

3 Influence of coupon structure on investors' decisions

3.1 Variables

Based on the described data set, this section investigates how the coupon structure of a GFSN influences an investor's investment, exercise and portfolio decisions. For this, we introduce two variables that—similar to our previous analysis in Table 1—describe the shape of the coupon structure at issuance and then at each later point in time.[7] First, we measure the relative steepness of the upcoming coupon structure (UPSTEEP), defined as the average linear increase in coupon payments until maturity:

$$UPSTEEP_t = \frac{C_T - C_t}{T - t}, \tag{1}$$

[7] This variable definition is in line with the study of Eickholt et al. (2014b).

where C is the coupon payment for the current year, t is the time index and T stands for the last year of maturity. As the second variable we use the Fisher-Weil duration (see Fisher and Weil, 1971) of the bond component (DURATION). As noted before, we ignore the value of the option in this calculation. In general, this duration value consolidates both information on the steepness and kurtosis of the underlying coupon structure. Still, it might also be interpreted as the sensitivity of the respective bond against interest curve shifts, or as the weighted average time of a GFSN until all coupons and the nominal value are paid back. In this paper we will typically refer to the latter interpretation.

We then take into account that besides the coupon structure, the current valuation of a GFSN might play an important role in investors' early exercise decision. To consider the economic benefit of exercising a GFSN, we calculate the following PVEV-ratio for each point in time:

$$PVEV_t = \frac{PV_t}{EV_t}, \tag{2}$$

where PV stands for the present value and EV for the exercise value which is paid immediately by the issuer if an investor makes use of his early exercise right. According to theory, an early exercise is only economically rational for an investor if this PVEV-ratio equals 1. In all other cases, it is optimal to keep holding the GFSN since the expected discounted value of all upcoming payments (continuation value) exceeds the amount of the exercise payment.

The calculation of the exercise value for our sample products is straightforward, as it simply equals the notional value plus accrued or compounded interests for the respective GFSN. However, determining the present value proves to be more complicated due to the early exercise right that is granted to an investor. For this valuation we first apply an essentially affine interest rate model $\mathrm{EA}_1(3)$ on a weekly basis (see Dai and Singleton, 2000) to model the dynamics of the interest rates (the parameterization and further explanations are outlined in Eickholt et al., 2014a). Following this, we estimate the value of the early exercise right via Monte-Carlo simulations with 10,000 paths using Euler discretization on a monthly basis, i.e. with a step width of $\Delta = 1/12$. To determine the continuation values in the simulation we utilize the least-square regression approach as proposed by Longstaff and Schwartz (2001), with the first four monomials as basis function.

3.2 Investment decision

Our first analysis investigates the influence of the product structure on the attractiveness of a newly issued GFSN ("*investment decision*"). We measure the attractiveness by the number of investors and the volume of overall investments.[8] As GFSN are issued in a standard structure every few weeks or months with varying coupon offerings, we do not have to account in this analysis for, e.g., new product features, underlying characteristics or diverging credit ratings. Yet, a major assumption in our analysis is that the share of investments booked in the German Finance Agency's debt register account (in contrast to investments held at banks) remains constant for all GFSN in our sample. This means we assume a comparatively stable distribution between direct and indirect investments in GFSN over time.

Moreover, we control in our analysis for several potential environmental influence factors. First, we incorporate the time (quarter of the year) of an issuance, the value of the bond component (BOND) and the value of the option component (OPTION) of the respective GFSN. Splitting the overall value of a GFSN here into two parts allows us to investigate the influence of both factors independently. This can be helpful, for example, in determining the influence of the bond value on decisions of investors with a lower financial literacy, who might not be able to evaluate the value of the early exercise right appropriately. Next, we consider the long-term trend and the overall demand for governmental fixed-income products at the time of issuance.

[8] We also test the logarithm of the volume as independent variable, which leads to similar results.

As proxy for the latter we define the variables LAST6INV, that consolidates the number of all investors in the last six issuances of the respective GFSN type, and LAST6VOL, which comprises the cumulated investment volume of all these investors. In some further analyses—not reported here—we substitute these trend variables by yearly dummies to control for further timing and trend influences but find few differences in the results, for which reason we decided to proceed with the described variables LAST6INV and LAST6VOL.

Table 3 shows the results of a regression of an issuance's attractiveness on the coupon structure and the control variables. As noted, we refer to the number of investors (left part) and the overall volume (right part) as indicators of attractiveness. Robust standard errors (see Huber, 1967; White, 1980, 1982) are used in this and all upcoming regression analyses.

[Table 3 about here.]

The regressions explain in all four models around 50% of the response variable variation. Focusing on the estimated coefficients, we note at first that a high valuation of a newly issued GFSN elicits a stronger interest among investors. Both the bond component and the option value have positive loadings (however, these are not statistically significant for the bond variable) indicating that they are positively correlated to the attractiveness of an issuance, which seems very reasonable. In fact, the high elasticities of these variables suggest that the economic value is an important determinant for investors in deciding on new investments. We then observe some time effects in the regression. There seems to be a higher investment demand in the first quarter of the year which diminishes over the year as expressed by the negative coefficients for the variables Q2 to Q4.

Most interesting for our study, the regressions reveal that the coupon structure has a statistically significant influence on the attractiveness of an issuance. The variable UPSTEEP, which represents the steepness of the coupon structure, receives significant positive loadings throughout all models. This suggests that investors prefer rising coupon structures and a high final coupon payment in their investment selection. On the other hand, the coefficients for our second proxy, the duration (DURATION), are consistently negative. Hence, Individual Investors apparently look for a short weighted average time until the investment and coupons are paid back. Separate regressions show that the described relations are robust for investor subsamples and different time (investment) periods. They are also robust even when we focus only on either UPSTEEP or DURATION to describe a product's coupon structure.

Summing up, our main finding in the regression analysis is that the coupon structure seems to influence Individual Investors' decisions to invest in a GFSN. In a more general context, the results point to a potential for issuers of fixed-income products to place more successful issuances, i.e. to extend the investor base and to achieve higher investment volumes, through offering specific investment profiles. For our sample, steep coupon structures combined with a low capital duration draw most interest among Individual Investors. The next sections focus on investigating whether such a coupon structure is also advantageous in the case of investors' early exercise and portfolio decisions.

3.3 Exercise decision

In this section we use—similar to Eickholt et al. (2014b)—pooled logit regressions to find whether the probability of an early exercise ("*exercise decision*") differs depending on the (upcoming) coupon structure of a GFSN. As discussed before, we emphasize that according to theory an investor's exercise decision should be linked only to the current valuation of the GFSN.

Besides the defined PVEV-ratio, which indicates if an exercise is economically reasonable, and the proxies for the coupon structure, we control in this analysis for three environmental factors. First, we control for an extraordinary early exercise effect in the first month after the initial one-year blocking period (BLOCK) of a GFSN. In this month, exercises might occur more frequently due to the long-deferred need to exercise that had developed during the first twelve months of maturity when investors could not liquidate their GFSN investments. Second, we account for two major changes in the German tax system during our observation period. Both in 1999 and 2006, the tax allowances for Individual Investors were significantly reduced in Germany, which might have induced increased exercise activities in the months shortly before the tax changes became effective by investors who wished to optimize their tax debts. We introduce two dummy variables (TAX99 and TAX06) to cover this potential effect in November and December 1998 and 2005. Third, the dummy variable NEWMARKET is designed to capture potential exercise peaks related to the introduction and growth phase of the "New Market" index NEMAX50 between 1998 and 2000 in Germany. This stock index listed new economy companies and gained a high popularity among Individual Investors in the last years of the 1990s. Hence, some Individual Investors might have exercised early their GFSN at this time so as to shift investments from the fixed-income market to the growing equity market. Finally, we incorporate for Type A GFSN the lifetime of a product (LIFETIME), i.e. the time since issuance.[9]

Compared to the number of decisions to continue holding a product, early exercise decisions are comparatively rare in our data set (see also the investor statistics in Table 2). Thus, to ensure that we have no (underestimation) bias in the estimated probabilities, we run rare event regressions according to King and Zeng (2001) on the data set. However, a comparison with the results of a pooled logit regressions does not show substantial differences, so that we decided to continue with standard regressions for efficiency and comparability reasons. Accordingly, Table

[9]We note, that the lifetime of a product is correlated to the duration variable and that this collinearity might potentially result in inflated standard errors. However, because running the logit regression with orthogonalized regressors and running the regression without accounting for the lifetime variable leads to similar findings, we decided to continue with the described variables.

