Estimating Implied Default Probabilities and Recovery Values

The Case of Greece during the 2010 European Debt Crisis

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ABSTRACT

This paper develops a framework to estimate implied recovery values and risk-neutral default probability term-structures from sovereign bond prices. The model is applied to Greek bonds during the European debt crisis of 2010. In April and May 2010, the probability of a Greek default quickly rises from 5% to 40%. On Monday 10 May 2010, after EU finance ministers, the ECB and the IMF agree on a EUR 750 billion EU-wide rescue package, the default probability drops instantaneously below 10%. The implied recovery value remains between 40 and 60 cents on the euro and does not get revised materially during this period.

Keywords: sovereign credit risk, probability of default, recovery value

JEL classifications:

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1. Introduction

With the recent debt crisis in Southern Europe, interest in the valuation of sovereign debt has revived. Although there is a large literature on the pricing and modeling of corporate debt, there has been comparably little attention for sovereign credit risk in the academic literature. This paper aims to fill this gap and develops a framework to simultaneously extract implied recovery values and the risk-neutral term-structure of default probabilities from sovereign bond prices. The reduced-form model employs a binomial lattice framework where the price of a bond is the probability-weighted average of promised cash-flows (if the obligor survives) and the recovery value (if the obligor defaults). By imposing a flexible parametric structure on the term-structure of default probabilities, it is possible to simultaneously extract default probabilities and the recovery value using the cross-section of outstanding bonds. The framework improves existing reduced-form credit models in two directions. First, the model allows for a term-structure of default risk. Second, the model also provides implicit market assumptions about the recovery value, which is valuable given that sovereign defaults are both rare and country-specific. Recasting market prices into default probabilities and recovery values provides market professionals and policy makers with information that is better to interpret than plain bond prices.

The model is applied to Greek bond prices during the period April-May 2010. Although painful for investors and European policy makers, the sample period provides a unique window to study the pricing of sovereign risks. The sample is characterized by a sharp re-pricing of Greek government debt, the announcement of severe austerity measures and great social unrest in both Greece and the rest of (Southern) Europe. The empirical section of this paper shows how the default probability term-structure and the recovery value implicit in Greek bonds evolved during the crisis. Model estimates show that the probability of a Greek credit event rises quickly from below 5% to more than 40% during this period. In the weekend of 8 and 9 May 2010, EU finance ministers, the ECB and the IMF announce a significant European rescue package. This leads to relief in sovereign bond prices and the probability of default falls to less than 10% over the weekend, somewhat elevated from “pre-stress” levels. The implicit recovery ratio gets hardly revised over this period and remains between 40 and 60 cents on the euro. This is close to the well-documented experience for corporate defaults and the scarce evidence from previous sovereign defaults.

The paper then studies the fit of the model by analyzing pricing errors for individual bonds and relates pricing errors to bond characteristics such as coupon, time-to-maturity and liquidity. This is the first paper to explicitly study the impact of additional variables on the pricing of sovereign bonds.[1] Bond pricing errors (the difference between market prices and fitted prices) are relatively small and there is

[1] Using a different pricing framework, Elton, Gruber, Agrawal and Mann (2004) analyze corporate bond characteristics that affect prices beyond the information contained in ratings.

a strong association between changes in market prices and model prices. Pricing errors decrease with the amount outstanding (a proxy for liquidity).

By analyzing the price adjustments of the outstanding publicly-traded Greek debt, this paper provides an in-depth analysis of how market participants adjusted their assumptions during the European debt crisis of 2010. For policy makers, this information provides a useful basis to study how probability default term-structures and the recovery values evolve over time during stressful market circumstances. For professionals in financial markets, this information can be used to transform price data into meaningful information about implicit default probabilities and recovery values. Investors can use this information to identify investment opportunities. For risk management professionals, finally, the parameter estimates from the model can be used to manage the risk of a portfolio of risky assets. Speculative investments beyond a certain threshold are sometimes precluded from investor portfolios. Non-investment-grade bonds are a prime example. Given that ratings are both sticky and relatively slow to adjust to new information, the framework in this paper can be used to dynamically adjust portfolio holdings to comply with the risk management limits.