4 shows the results of a pooled logit regression of investors' holding and exercise decisions on the defined variables for Type A and Type B GFSN. In addition, we estimate—if applicable—the respective elasticities at means indicating the proportional change in the exercise probability for a proportional change in the respective dependent variable.

[Table 4 about here.]

Beginning with the overall model output, we note that the regression is based on 15.924 million decisions for Type A and 9.991 million decisions for Type B GFSN. The pseudo-R^2 lies at 5.34% and 3.90%. We highlight three regression results. First, all four environmental variables have—as expected—a statistically significant positive coefficient, which suggests that the first month after the initial blocking period, tax effects and growth phases in the equity market are all associated with higher exercise rates. Following the argumentation in Eickholt et al. (2014b), this is not surprising as the demand for financial flexibility and liquidity seems to play an important role in the decision-making of Individual Investors with regard to fixed-income investments. Second, the coefficient for the valuation variable (PVEV) is strongly negative implying that the exercise probability decreases with a higher valuation of the respective product. As noted before, this is economically reasonable, since only at the lowest possible PVEV-ratio of 1 is an exercise profitable from a theoretical point of view. Moreover, the high elasticity for this variable indicates that Individual Investors are indeed very sensitive to valuation changes in their investments, which is in line with our observations on investment decisions in the previous subsection. Our third finding is that the coupon structure of a GFSN has (again) a significant influence on the probability of exercise. Both regressions for Type A and Type B GFSN in Table 4 exhibit negative coefficients for the upcoming steepness of the coupon structure (UPSTEEP) and positive loadings for the duration variable (DURATION). This suggests that Individual Investors hesitate to exercise early investments which promise strongly rising coupons in the future, whereas they more quickly redeem products with only slightly sloping coupon structures. Further, investors apparently value more highly products with a comparatively short weighted average time until coupons and investments are paid back, than financially fully equivalent products with a longer duration. Separate analyses show that these relations are robust even when we focus only on either UPSTEEP or DURATION to describe a product's coupon structure.

Overall, the empirical patterns in Individual Investors' exercise decisions are consistent with our above-described analysis on investment decisions, where we show that issuances with increasing coupon payments until maturity entice more investors and attract higher investment volumes. In summary, we interpret the economically irrational—and contrary to standard theory—penchant for high future coupons in both decisions as a "behavioral bias" of Individual Investors, which may be regarded based on psychological reasons.

Next, we aim to determine whether this bias in exercise behavior also applies to subsamples. We again regress investors' decisions on the defined product and environmental variables, but restrict the analysis in each case to selected time frames and specific investor groups that differ with regard to personal or investment characteristics. In addition, we investigate two special valuation cases and two different investment history scenarios. Regarding the valuation cases, we consider in a first regression only exercise decisions made at times when the PVEV-ratio is close to 1 (PVEV$\leq$1.025). In contrast, we focus in another regression on exercise decisions that occur at—from a theoretical point of view—clearly suboptimal points in time (PVEV>1.025). Regarding the investment history cases, we incorporate in one regression all decisions to hold or exercise a GFSN that are made until maximal three feasible exercise opportunities have occurred. Another regression considers only decisions on GFSN that are made after the respective investor has already left out several attractive exercise opportunities. Table 5 presents the results for the described subsamples.

[Table 5 about here.]

In short, we observe that our results are quite robust for the subsample analyses. Beginning again with the environmental variables, the coefficients for BLOCK and NEWMARKET point in the same direction as in our last regression for all subsample regressions and for both Type A and Type B GFSN. The coefficients for the tax variable are again mostly positive. Furthermore, the results show a very consistent influence of the coupon structure. In general, the probability of an exercise decreases for GFSN that offer a significant growth of coupon payments towards maturity (negative coefficients for UPSTEEP) and increases in almost all samples with a higher duration (positive coefficient for DURATION), which seems to support our hypothesis of a behavioral bias in Individual Investors' exercise behavior. Few exceptions appear. For investors with a high number of early exercises, for products with a high ratio of present to exercise value (PVEV) and for products for which an exercise would have been advantageous several times beforehand the estimated influenced of the UPSTEEP variable differs from the other regressions. Still, this must not contradict our former findings regarding a behavioral bias among investors as it seems reasonable to assume that investors who, e.g, regularly omit profitable exercise chances and who use their option right at clearly suboptimal points in time, assign a lower relevance to the coupon design than other investors. A possible motive behind these exercise decisions—even though the respective GFSN currently has a high PVEV-ratio and thus an exercise is not economically advantageous—is the need for liquidity (see also the discussion in Eickholt et al., 2014b), in which case the upcoming coupon structure does naturally matter less.

Besides indicating robustness, the results in Table 5 also suggest that the penchant for specific coupon structures persists over different investor subgroups and applies for investors with varying personal characteristics. Even investors, who might be ascribed a higher financial literacy—such as investors holding a doctoral degree or investors who very frequently exercise

GFSN early—seem to prefer investments with higher final coupon payments and short durations.

3.4 Portfolio decision

In this section we focus on investors who hold a portfolio of several GFSN. Following our former results, we aim to examine if the coupon structure is also a relevant decision criteria for Individual Investors in selecting a specific portfolio item for early exercise.

As the first step in this analysis, we create a new data set that comprises only "*portfolio decisions*" of the investor base. We define an Individual Investor's decision as a portfolio decision if he holds at least two exercisable GFSN at the time of decision. This means that the investor has a choice among two or more items when he contemplates the early exercise of a product. As there are only a few differences between both GFSN types we consider the whole portfolio of an investor at this stage, i.e. we no longer differentiate between decisions on Type A and Type B GFSN. Moreover, we simplify our analysis at two points for a clearer presentation of the results. First, we focus on exercise decisions, i.e. we exclude decisions to continue holding the complete portfolio without any changes. Second, we consider a maximum of six items per portfolio and month. If an Individual Investor's portfolio comprises more than six GFSN investments at the time of exercise we ignore the items with the highest PVEV-ratios, as these products seem to be—as discussed in the last section—less likely to be selected for exercise.

Next, for each month and each portfolio we determine a ranking (from the lowest to the highest value) of all portfolio items according to each of the following product characteristics: valuation (PVEV), duration (DURATION), yearly growth of upcoming coupon payments (UP-STEEP) and investment volume (VOLUME). We also test if exogenous effects, such as tax changes, or the lifetime of a product, have an impact on portfolio decisions. However, separate analyses—not reported here—show that incorporating exogenous effect variables and running the regressions with the lifetime variable does not change the overall results, thus we decided to continue with the described approach.

As a final step, we use random effects logit regressions to estimate the influence of the ranking position of each considered product characteristic on an investor's portfolio decision, i.e. on the selection of a portfolio item to be exercised early. Technically, we assume for the panel regression that each portfolio represents its own group of observations. Table 6 presents the results of a regression on the overall data set (second column). To examine the robustness of our results we also conduct panel regressions for several investor subsamples (third-to-last columns).

[Table 6 about here.]

Focusing first on the overall statistics, we observe that Individual Investors made overall 179,820 portfolio decisions for 48,590 different portfolios during our sample period, which implies that the average portfolio comprehends circa 3.7 investments in Type A or Type B GFSN.[10] The number of examined portfolio observations is significantly lower here compared to our previous analysis of exercise decisions (see Table 4) due to the exclusion of pure holding decisions and due to a high share of investors holding only one product in their portfolio for most of the time (see investor statistics in Table 2). Nevertheless, we note that the regression on this smaller subsample of portfolio decisions generally resembles the findings in our previous discussion. Three observations are most striking: first, the PVEV-ratio remains an important basis for portfolio decisions. The negative coefficients for this variable for the lower ranking positions imply that investors prefer to hold items in their portfolio with a comparatively high PVEV-ratio. On the other hand, the probability of an early exercise increases for products that have a comparatively low valuation, which seems very reasonable.

[10] In fact, the average portfolio is slightly larger since we restrict—as outlined—our analysis to the first six items in an investor's portfolio.

Second, we observe a tendency among investors to select portfolio items with higher investment volumes (positive coefficients for volume). Additionally, the results suggest that Type B GFSN are more often exercised early. Third, the statistically significant coefficients for UPSTEEP and DURATION indicate that an investor's decision as to which item in a portfolio to exercise early also depends on the coupon structure of the respective portfolio items. This is in line with our previous discussion. While we find a negative influence of the UPSTEEP variable, the loadings for DURATION are mostly positive and tend to increase with later ranking positions in the portfolio. This means that the probability of an early exercise decreases for portfolio items with a relatively steep coupon structure and thus with a comparatively high final coupon payment. On the other hand, the exercise probability increases in the case of a long weighted average time until the investment plus coupons is paid back, i.e. for portfolio items with a lower ranking position regarding the duration.

In the following, the right part of Table 6 (third-to-last column) reflects—as noted—the robustness of our results. For this, we rerun the described random effects logit regression but restrict the analysis to portfolio decisions of specific investor groups. In short, our main finding is that the regressions on these subsamples produce coefficients very similar to the results for the overall sample. Interestingly, we also note that only a few differences occur in the decision-making of investors with different personal characteristics. For instance, investors with considerable experience (more than 10 investments in GFSN) and high average investment volumes (more than €10,000) seem to use decision criteria in the selection of portfolio items for exercise that are very similar to those of investors who invest only rarely and make small investments. For both investor groups, the subsample regressions reveal that not only the current valuation level (PVEV-ratio) but also the coupon structure has some influence. As in our analysis above, we conclude that portfolio holders seem to rate items with slowly rising coupon payments and—less strongly pronounced—a high duration less favorably than portfolio items with different coupon structures.

4 Financial relevance of coupon structure

Following our empirical investigation, we use in this section scenario analyses[11] to investigate the financial relevance of the coupon structure of a putable bond. Furthermore, we seek to determine how issuers of putable bonds can potentially exploit the apparent penchant of Individual Investors for specific coupon structures.

Our approach can be divided into three steps. First, we design several exemplary bonds with varying coupon structures that are financially fully equivalent in four different interest rate environments (Section 4.1). Second, we use Monte-Carlo simulations to quantify for each of these bonds an issuer's potential advantage from the often suboptimal exercise behavior of Individual Investors (Section 4.2). For this purpose, we examine the "spread" between the financial fair value at issuance and the "empirical value" of a product, which we estimate based on the empirically observed exercise strategies of Individual Investors in our sample. Moreover, we compute for each product the theoretically optimal and the empirical exercise frequency over all simulation paths to gain a better understanding of the potential demand for liquidity during the years to maturity. Third, we discuss the results and derive implications for issuers (Section 4.3).

[11] We refer here to scenario analyses instead of using the empirical data to ensure comparability of the results and to exclude exogenous influences on the data, such as diverging bond and option values at issuance, changes in the tax laws or time effects.

4.1 Scenario description

We construct five hypothetical Type A and Type B GFSN with different coupon structures, whereby each bond resembles one of the issued GFSN in the empirical sample. The exemplary bonds cover a representative variety of degrees of steepness and kurtosis. First, we consider a GFSN that pays constant coupons over the respective six or seven years to maturity ($C_t = CC$, where C is the yearly coupon payment, t the year and CC the constant coupon rate). Second, we examine a product with a concave coupon structure, which implies a decreasing growth of coupon payments over time. For simplicity, we assume for this GFSN that the coupon payments grow each year by a fixed value divided by the current year of maturity ($C_t = C_{t-1} + \frac{CF}{t}$, where CF is a fixed value). Our third bond offers linearly increasing coupon payments over time ($C_t = t \times CL$, where CL is the linear multiplicator). Fourth and fifth, we consider bonds with convex coupon structures and thus with exponentially growing payments over time ($C_t = C_{t-1} \times CX$, where CX is the convexity degree). Because such convex coupon structures seem to be most interesting for our analysis, we design two similar products here that only differ as to the degree of convexity (1.50 and 1.65) and thus as to their kurtosis.

We analyze the exercise strategies and valuations for these bonds in four different interest rate environments. Figure 1 shows the exemplary spot rate curves we assume for the simulation, which we construct based on the well-known function of Nelson and Siegel (1987), i.e.:

$$R(t) = \beta_0 + \beta_1 \frac{1 - e^{(-t/\tau)}}{t/\tau} + \beta_2 \left(\frac{1 - e^{(-t/\tau)}}{t/\tau} - e^{(-t/\tau)} \right), \tag{3}$$

where r is the spot rate at time t. We use diverging parameters for β_0, β_1, β_2 and τ.

[Figure 1 about here.]

Our first scenario is a normal or positive spot rate curve that slopes upwards ("normal"). In the second scenario we assume a similar term structure, where, however, the spot rates increase more steeply over time ("steep"). The third scenario represents an interest rate environment with a humped term structure ("humped"), which implies that spot rates grow at the beginning but decrease in the midterm, so that later spot rates again approach the initial level. In our last scenario we assume constant spot rates over time ("flat").

4.2 Valuation

Our next step is to quantify for each of the described five hypothetical GFSN and for each interest rate environment the potential financial advantage for an issuer. For this, we compare the financial fair value of all products at issuance with an "empirical value" that considers Individual Investors' empirically observed exercise behavior.

To determine the fair value of a GFSN, we follow an approach similar to that outlined in Section 3. First, we model the dynamics of the interest rates using a 1-factor short rate model according to Hull and White (1990), i.e. $dr(t) = \kappa(\theta(t) - r(t))dt + \sigma dW(t)$.[12] For all bond valuations we use the same parameters (mean reversion speed $\kappa = 30\%$, short rate volatility $\sigma = 1.0\%$, 2.5% and 4.0%, whereby the time-dependent drift θ is adjusted to the initial forward rates of the respective scenario following the approach of Brigo and Mercurio (2006). Next, we determine the value of all considered GFSN at each time step via a Monte-Carlo simulation with 10,000 paths and a step size of $\Delta t = 1/12$ using Euler discretization and applying the least square regression method as proposed by Longstaff and Schwartz (2001).

For result comparability, we assume that all GFSN in all interest rate environments are issued at a financial fair value of 1.020 and with a nominal value of the bond component of 1.000.[13]

[12] $W(t)$ stands for a standard Brownian motion.

[13] We also run the simulations with fair values of 1.000 for all constructed GFSN and obtain similar results. The assumed fair value of 1.020 represents an approximate average of the valuations of Type A and B GFSN at issuance during our sample period.

This means that from a theoretical point of view all considered products should be equally attractive for investors. To construct a coupon structure for each exemplary bonds that leads to the same fair value, we refer to a non-linear optimization algorithm based on the interior-point method. With this algorithm we estimate the best fitting values for the parameters CC, CF, CL, $CX_{1.5}$ and $CX_{1.65}$, using the mean squared error as goodness-of-fit criteria. We rerun the optimization until the distance from the previous best estimate to the current best estimate is less than 1×10^{-16}. As a short summary of the optimization approach, Table 7 presents the estimated first and last coupon for each product in each interest rate scenario.

[Table 7 about here.]

In general, the statistics show that—as expected—the estimated final coupon payment increases from the first bond with a flat coupon structure to the last example, with a strongly convex coupon structure. In contrast, it generally decreases with a rising volatility level, which is due to a higher value of the early exercise right in more volatile environments. We will discuss this effect in detail at a later stage.

In contrast to the financial fair values, we expect that the empirical values of our exemplary designed GFSN differ among the scenarios due to the preferences of Individual Investors for specific coupon structures and payment profiles. To estimate the empirical values we basically apply a reduced-form model and refer to the estimated determinants of early exercising from Table 4. We ignore the influence of changes in the tax legislation and changes in the market structure, as these cannot be anticipated by investors. This means that the probability of an exercise is given by:

$$
\begin{aligned}
Pr(ex_t) = exp[&\hat{\beta}_1 PVEV_t + \hat{\beta}_2 UPSTEEP_t + \hat{\beta}_3 DURATION_t \\
&+\hat{\beta}_4 BLOCK_t + \hat{\beta}_5 LIFETIME_t + Constant]/ \\
[1 + exp(&\hat{\beta}_1 PVEV_t + \hat{\beta}_2 UPSTEEP_t + \hat{\beta}_3 DURATION_t \\
&+\hat{\beta}_4 BLOCK_t + \hat{\beta}_5 LIFETIME_t + Constant)]
\end{aligned}, \tag{4}
$$

where ex stands for an early exercise event, t for the current time step and $\hat{\beta}$ for the previously estimated regression coefficients. The variables UPSTEEP, DURATION, BLOCK and LIFETIME (for Type A GFSN) are defined as in our former analysis. For the PVEV variable we utilize the results from the theoretical valuation.

Besides considering the influence of the coupon structure, the modeled empirical values also represent Individual Investors' generally suboptimal exercise behavior. As outlined in the study by Eickholt et al. (2014b), Individual Investors often tend to omit attractive exercise opportunities and use their early exercise right at times that are not economically advantageous. The reduced-form model implicitly accounts for both effects.