The remainder of this paper is organized as follows. Section 2 outlines the sovereign credit model to extract implied default probabilities and the recovery value and Section 3 describes the data. Section 4 discusses the results and contains an analysis of the relation between pricing errors and bond characteristics. Section 5 summarizes and concludes.

2. Model

The binomial model to price credit-risky sovereign debt is set in discrete time and follows the lines of the risk-neutral valuation framework of Jarrow, Lando and Turnbull (1997). Each node in the lattice coincides with the date of a promised cash flow. In contrast to corporate debt, the default event for sovereign debt is a restructuring of the outstanding bonds. This makes the reduced-form approach taken in this paper more suitable than the structural approach originally developed by Merton (1974), where default follows automatically if the value of the firm's assets falls below the value of the liabilities. In a sovereign restructuring, the terms of existing bonds are replaced with more lenient conditions for the obligor, which represents a loss for the bondholder. A crucial ingredient to value credit-risky sovereign bonds is the expected recovery value in the case of a default. For corporate debt, there is rich history of empirical default rates and recovery values. Altman and Kishore (1996) estimate a recovery rate of around 40 cents on the dollar using more than 700 defaulting corporate bond issues over the period 1978-1995. Using a sample of 465 defaulted firms over the period 1982-1999, Acharya, Bharath and Srinivasan (2007) estimate an average recovery value of around 50 cents on the dollar. In comparing the abilities of two rating-based models for corporate debt, Elton, Gruber, Agrawal and Mann (2003) use historical recovery rates. Since sovereign defaults rates have been lower than corporate default rates, a rich historical record of recovery values for sovereign debt restructurings is lacking. Furthermore, recovery rates are very country-specific. Moody's (2007) documents the default experience of sovereign bond issuers over the period 1983-2006. On an issuer-weighted basis, the historical recovery rate is 55% (29% volume-weighted). Merrick (2001) estimates the implicit recovery value for Russia to drop from 27% to 10% in 1998. The implied recovery value of Argentina is relatively stable around 50% over this period.

Given the scarceness of sovereign defaults, it is hard to obtain reliable recovery values. Furthermore, the country-specific variation in recovery values makes it even harder to obtain values relevant for the country of interest. The framework to price sovereign credit-risky debt in the paper therefore extracts both the recovery value and the risk-neutral term-structure of default probabilities from bond prices. The basic idea behind the model is to discount the probability-weighted cash-flows (using risk-neutral probabilities) at risk-free rates. Denote the probability of default at cash-flow date n as π_n, in which case the bondholder receives the unknown recovery value *RV*. If there is no default (probability: 1 - π_n), the bond holder receives the promised cash-flow CF_n. Cash-flows consist of coupon payments and the principal at maturity.

The bond price can be represented as the default-probability-weighted sum of promised cash-flows and the recovery value:

$$P_0 = \sum_{n=1}^{N} df_n \left[\left(CF_n \times S_n \right) + \left(RV \times S_{n-1} \times \pi_n \right) \right], \tag{1}$$

Where df_n is the risk-free discount factor for cash-flow n and S_n is the cumulative probability of survival:

$$S_n = \prod_{i=1}^{n} \left(1 - \pi_i \right) \tag{2}$$

The cumulative probability of survival at time 0 is 1: $S_0 = 1$. The intuition behind the pricing equation is as follows. If the obligor has survived until date $n-1$ and continues to survive at date n, it pays the promised cash-flow. If, however, the obligor has survived until date $n-1$ but defaults at date n, investors receive the recovery value. The price of the bond is the probability-weighted summation over all cash-flow dates.