4.3 Scenario results

Table 8 compares the computed "spread" between the financial fair value and the empirical value at issuance for all products and for all interest rate environments.

[Table 8 about here.]

In addition, Table 9 presents for each scenario the simulated exercise frequency over all Monte-Carlo paths for the theoretical optimal strategy (Panel A) and for the empirical valuation approach based on the reduced-form model (Panel B).

[Table 9 about here.]

Beginning with the valuation results in Table 8, we observe clear differences over the presented scenarios. The lowest spreads occur in the simulations for GFSN with strongly convex coupon structures in the case of a steep spot rate curve (0.116% points to 4.766% points for Type A and 0.243% points to 5.477% points for Type B GFSN), whereas the highest spreads are linked to bonds with flat coupon payments (7.728% points to 13.156% points and 8.892% points to 15.604% points). More generally, we find that the spread is positively correlated to a higher volatility and that it varies depending on the assumed interest rate environment. We concentrate in the following on discussing the influence of the volatility and the coupon structure.

Regarding the impact of the volatility, we recap that the option component in a GFSN represents an unilateral right of the investor to reclaim his investment. This means the number of potentially attractive exercise opportunities and hence the value of the early exercise right increase in a high volatility environment. Accordingly, the results in Panel A of Table 9 show in general a rising percentage of exercised paths over the volatility scenarios. For instance, for our exemplary GFSN with a strongly convex coupon structure, the optimal exercise frequency grows from 16.480% for the low volatility scenario to 82.690% for the high volatility scenario (normal term structure, from 16.650% to 84.350% for Type B GFSN). Yet this increasing number of economically reasonable exercise points also means that the optimal exercise strategy acquires a greater financial relevance. Missing attractive exercise opportunities and exercising too early or too late is more disadvantageous in a more volatile environment. In fact, this is the reason why the spread between the fair and the empirical value—which incorporates the frequently suboptimal decision-making of the investor base—widens over the volatility scenarios.

Moreover, we find that the estimated spread typically diminishes along the five designed products. In short, the decreasing values are due to the declining relevance of the early exercise right and thus to the declining importance of the negative influence of Individual Investors' often suboptimal exercise behavior. To explain this effect in detail, we compare, as an example, the simulated exercise frequencies and valuations for our first and last constructed GFSN. First and most importantly, we note that for a GFSN with a flat coupon structure significantly more attractive exercise opportunities arise until maturity than for the last case, a GFSN with a strongly convex coupon structure, where the highest coupon payments are deferred towards maturity. The statistics in Panel A of Table 9 show that the percentage of optimally exercised simulation paths decreases for the low volatility scenario and a normal spot rate curve from 99.070% for the first GFSN to the above-mentioned 16.480% for the last analyzed product (from 99.590% to 16.650% for Type B GFSN). Similarly, the optimal exercise timing differs. A separate analysis—not reported here—indicates that the average optimal holding times over all simulated paths for these two bonds are respectively 28 months and 63 months (28 months and 73 months). Both the lower exercise frequency and the longer holding period, i.e. the later exercise time, are due to on average higher continuation values and thus to an on average higher PVEV-ratio of products that offer high final coupon payments. Recalling our former argument that an early exercise is economically only reasonable if the PVEV-ratio reaches 1, it becomes obvious that the theoretical and empirical option value decreases along the ordered product scenarios. Thus we can infer the main reason for the narrowing spread is the smaller number of economically advantageous exercise opportunities that Individual Investors can potentially omit due to suboptimal exercise decisions. In other words, the risk of missing attractive exercise points is reduced for products with steeply rising coupon structures.

However, in addition to the development of the PVEV-ratio, a second factor also drives—as discussed earlier—differences between the product scenarios, namely the penchant of Individual Investors for specific coupon structures. The reduced-form model for the estimation of the empirical values considers that investors more often hesitate to exercise their investments early in the case of coupon payments that grow more strongly towards maturity (negative coefficient on UPSTEEP in the model), and that they generally prefer to hold products with a short duration (positive coefficient on DURATION). Taken together, this “behavioral bias” leads to a reduced exercise probability in products with steeply rising coupon payments as the influence of UPSTEEP outbalances the influence of the DURATION variable. Compared to the last argument this bias acts in the opposite direction. It has a positive and increasing impact on the spread along the five exemplary GFSN.

Nevertheless, looking at the spread statistics, we find that this positive second effect is widely overcompensated by the negative influence of the above-described diminishing relevance of the option component. However, it is more obvious in the statistics on the modeled empirical exercise strategies shown in Panel B of Table 9. Here, the tendency among investors to continue holding allegedly more attractive bonds further reduces the average exercise frequency for GFSN with high final coupon payments, and contributes—on the other hand—to an increasing number of early exercises for GFSN that offer flat coupon payments.

In summary, the scenario analyses imply that issuers of putable bonds for Individual Investors can gain a significant financial advantage through “behavioral financial engineering”. In particular, issuers might benefit from two empirical patterns. First, our results suggest that offering products with a (strongly) convex coupon structure allows issuers to reduce their liquidity reserves as Individual Investors prefer to continue holding such bonds and instead tend to exercise early products with visually less attractive coupon offerings. Second, flat or concave coupon structures seem to be most suitable for issuers that aim to maximize the spread between the empirical and the theoretical value of their issuances. The reason is that for such products, the exercise right has a comparatively high theoretical value, which is advantageous for issuers since Individual Investors regularly forfeit attractive exercise opportunities and typically exploit even very valuable exercise rights to only a small extent. This is also expressed by the difference between the statistics in Panel A and B in Table 9.

5 Conclusions

In this paper we investigated the influence of different product designs on Individual Investors' decision-making in putable bonds. Our main finding is that the coupon structure plays an important role in how investors make investment, exercise and portfolio decisions. Bonds with a steep coupon structure and a short weighted average time until all payouts have been made tend to attract more investors and have a lower exercise probability than products with the same financial fair value that offer a flatter coupon structure. This empirical observation, which appears to be robust for almost all subsamples in our data set, cannot be explained by economic arguments. Hence, we interpret our results as indicating a behavioral bias among Individual Investors. Apparently, Individual Investors value putable bonds differently, depending on the psychological or visual attractiveness of the remaining coupon payments.

A main conclusion of our study is that there is some potential for issuers of fixed-income products with early exercise rights for Individual Investors to increase the attractiveness of their products and to steer investors' exercise behavior through proficient "behavioral financial engineering". Our analyses indicate that issuers who are looking for high investment volumes and a low capital outflow throughout maturity should prefer putable bonds with significantly increasing coupon payments until maturity. Issuers benefit in this case in two ways. First, they must have less liquidity available, as the early exercise volume tends to diminish as Individual Investors prefer to continue holding this kind of bonds. Second, the share of exploited attractive exercise opportunities tends to be lower than in the case of other coupon structures.

On the other hand, for issuers who seek to maximize the spread between the theoretical and empirical value of a newly issued putable bond, flat or concave coupon structures might be more suitable. The reason is that—as discussed in detail in the study of Eickholt et al. (2014b)—Individual Investors typically exploit even very valuable option rights to only a small extent. Consequently, the spread between theoretical and empirical value is—measured in percent points—larger for products for which the probability of an early exercise, and thus the theoretical option value, is comparatively high, such as putable bonds with flat coupon offerings.

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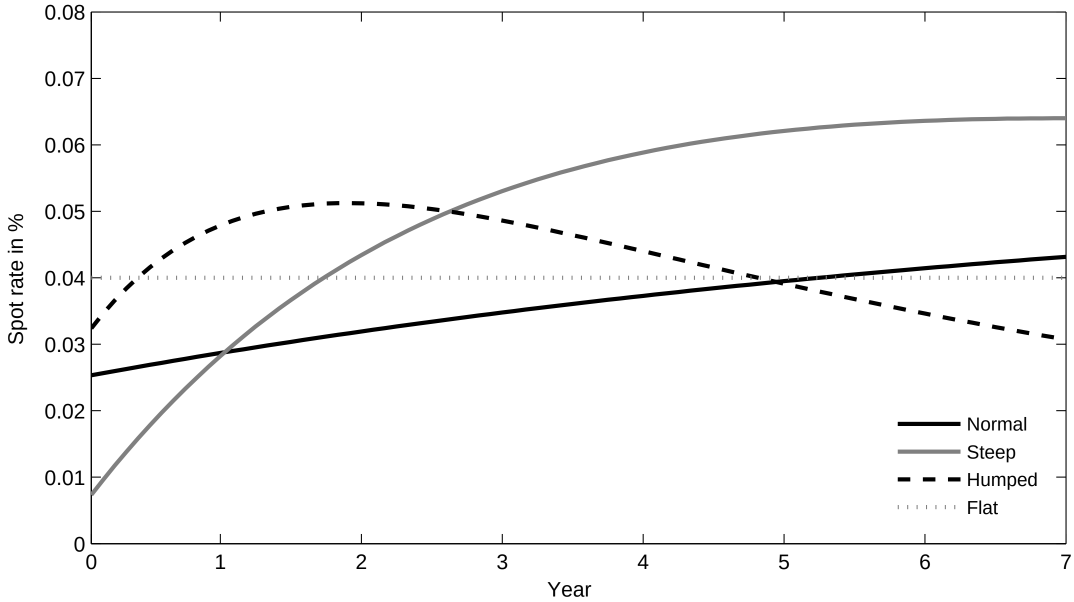
Figures

Figure 1: Interest rate scenarios for scenario analyses
This figure shows the exemplary spot rate curves at issuance for the scenario analyses. The spot rates are calculated using the formula of Nelson and Siegel (1987), i.e. $R(t) = \beta_0 + \beta_1 \frac{1-e^{(-t/\tau)}}{t/\tau} + \beta_2 \left(\frac{1-e^{(-t/\tau)}}{t/\tau} - e^{(-t/\tau)}\right)$, with the following parameters. Normal: $\beta_0 = 0.06$, $\beta_1 = -0.035$, $\beta_2 = 0.020$, $\tau = 7.000$. Steep: $\beta_0 = 0.035$, $\beta_1 = -0.030$, $\beta_2 = 0.140$, $\tau = 3.000$. Humped: $\beta_0 = 0.000$, $\beta_1 = 0.030$, $\beta_2 = 0.120$, $\tau = 1.500$. Flat: $\beta_0 = 0.040$, $\beta_1 = 0.000$, $\beta_2 = 0.000$, $\tau = 6.000$.



Tables

Table 1: Summary statistics on GFSN

	Type A GFSN						Type B GFSN					
	Mean	Med.	p5	p95	Std.dev.	ΔSR	Mean	Med.	p5	p95	Std.dev.	ΔSR
Coupon p.a. in %												
Year 1	2.745	2.750	1.500	4.000	0.812	-0.641	2.745	2.750	1.500	4.000	0.812	-0.641
Year 2	3.199	3.250	1.750	4.250	0.813	-0.342	3.199	3.250	1.750	4.250	0.813	-0.342
Year 3	3.627	3.625	2.500	5.000	0.807	-0.072	3.627	3.625	2.500	5.000	0.807	-0.072
Year 4	4.034	4.000	3.000	5.750	0.821	0.181	4.034	4.000	3.000	5.750	0.821	0.181
Year 5	4.409	4.250	3.250	6.250	0.858	0.415	4.250	4.250	3.250	6.250	0.858	0.415
Year 6	4.821	4.500	3.750	7.000	0.929	0.700	4.821	4.500	3.750	7.000	0.929	0.700
Year 7							4.944	4.750	4.000	7.000	0.924	0.709
Steepness of coupon structure												
Diff. in % points	2.076	2.000	0.750	4.000	1.066		2.199	2.250	0.750	4.250	1.128	
Rel. in %	92.061	80.000	18.750	171.429	69.220		98.581	81.818	18.750	216.667	77.121	
Fisher-Weil duration												
Years	5.539	5.529	5.403	5.712	0.098							

The table exhibits statistics on the coupon offerings for Type A and Type B GFSN for all 204 issuances (102 Type A, 102 Type B) in our sample period from July 1996 to February 2009 and on the corresponding spot rates in Germany. For year 1 to 6 identical coupons are offered for Type A and Type B GFSN at each issuance date, whereas the coupons in year 7 are only applicable for Type B. ΔSR stands for the difference between the coupon rate and the respective spot rate for the respective year, whereby the spot rates represent the term structure of interest rates on listed Federal securities (method by Svensson) at the respective issuance date according to Deutsche Bundesbank. Absolute steepness of the coupon structure describes the difference between the last and the first coupon, the relative steepness is the ratio of the last to the first coupon payment.

Table 2: Summary statistics on investor base

	Type A GFSN					Type B GFSN				
	Percent	Abs.	Ø Invest-ments	Ø Volume in €	Ø Early exercises	Percent	Abs.	Ø Invest-ments	Ø Volume in €	Ø Early exercises
Gender										
Male	33.47	52,717	3.282	5,670	0.582	38.41	35,595	2.948	2,858	0.563
Female	38.36	60,425	2.938	11,212	0.450	38.00	35,214	2.561	8,610	0.424
n/a	28.17	40,370	3.273	10,885	0.561	23.60	21,871	2.901	5,053	0.590
Age										
0 to 40 years	42.64	67,168	2.785	6,910	0.534	59.50	55,146	2.543	4,308	0.470
41 to 100 years	54.09	85,194	3.560	9,996	0.550	37.62	34,867	3.314	7,838	0.630
n/a	3.27	5,150	1.042	10,319	0.002	2.88	2,667	1.037	5,053	0.003
Doctoral degree										
Doctorate or professorship	4.15	6,536	3.911	12,382	0.604	3.50	3,243	3.896	11,160	0.594
No doctoral degree	95.85	150,976	3.114	8,664	0.522	96.50	89,473	2.750	4,865	0.514
Preferred distribution(1)										
Indirect (via banks)	59.18	93,217	1.607	9,016	0.323	54.01	50,057	1.489	4,531	0.356
Direct (at German Finance Agency)	40.82	64,295	5.380	8,533	0.819	45.99	42,263	4.318	5,734	0.706
Overall	100.00	157,512	3.147	8,818	0.526	100.00	92,680	2.790	5,085	0.517

The table exhibits information on personal and investment characteristics of all 223,017 Individual Investors in our data sample, whereof 27,175 investors hold both Type A and Type B GFSN. The first and second column show the relative distribution and absolute numbers of investors with the respective personal characteristics, the third column lists the average number of investments, the fourth column shows the mean investment volume, while the last column shows the average number of early exercises for each cluster. (1) We define the preferred distribution channel as direct if an investor executes at least one direct transaction. Indirect means that an investor purchases a GFSN at a bank and later transfers his investment to the German Finance Agency.

Table 3: Influence of coupon structure on investment attractiveness

	Number of investments				Investment volume			
	Type A GFSN		**Type B GFSN**		**Type A GFSN**		**Type B GFSN**	
	Coefficient	Elasticity	Coefficient	Elasticity	Coefficient	Elasticity	Coefficient	Elasticity
Valuation								
BOND	25.316	5.168	23.620*	9.204*	276.223	7.734	124.353*	11.735*
OPTION	100.107*	0.448*	62.421*	0.740*	857.074*	0.526*	283.416*	0.814*
Coupon structure								
UPSTEEP	1,163.491*	1.932*	660.747*	1.841*	11,050.160*	2.516*	3,016.935*	2.036*
DURATION	-6.358*	-7.320*			-53.675*	-8.476*		
Trend								
LAST6INV	0.027	0.164	0.046	0.277				
LAST6VOL					0.014	0.082	0.023	0.165
Timing								
Q2	-1.850*		-1.168*		-16.231*		-5.895*	
Q3	-1.605		-0.986*		-13.566		-4.306*	
Q4	-1.048		-0.283		-10.011		-1.933	
Constant	4.081		-27.258*		-38.339		-140.023*	
N	102		102		102		102	
R^2 *in %*	50.30		55.76		48.86		50.85	

The table exhibits the results of standard regressions on Individual Investors' investment decisions in Type A and Type B GFSN. In the left part of the table the dependent variable is the overall number of investments, whereas in the right part the cumulated volume per issuance is used. Only investments and decisions after the initial one-year blocking period are considered. The lifetime variable is not considered for Type B GFSN as it equals maturity. The variables LAST6INV and LAST6VOL represent the cumulated number of investors respectively the cumulated GFSN volume over the last 6 issuances and thus represent a mid-term trend. The elasticities (ey/ex) are calculated at means and are not determined for dummy variables. Robust standard errors are used. * signals statistical significance at the 5% level.