Previous studies usually assume a time-invariant default rate, see Bhanot (1998) for example, or assume a known recovery value and then estimate the probability of default, see Elton, Gruber, Agrawal and Mann (2003) for example. By imposing a structure on the default rates, I estimate both the recovery value and the term-structure of default rates from a cross-section of sovereign bond prices with different maturities. This is along the lines of Merrick (2001, 2005).[2] I employ a flexible parametrization for the probability of default:

$$\pi_i = \alpha + \beta \times \left(1 - e^{-t_i}\right) / t_i, \tag{3}$$

where t_i is the number of years until the next cash-flow at time i. This parsimonious 2-parameter specification is flexible enough to capture the slope in the term-structure of default rates. The instantaneous default rate is equal to $\alpha+\beta$, while the infinite-maturity default probability equals α. Equation (3) is the first part of the well-known Nelson and Siegel (1987) formula for the term-structure of (default-free) yields, also employed by Merrick (2005). Equation (3) is flexible enough to capture both upward- and downward-sloping term-structures that may arise due to stress in credit markets.

Under the assumption that the recovery value is the same for each outstanding bond (irrespective of the issued amount or time-to-maturity), default rates and the recovery value can be jointly estimated. Combining equations (1) through (3) results in the bond pricing equation:

$$P_0 = \sum_{n=1}^{N} df_n \left[\begin{array}{l} \left(CF_n \times \prod_{i=1}^{n} \left(1 - \left\{\alpha + \beta \times \left(1 - e^{-t_i}\right)/t_i\right\}\right) \right) \\ + \left(RV \times \prod_{i=1}^{n-1} \left(1 - \left\{\alpha + \beta \times \left(1 - e^{-t_i}\right)/t_i\right\}\right) \times \left\{\alpha + \beta \times \left(1 - e^{-t_n}\right)/t_n\right\} \right) \end{array} \right], \tag{4}$$

where α, β and RV are the unknown parameters. These parameters are estimated by minimizing the sum of squared pricing errors (i.e. the differences between market and fitted prices):

[2] There are, however, two material differences that follow from the binomial model structure that I impose. First, the model implies that the probability of default can be written as: $\pi_n = 1 - S_n / S_{n-1}$, whereas Merrick (2001, 2005) assumes that the default probability equals: $\pi_n = S_{n-1} - S_n$. Second, the cumulative probability of survival is $S_n = \prod_{i=1}^{n} \left(1 - \pi_i\right)$ in this framework, whereas Merrick (2001, 2005) assumes that $S_n = \left(1 - \pi_n\right)^n$.

$$\min_{\alpha,\beta,RV} \sum_{j=1}^{J} \left(P_j - \hat{P}_j\right)^2 , \qquad (5)$$

where P_j is the market price and $\hat{P}_j$ is the fitted (or model) price of bond j. Parameters are estimated for each day in the sample period using the J outstanding bonds in each cross-section.

3. Data

The model in equation (4) is estimated for all outstanding bonds of the Hellenic Republic (Greece) for which daily prices are available in April and May 2010. Floating rate debt, zero-coupon bonds, inflation-linked bonds, bonds without daily prices, and bonds with a remaining maturity of less than a month or more than 10 years are excluded. This leaves 30 bonds in the sample for which summary statistics are shown in Table 1.

[Insert Table 1 around here]

Maturity dates range from 2010 to 2020 and coupons from 2% through 7.5%. Figure 1 shows the price developments of the Greek bond with 4.3% coupon and maturity date 03/20/2012 over the sample period. This bond serves as an illustration and the price pattern of the other bonds is very similar over this period.

[Insert Figure 1 around here]

Starting at the beginning of April 2010, bond prices start to deteriorate on concerns about the financial situation in Greece. The developments during the beginning of May are as follows:

- In the weekend of 1 and 2 May, Euro finance ministers approve a EUR 110 billion rescue package for Greece of which EUR 80 billion comes from the EU and EUR 30 billion from the IMF. Greek Finance Minister George Papaconstantinou says that Greece will cut 30 billion in spending over the next three years. Greek bond prices recover somewhat on this announcement, but this recovery is short-lived.
- On May 4, public workers commence a 48-hour national strike in Greece.
- On May 5, Greek protesters throw petrol bombs at a bank in Athens, thereby killing three people.
- On May 6, Greek lawmakers approve drastic austerity cuts to secure international rescue loans. CNBC shows live footage of the riots in Athens. During the 'flash crash', the Dow Jones index drops 1,000 points in less than half an hour.
- In the weekend of 8 and 9 May, European Union finance ministers meet in a 14 hour session and agree on a EUR 750 billion European-wide rescue package. The IMF is also involved and the ECB announces

to buy European public and private debt. Greek bond prices increase substantially on this announcement on the Monday following the announcement.