Table 4: Influence of coupon structure on early exercise probability

	Type A GFSN		**Type B GFSN**	
	Coefficient	Elasticity	Coefficient	Elasticity
Economic benefit				
PVEV	-19.291*	-19.982*	-14.277*	-15.003*
Coupon structure				
UPSTEEP	-23.006*	-0.118*	-31.232*	-0.132*
DURATION	4.557*	13.592*	0.305*	1.139*
Environmental circumstances				
BLOCK	0.220*		0.150*	
NEWMARKET	0.732*		0.648*	
TAX99			0.225*	
TAX06			0.585*	
Lifetime in years				
LIFETIME	3.682*	6.783*		
Constant	-6.281*		8.058*	
N	15.924m	15.924m	9.991m	9.991m
Pseudo-R^2 *in %*	5.34		3.90	

The table exhibits the results of a pooled logit regression on Individual Investors' early exercise decisions for Type A and Type B GFSN. Only decisions to hold or exercise after the initial one-year blocking period and before the last year of maturity are considered. The lifetime variable is not considered for Type B GFSN as it is perfectly correlated to the duration. The elasticities (ey/ex) are calculated at means and are not determined for dummy variables. Robust standard errors are used. Pseudo-R^2 is the percentage improvement in the log-likelihood achieved by our model compared to a constant-only model. * signals statistical significance at the 5% level.

Table 5: Influence of coupon structure on early exercise probability for subsamples

Type A GFSN	PVEV	UP-STEEP	DURA-TION	BLOCK	NEW-MARKET	TAX99	TAX06	LIFE-TIME	*Const.*	*N*	*Pseudo-R^2* in %
Issuance date											
2002 or earlier	-12.981*	-15.166*	5.693*	0.274*	0.895*			4.758*	-18.343*	12.460m	4.31
After 2002	-46.038*	-120.364*	2.830*	0.167*				2.148*	29.383*	3.464m	5.96
Gender											
Male	-18.948*	-16.233*	4.548*	0.246*	0.731*			3.684*	-6.573*	5.498m	5.23
Female	-18.101*	-33.709*	4.688*	0.236*	0.734*			3.846*	-8.225*	5.854m	4.73
Age											
$\leq$ 40 years	-15.722*	-15.342*	4.293*	0.236*	0.735*			3.498*	-8.689*	6.072m	4.24
$>$ 40 years	-22.548*	-32.116*	4.772*	0.204*	0.698*			0.137	-3.938*	9.851m	6.35
Doctoral degree											
Doctorate or professorship	-19.72*	-20.939*	5.075*	0.310*	0.900*			4.147*	-8.388*	0.794m	5.78
No doctoral degree	-19.273*	-23.082*	4.537*	0.216*	0.724*			3.664*	-6.194*	15.130m	5.32
Preferred distribution channel											
Direct	-28.761*	-68.844*	3.818*	0.228*	0.486*			2.972*	7.126*	6.546m	6.71
Indirect	-14.258*	-4.784	4.037*	0.157*	0.904*			3.285*	-9.34*	9.377m	4.20
Number of investments											
$\leq$ 3	-15.94*	-2.649	3.986*	0.208*	0.767*			3.228*	-7.278*	10.437m	4.06
$>$ 3	-27.734*	-60.584*	4.553*	0.197*	0.630*			3.592*	2.638*	5.487m	7.44
Ø Investment volume											
$\leq$ €10,000	-19.199*	-25.043*	4.579*	0.207*	0.720*			3.703*	-6.430*	11.891m	5.37
$>$ €10,000	-19.401*	-14.103*	4.256*	0.271*	0.776*			3.410*	-4.928*	4.033m	5.12
Number of early exercises											
$\leq$ 2	-16.809*	-5.861*	3.339*	0.219*	0.894*			2.653*	-3.689*	15.137m	4.09
$>$ 2	-19.309*	-21.672*	5.536*	0.133*	0.249*			4.679*	-9.277*	0.786m	5.69
Valuation scenarios											
PVEV $\leq$ 1.025	-67.256*	-54.345*	3.538*	0.225*	0.422*			2.735*	47.009*	5.023m	6.24
PVEV $>$ 1.025	-6.582*	37.571*	0.276	0.196*	0.452*			-0.039	-0.217	10.901m	1.44
Investment history											
$\leq$ 3 missed chances	-15.744*	-26.358*	3.557*	0.359*	0.763*			2.781*	-5.359*	12.760m	4.43
$>$ 3 missed chances	-31.94*	-28.759*	4.995*		0.472*			4.048*	4.652*	3.164m	5.66
Type B GFSN											
Issuance date											
2002 or earlier	-9.832*	-52.418*	0.006	0.191*	0.873*	0.268*	1.112*		3.614*	7.692m	3.50
After 2002	-27.745*	-78.055*	0.350*	0.113*			0.227*		21.874*	2.299m	4.29
Gender											
Male	-14.583*	-40.286*	0.318*	0.158*	0.642*	0.220*	0.576*		8.403*	4.022m	4.13
Female	-14.219*	-28.031*	0.280*	0.177*	0.638*	0.229*	0.475*		7.935*	3.664m	3.57
Age											
$\leq$ 40 years	-12.933*	-29.823*	0.286*	0.160*	0.673*	0.192*	0.617*		6.681*	5.730m	3.57
$>$40 years	-15.936*	-35.348*	0.320*	0.136*	0.657*	0.284*	0.550*		9.786*	4.261m	4.33
Doctoral degree											
Doctorate or professorship	-16.042*	-86.969*	0.371*	0.265*	0.817*	-0.097	0.455*		9.733*	0.409m	5.09
No doctoral degree	-14.233*	-28.537*	0.303*	0.142*	0.642*	0.234*	0.593*		8.016*	9.582m	3.86
Preferred distribution channel											
Direct	-21.171*	-50.274*	0.354*	0.150*	0.394*	0.041	0.429*		15.053*	4.568m	4.90
Indirect	-8.863*	-52.309*	0.208*	0.160*	0.976*	0.337*	0.875*		2.705*	5.422m	3.53
Number of investments											
$\leq$ 3	-11.347*	-24.923*	0.238*	0.167*	0.720*	0.339*	0.701*		5.207*	6.825m	3.02
$>$ 3	-20.921*	-38.88*	0.410*	0.111*	0.566*	-0.048	0.412*		14.491*	3.166m	5.86
Ø Investment volume											
$\leq$ 10.000	-14.403*	-30.529*	0.308*	0.138*	0.633*	0.175*	0.607*		8.171*	9.031m	3.92
$>$ 10.000	-13.505*	-40.409*	0.281*	0.250*	0.805*	0.601*	0.349*		7.431*	0.960m	3.94
Number of early exercises											
$\leq$ 2	-11.023*	-36.744*	0.217*	0.190*	0.921*	0.309*	0.635*		4.655*	9.482m	3.10
$>$ 2	-16.833*	22.010*	0.241*	0.054	0.204*	-0.034	0.449*		12.51*	0.509m	4.17
Valuation scenarios											
PVEV $\leq$ 1.025	-53.159*	-33.131*	0.335*	0.162*	0.474*	-0.014	0.492*		47.273*	2.357m	5.26
PVEV $>$ 1.025	-4.335*	19.051*	0.166*	0.202*	0.520*	0.589*	0.684*		-2.212*	7.634m	1.33
Investment history											
$\leq$ 3 missed chances	-11.601*	-32.164*	0.265*	0.311*	0.661*	0.313*	0.714*		5.369*	8.796m	3.06
$>$ 3 missed chances	-21.08*	16.466	0.486*		0.449*		-0.008		14.169*	1.194m	5.57

The table exhibits the results of several pooled logit regressions (each row shows a specific regression result) on Individual Investors' early exercise decisions in Type A and Type B GFSN. The regressions differ according to the issuance time of the underlying GFSN, investors' personal and investment characteristics, valuation ranges and the investment history. The lifetime variable is not considered for Type B GFSN as it is perfectly correlated to the duration. Only investments and decisions after the initial one-year blocking period and before the last year of maturity are considered. Robust standard errors are used. Pseudo-R^2 is the percentage improvement in the log-likelihood achieved by our model compared to a constant-only model. * signals statistical significance at the 5% level.

Table 6: Influence of coupon structure on early exercise probability of portfolio items

Portfolio items ranked from low to high	**All**	**Gender**		**Age in years**		**Doctoral degree**		**Preferred distribution**		**Number of investments**		**Ø Investment volume in €**	
		Male	Female	≤40	>40	Yes	No	Direct	Indirect	≤10	>10	≤10,000	>10,000
Economic benefit (PVEV)													
Rank 2	-0.905*	-0.897*	-0.873*	-0.952*	-0.874*	-0.863*	-0.907*	-0.907*	-0.899*	-0.923*	-0.782*	-0.857*	-0.918*
Rank 3	-1.432*	-1.387*	-1.456*	-1.521*	-1.368*	-1.542*	-1.425*	-1.431*	-1.412*	-1.467*	-1.206*	-1.313*	-1.461*
Rank 4	-1.739*	-1.716*	-1.792*	-1.814*	-1.683*	-1.786*	-1.736*	-1.722*	-1.744*	-1.767*	-1.538*	-1.64*	-1.764*
Rank 5	-1.962*	-1.938*	-1.964*	-2.059*	-1.883*	-1.944*	-1.962*	-1.961*	-1.924*	-1.973*	-1.785*	-1.881*	-1.979*
Rank 6	-2.053*	-2.072*	-2.111*	-2.192*	-1.947*	-2.138*	-2.048*	-2.033*	-2.062*	-2.085*	-1.838*	-2.051*	-2.043*
Steepness of coupon structure (UPSTEEP)													
Rank 2	-0.268*	-0.293*	-0.275*	-0.28*	-0.261*	-0.205*	-0.272*	-0.299*	-0.224*	-0.250*	-0.332*	-0.285*	-0.263*
Rank 3	-0.497*	-0.506*	-0.516*	-0.500*	-0.494*	-0.284*	-0.510*	-0.496*	-0.484*	-0.490*	-0.429*	-0.498*	-0.492*
Rank 4	-0.602*	-0.599*	-0.633*	-0.590*	-0.603*	-0.521*	-0.607*	-0.601*	-0.576*	-0.567*	-0.562*	-0.636*	-0.584*
Rank 5	-0.669*	-0.669*	-0.711*	-0.651*	-0.67*	-0.574*	-0.674*	-0.665*	-0.645*	-0.610*	-0.628*	-0.720*	-0.644*
Rank 6	-0.733*	-0.785*	-0.753*	-0.709*	-0.736*	-0.743*	-0.732*	-0.747*	-0.666*	-0.578*	-0.800*	-0.840*	-0.689*
Duration ratio (DURATION)													
Rank 2	0.427*	0.437*	0.408*	0.491*	0.391*	0.560*	0.421*	0.418*	0.440*	0.415*	0.495*	0.391*	0.435*
Rank 3	0.494*	0.533*	0.466*	0.617*	0.428*	0.576*	0.491*	0.506*	0.499*	0.470*	0.712*	0.505*	0.495*
Rank 4	0.608*	0.641*	0.536*	0.720*	0.557*	0.570*	0.612*	0.680*	0.511*	0.585*	0.878*	0.669*	0.594*
Rank 5	0.719*	0.747*	0.669*	0.887*	0.646*	0.806*	0.716*	0.767*	0.692*	0.698*	1.054*	0.760*	0.716*
Rank 6	0.864*	0.864*	0.834*	1.063*	0.783*	0.989*	0.86*	0.906*	0.865*	0.817*	1.270*	0.903*	0.863*
Investment volume													
Rank 2	0.206*	0.180*	0.185*	0.282*	0.154*	0.163*	0.209*	0.194*	0.225*	0.224*	0.103*	0.261*	0.195*
Rank 3	0.055*	0.043	0.048	0.102*	0.025	-0.106	0.064*	0.075*	0.046	0.073*	0.056	0.185*	0.025
Rank 4	0.047*	0.039	0.089*	0.143*	-0.011	-0.010	0.051*	0.100*	-0.018	0.060*	0.098*	0.151*	0.027
Rank 5	0.071*	0.030	0.076	0.172*	0.018	0.021	0.075*	0.146*	-0.048	0.094*	0.128*	0.157*	0.057*
Rank 6	0.117*	0.058	0.155*	0.257*	0.044	0.069	0.120*	0.182*	0.026	0.099*	0.256*	0.175*	0.115*
Product type													
Type B GFSN	0.054*	0.082*	0.025	0.015	0.014	-0.050	0.059*	0.054*	0.054*	0.023	0.095*	0.018	0.092*
Constant	0.067*	0.057	0.127*	0.216*	-0.017	-0.066	0.074*	-0.058*	0.199*	0.173*	-0.660*	-0.179*	0.116*
N	179,820	71,304	54,230	71,261	108,559	9,718	170,102	113,698	66,0122	130,907	48,913	41,749	138,071
Portfolios	48,590	18,993	15,117	20,074	28,516	2,482	46,108	28,531	20,059	38,759	9,831	10,204	38,387
Portfolio observations													
Min.	2	2	2	2	2	2	2	2	2	2	2	2	2
Mean	3.7	3.8	3.6	3.5	3.8	3.7	3.9	4.0	3.3	3.4	5.0	4.1	3.6
Max.	6	6	6	6	6	6	6	6	6	6	6	6	6
Pseudo-R^2 in %	10.58	10.43	11.01	11.23	10.19	10.53	11.62	10.49	10.52	10.42	10.59	10.26	10.64

The table shows the results of several random effects logit regressions (each column shows a specific regression result) on Individual Investors' exercise decision depending on the ranking positions of the product in a portfolio. To determine the respective rank per criteria, all products in an investor's portfolio are ordered at each point in time from the smallest to the highest value. The first column shows the results of an overall analysis. The following columns show the results of panel regressions on subsamples that differ regarding personal and investment characteristics. The number of investments describes the cumulated amount of investments of an investor in GFSN over the whole sample period. Only exercise decisions after the initial one-year blocking period and exercise decisions that occur at times when the respective investor holds at least two GFSN are considered. For portfolios that comprise more than six GFSN, we consider only the first six products with the lowest valuation ratio (PVEV). Pseudo-R^2 is the percentage improvement in the log-likelihood achieved by our model compared to a constant-only model. * signals statistical significance at the 5% level.

Table 7: Scenario analyses – exemplary coupon structures

Panel A	**Type A GFSN**				**Type B GFSN**			
First coupon in %	*Interest rate scenario*				*Interest rate scenario*			
	Normal	Steep	Humped	Flat	Normal	Steep	Humped	Flat
Volatility 1.0%								
Flat	2.752	5.042	2.741	2.314	2.734	5.037	2.353	2.280
Concave	1.849	3.674	1.521	1.466	1.797	3.417	1.222	1.396
Linear	1.071	2.055	0.818	0.835	0.967	1.721	0.604	0.738
Convex	1.103	2.114	0.830	0.857	0.858	1.515	0.528	0.654
Strongly convex	0.788	1.514	0.587	0.611	0.561	0.990	0.343	0.427
Volatility 2.5%								
Flat	1.961	4.512	2.138	1.457	1.897	4.442	1.754	1.366
Concave	1.334	3.214	1.272	0.963	1.257	2.974	0.981	0.873
Linear	0.832	1.924	0.714	0.591	0.740	1.612	0.509	0.507
Convex	0.888	1.998	0.732	0.633	0.703	1.443	0.456	0.486
Strongly convex	0.657	1.446	0.525	0.468	0.476	0.950	0.307	0.330
Volatility 4.0%								
Flat	1.206	3.696	1.423	0.616	1.106	3.537	1.043	0.492
Concave	0.825	2.623	0.880	0.411	0.739	2.387	0.610	0.317
Linear	0.533	1.649	0.516	0.263	0.457	1.378	0.333	0.195
Convex	0.583	1.738	0.539	0.287	0.459	1.274	0.310	0.196
Strongly convex	0.446	1.284	0.396	0.221	0.326	0.854	0.209	0.142

Panel B								
Final coupon	*Interest rate scenario*				*Interest rate scenario*			
at maturity in %	Normal	Steep	Humped	Flat	Normal	Steep	Humped	Flat
Volatility 1.0%								
Flat	2.752	5.042	2.741	2.314	2.734	5.037	2.353	2.280
Concave	4.529	9.001	3.727	3.592	4.660	8.860	3.168	3.619
Linear	6.425	12.329	4.909	5.007	6.769	12.049	4.226	5.162
Convex	8.372	16.054	6.302	6.511	9.773	17.256	6.011	7.446
Strongly convex	9.633	18.514	7.182	7.473	11.316	19.979	6.923	8.618
Volatility 2.5%								
Flat	1.961	4.512	2.138	1.457	1.897	4.442	1.754	1.366
Concave	3.269	7.875	3.117	2.359	3.258	7.710	2.544	2.263
Linear	4.990	11.542	4.283	3.548	5.183	11.280	3.564	3.550
Convex	6.745	15.171	5.561	4.804	8.004	16.438	5.190	5.530
Strongly convex	8.033	17.689	6.414	5.727	9.601	19.168	6.202	6.665
Volatility 4.0%								
Flat	1.206	3.696	1.423	0.616	1.106	3.537	1.043	0.492
Concave	2.022	6.427	2.155	1.006	1.916	6.190	1.582	0.821
Linear	3.199	9.896	3.098	1.581	3.197	9.648	2.333	1.362
Convex	4.425	13.196	4.095	2.179	5.230	14.508	3.527	2.231
Strongly convex	5.456	15.708	4.843	2.705	6.584	17.240	4.225	2.855