The final inputs needed to estimate equation (4) are the risk-free discount factors appropriate for each cash-flow date. Constant maturity German zero-coupon yields for maturities 3-, and 6-months, 1- to 10-year, and 15-, 20-, and 30-year are obtained from Bloomberg. To match the exact horizon until the next cash-flow date, I use the flexible yet parsimonious approach of Svensson (1994). The ECB uses the same approach to construct daily published Euro-area term-structures on their website. The functional form is:

$$y_t(n) = \beta_{0t} + \beta_{1t}\left[\frac{1-e^{(-n/\tau_1)}}{\frac{n}{\tau_1}}\right] + \beta_{2t}\left[\frac{1-e^{(-n/\tau_1)}}{\frac{n}{\tau_1}} - e^{\left(-\frac{n}{\tau_1}\right)}\right] + \beta_{3t}\left[\frac{1-e^{(-n/\tau_2)}}{\frac{n}{\tau_2}} - e^{\left(-\frac{n}{\tau_2}\right)}\right], \qquad (6)$$

where $y_t(n)$ is the zero-coupon yield at time t and maturity n, and β_{0t}, β_{1t}, β_{2t}, β_{3t}, τ_1 and τ_2 are the unknown parameters to be estimated by minimizing the sum of squared deviations between observed and fitted yields at each time t. Discount factors are obtained by plugging in the exact date until the next cash-flow in the fitted German zero coupon yield curve.

4. Results

4.1 Estimated default probabilities and recovery values

Figure 2 shows the estimated long-term default rate, and the recovery value during the sample period.

[Insert Figure 2 around here]

Beginning in the second week of April 2010, the estimated long-term default rate steadily increases from around 5% to more than 40%. The impact of the announced rescue package by the EU, IMF and ECB in the weekend of 8 and 9 May 2010 decreases the default rate instantaneously from 40% to less than 10%. The estimated recovery value ranges between 40 and 60 cents on the euro over this period. This is remarkably close to the previously observed recovery values in the corporate bond market (see Altman and Kishore, 1996 and Acharya, Bharath and Srinivasan, 2007) and the limited number of previous sovereign defaults (see Moody's, 2007). The chain of events during April and May 2010 thus primarily affected the implied default probability of Greece and not so much the expected recovery value of the bonds in a restructuring event. The pre-announcement default probability hovers around 5%. After the rescue package is announced, the new level settles at a higher level around 10%.

The stress in the sovereign bond market during this period also affected the shape of the risk-neutral term-structure. Figure 3 presents the estimated risk-neutral term-structures on Friday May 7 and Monday May 10, the trading day before and after the announcement of the EU rescue package.

[Insert Figure 3 around here]

Figure 3 shows that the shape of the default rate term-structure changes materially after the announcement. Although the instantaneous probability of default decreases somewhat, the gap widens significantly for longer cash-flow dates. For longer-term dates, the probability of default is 40% on Friday May 7 and less than 10% on Monday May 10. Moreover, the term-structure also flattens significantly.

4.2 Model fit and the determinants of pricing errors

This paper shows how to estimate the risk-neutral term-structure of default probabilities and the implied recovery value. The framework employs the cross-section of outstanding Greek bonds at each trading day in April and May 2010. The parameters are estimated by minimizing the squared differences between actual and model prices. How well the model fits individual bonds prices is the subject of this section. There are three central questions. First, how large are pricing errors for individual bonds? Second, what is the time-series relationship between changes in actual prices and changes in model prices? Third and finally, do individual bond characteristics explain average pricing errors?