The table shows the estimated first (Panel A) and final coupon (Panel B) at maturity for 5 hypothetical GFSN. All GFSN have a financial fair value of 1.020. The respective coupon structure parameters for each bond (CC, CF, CL, $CX_{1.5}$ and $CX_{1.65}$) are estimated via a non-linear optimization algorithm based on the interior-point method and using the mean squared error as goodness-of-fit criteria. The dynamics of the interest rates are modeled using a 1-factor short rate model according to Hull and White (1990), i.e. $dr(t) = \kappa(\theta(t) - r(t))dt + \sigma dW(t)$, with $\kappa = 30\%$, σ as shown and θ being adjusted to the initial forward rates of the respective scenario following the approach of Brigo and Mercurio (2006). The fair value of a product is calculated via a Monte-Carlo simulation with 10,000 paths and a step size of $\Delta t = 1/12$ using Euler discretization and the least square regression method as proposed by Longstaff and Schwartz (2001).

Table 8: Scenario analyses – differences between theoretical and empirical value

	Type A GFSN				Type B GFSN			
Value difference	*Interest rate scenario*				*Interest rate scenario*			
in % points	Normal	Steep	Humped	Flat	Normal	Steep	Humped	Flat
Volatility 1.0%								
Flat	4.286	7.728	0.751	2.812	6.096	8.892	0.946	4.006
Concave	1.766	0.946	0.491	1.391	2.536	1.318	0.787	1.953
Linear	0.705	0.216	0.408	0.721	1.014	0.591	0.710	1.017
Convex	0.537	0.191	0.426	0.611	0.739	0.353	0.588	0.772
Strongly convex	0.447	0.116	0.358	0.549	0.635	0.243	0.555	0.649
Volatility 2.5%								
Flat	7.424	10.018	3.289	6.098	10.239	11.702	4.024	8.512
Concave	5.862	4.769	2.473	5.214	7.902	5.875	3.344	7.123
Linear	4.350	2.261	2.031	4.266	5.756	2.991	2.705	5.758
Convex	3.811	1.960	1.858	3.842	4.525	2.310	2.408	4.833
Strongly convex	3.255	1.567	1.693	3.465	3.900	1.864	2.008	4.428
Volatility 4.0%								
Flat	10.238	13.156	6.016	8.664	14.479	15.604	7.781	12.859
Concave	9.593	9.306	5.467	8.439	13.155	11.274	7.206	12.285
Linear	8.811	6.242	4.891	8.292	11.712	7.721	6.457	11.807
Convex	8.341	5.640	4.794	7.963	10.752	6.345	6.126	11.276
Strongly convex	7.865	4.766	4.408	7.813	9.945	5.477	5.832	10.941

The table shows the estimated difference at issuance between financial fair value and the empirical value for exemplary Type A and B GFSN with different coupon structures in varying interest rate environments (see Figure 1 for the corresponding spot rate curves). The coupon structures of all bonds are designed for a fair value of 1.020. The interest rate environment is estimated using the 1-factor-model of Hull and White (1990), i.e. $dr(t) = \kappa(\theta(t) - r(t))dt + \sigma dW(t)$, with $\kappa = 30\%$, σ as shown and θ being adjusted to the initial forward rates of the respective scenario following the approach of Brigo and Mercurio (2006). For the valuation a Monte-Carlo simulation with 10,000 paths with a step size of $\Delta t = 1/12$ and least squares regression methods are applied. The estimation of the empirical value is based on a reduced-form model that considers the observed exercise behavior of Individual Investors (see regression results in Table 4).

Table 9: Scenario analyses – simulated exercise frequency in theoretical and empirical valuation

Panel A	**Type A GFSN**				**Type B GFSN**			
Optimal exercise frequency in %	*Interest rate scenario* Normal	Steep	Humped	Flat	*Interest rate scenario* Normal	Steep	Humped	Flat
Volatility 1.0%								
Flat	99.070	99.840	29.220	93.520	99.590	99.870	29.210	95.910
Concave	80.970	50.740	9.960	70.220	86.280	47.960	11.830	76.470
Linear	39.730	9.310	3.880	37.440	43.960	10.630	4.920	42.130
Convex	23.880	8.230	3.550	23.550	23.110	7.540	3.810	23.240
Strongly convex	16.480	4.390	2.750	17.190	16.650	4.340	3.150	17.900
Volatility 2.5%								
Flat	95.290	97.070	68.680	91.770	97.110	97.440	71.180	94.170
Concave	89.070	79.740	57.600	86.130	92.570	80.700	62.040	89.780
Linear	78.360	52.480	46.390	78.400	82.220	55.050	52.260	82.590
Convex	70.370	44.300	41.060	72.820	70.560	42.580	44.330	74.440
Strongly convex	63.360	36.050	37.030	67.740	63.140	35.860	41.920	68.990
Volatility 4.0%								
Flat	94.520	95.770	79.400	91.770	96.370	96.710	81.840	94.210
Concave	92.190	87.700	74.910	90.360	94.660	89.530	78.840	93.140
Linear	88.520	74.260	70.560	88.600	91.680	77.070	75.120	91.730
Convex	85.690	67.530	67.210	87.150	87.640	66.890	71.190	89.910
Strongly convex	82.690	59.610	64.540	85.610	84.350	59.890	68.870	88.580

Panel B								
Modeled empirical exercise frequency in %	*Interest rate scenario* Normal	Steep	Humped	Flat	*Interest rate scenario* Normal	Steep	Humped	Flat
Volatility 1.0%								
Flat	25.150	16.800	17.820	27.120	31.430	32.220	20.950	30.800
Concave	16.930	7.230	11.890	20.760	25.610	20.000	16.400	25.550
Linear	11.180	2.730	8.030	14.530	18.100	9.580	12.530	20.340
Convex	9.480	2.020	8.330	13.310	11.670	4.540	9.630	14.040
Strongly convex	8.150	1.360	6.760	11.640	9.910	2.960	8.310	10.870
Volatility 2.5%								
Flat	28.550	17.210	21.470	30.460	30.410	31.290	22.860	29.080
Concave	20.690	8.730	16.310	24.430	25.640	21.750	19.140	26.530
Linear	15.980	4.530	13.320	21.180	21.820	13.170	16.980	22.510
Convex	13.520	3.150	11.820	19.100	15.800	6.650	12.990	18.000
Strongly convex	11.840	2.130	11.430	16.710	12.490	4.640	11.190	15.560
Volatility 4.0%								
Flat	32.300	18.760	25.700	36.540	28.470	30.380	23.570	27.530
Concave	27.480	11.320	21.350	33.050	27.110	23.310	21.190	27.530
Linear	22.100	6.200	17.690	29.960	23.940	15.470	19.070	25.320
Convex	20.750	4.430	16.880	29.820	20.190	8.830	16.850	24.150
Strongly convex	19.160	3.520	16.620	28.030	17.090	6.760	15.370	22.080

The table shows the simulated exercise frequency (percentage of exercised Monte-Carlo simulation paths) for exemplary Type A and Type B GFSN with different coupon structures and in varying interest rate environments (see Figure 1 for the corresponding spot rate curves). Panel A shows the results for the fair valuation approach, whereas Panel B shows the results for the estimated empirical value based on a reduced-form model that refers to the estimated determinants of early exercising from Table 4. The coupon structures of all bonds are designed for a fair value of 1.020. The interest rate environment is estimated using the 1-factor-model of Hull and White (1990), i.e. $dr(t) = \kappa(\theta(t) - r(t))dt + \sigma dW(t)$, with $\kappa = 30\%$, σ as shown and θ being adjusted to the initial forward rates of the respective scenario following the approach of Brigo and Mercurio (2006). For the valuation, we apply a Monte-Carlo simulation with 10,000 paths with a step size of $\Delta t = 1/12$ and least squares regression methods.

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