To examine the first question, the left panel of Table 2 presents the average pricing error and standard deviation of pricing errors for each individual bond issue (in euro). To answer the second question, the right panel in Table 2 reports the parameter estimates, t-values and R-square values from a regression of changes in actual bond prices and changes in fitted bond prices:

$$\Delta P_{j,t} = c_0 + c_1 \Delta \hat{P}_{j,t} + \eta_{j,t} \ , \tag{7}$$

where $\Delta P_{j,t}$ is the change in the actual price of bond j ($P_{j,t} - P_{j,t-1}$), $\Delta \hat{P}_{j,t}$ is the change in the fitted price of bond j ($\hat{P}_{j,t} - \hat{P}_{j,t-1}$), $\eta_{j,t}$ is the error term and c_0 and c_1 are the estimated parameters.

[Insert Table 2 around here]

The individual bond pricing errors are fairly small and the intercept terms from the changes in price regressions are never significantly different from zero. In addition, the explanatory power for the regressions are very high (varying from a low of 87% to a high of 99%). This signals that changes in actual bond prices are closely tracked by changes in model prices. Finally, the slope coefficients are often close to unity. The model thus seems flexible enough to price a wide array of outstanding bonds that vary in terms of coupon levels, maturities and liquidity. Nevertheless, there are exceptions at the individual bond level. An obvious example is the longest-maturity bond (the GGB 6 1/4 06/19/20). Actual prices are, on average, 3.6 points higher than what the model would imply. Therefore, a natural question is whether average pricing errors are related to bond characteristics. For example, is the model perhaps less accurate in pricing long-maturity bonds than pricing short- and intermediate-maturity bonds?

Elton, Gruber, Agrawal and Mann (2004) examine factors that affect the pricing of corporate bonds. The authors relate the pricing errors of a large panel of corporate bonds to individual bond characteristics such as default risk, liquidity, coupons. Incorporating some of these characteristics enhances the accuracy of their bond pricing model. For the first time in the literature, this paper relates individual bond characteristics to systematic (or average) bond pricing errors for a panel of sovereign bonds. Three bond characteristics are examined: the coupon rate, the issued amount, and the time-to-maturity. Elton, Gruber, Agrawal and Mann (2004) argue that the coupon of the bond may be of interest to investors because of differential tax treatments between interest income and capital gains. Even though both may be taxed at the same rate, there could be differences in the time at which taxes have to be paid. Investors furthermore care about the liquidity of a bond, as this affects the speed and price at which the bond can be traded. The issued amount is included as a proxy for bond liquidity. Third and finally, the time-to-maturity of the bond is included to analyze whether model accuracy differs with maturity.

The model specification is:

$$\overline{e}_j = c + \sum_{k=1}^{K} b_k F_{kj} + u_j \quad , \tag{8}$$

where $\overline{e}_j$ is the average pricing error of bond $j : \frac{1}{T}\sum_{t=1}^{T}\left(P_{j,t} - \hat{P}_{j,t}\right)$ and F_{kj} is explanatory factor k for bond j. The left panel in Table 3 presents estimates of the model without explanatory variables and the right panel is the model with the three bond characteristics.

[Insert Table 3 around here]

The left panel of Table 3 shows that the average pricing error across bonds is 5 cents, which is statistically indistinguishable from zero (t-value 0.78). Furthermore, the model estimates indicate that pricing errors increase with coupons and time-to-maturity, but both are insignificant. The relation with the amount outstanding, however, is significant (t-value -1.91). The association is negative, which implies that more liquid bonds (larger outstanding amount) have lower pricing errors, on average.

5. Summary and Conclusions

This paper presents a framework to simultaneously extract the risk-neutral term-structure of default probabilities and the expected recovery value from the cross-section of sovereign bond prices. This paper improves existing reduced-form credit risk models in two main directions. First, default probabilities can vary with the time to the next promised cash-flow (i.e. the model allows for a term-structure of default risk which has been shown to exist in the corporate bond market). Second, the model also provides an implicit recovery value. This is especially valuable in the context of sovereign credit risk, as historical defaults are both rare and country-specific. It is therefore almost impossible to base estimates on previous default records.

For investors, the framework from this paper can be used to transform raw price data into readily interpretable information on default probabilities and recovery values. This information can be used to assess the opportunities and risks in dynamic credit trading strategies. Risk managers could base the appropriateness of sovereign credit-risky investments on this methodology, reducing the need to rely on less-timely and sticky credit ratings. For policy makers, the results in this paper provide an opportunity to better understand how probability-of-default term-structures and implied recovery values evolve over time and how markets respond to policy measures during times of financial stress.

The model is applied to Greece during April and May 2010. This sample period is characterized by a sharp re-pricing of Greek sovereign debt, the announcement of severe austerity measures, great social unrest, and finally the announcement of a significant European rescue package. Model estimates imply that the probability of a Greek credit event rises quickly from below 5% to more than 40% during this period. After EU finance ministers, the ECB and the IMF announce the rescue package, the default probability quickly drops to a new level around 10%, somewhat elevated from pre-stress levels. Market participants do not revise their recovery value assumptions materially during this period, which stays between 40 and 60 cents on the euro. This is very close to the previously documented evidence for the corporate bond market and the limited evidence from sovereign debt restructurings.

An analysis of pricing errors (actual prices minus fitted prices) shows that the model has a good fit. The average pricing error, however, decreases with the amount outstanding (a proxy for liquidity). A further exploration of the link between liquidity and credit risk models seems an interesting avenue for future work.

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Table 1: Overview of Outstanding Greek Bonds

Issue	Coupon	Outstanding amount (€ bln.)	Issue Date	Maturity Date	Price range Min	Price range Max	Yield range Min	Yield range Max
GGB 6 09/29/10	6.00	0.180	09/29/2000	09/29/2010	96.11	100.54	4.69	16.25
GGB 2 01/11/11	2.00	0.016	01/11/2002	01/11/2011	91.14	97.91	4.82	16.62
GGB 3.8 03/20/11	3.80	8.810	02/01/2008	03/20/2011	89.03	99.06	4.82	18.07
GGB 5.35 03/30/11	5.35	0.176	03/30/2001	03/30/2011	91.01	100.39	4.93	16.95
GGB 5.35 05/18/11	5.35	6.460	01/30/2001	05/18/2011	87.56	100.58	4.79	19.57
GGB 5.35 05/31/11	5.35	0.417	05/31/2001	05/31/2011	89.43	100.37	4.99	17.15
GGB 3.9 08/20/11	3.90	6.000	05/24/2006	08/20/2011	83.94	98.84	4.78	18.81
GGB 4.4 12/19/11	4.40	1.172	12/19/2008	12/19/2011	83.41	98.71	5.20	17.00
GGB 2 01/11/12	2.00	0.016	01/11/2002	01/11/2012	79.67	94.70	5.22	16.97
GGB 4.3 03/20/12	4.30	14.500	02/17/2009	03/20/2012	79.57	98.60	5.07	18.22
GGB 5 1/4 05/18/12	5.25	8.060	01/17/2002	05/18/2012	79.04	99.97	5.26	18.65
GGB 5 1/4 06/20/12	5.25	0.414	06/20/2002	06/20/2012	80.57	99.70	5.39	16.95
GGB 4.1 08/20/12	4.10	7.845	03/02/2007	08/20/2012	75.85	97.24	5.36	17.90
GGB 4.6 05/20/13	4.60	7.980	01/17/2003	05/20/2013	71.68	96.95	5.69	17.43
GGB 7 1/2 05/20/13	7.50	2.498	05/20/1998	05/20/2013	78.02	104.63	5.82	17.46
GGB 4 08/20/13	4.00	5.850	03/26/2008	08/20/2013	70.11	94.60	5.81	16.51
GGB 4.52 09/30/13	4.52	0.299	09/30/2003	09/30/2013	71.35	96.06	5.79	16.12
GGB 6 1/2 01/11/14	6.50	4.602	01/11/1999	01/11/2014	73.79	101.77	5.95	16.56
GGB 4 1/2 05/20/14	4.50	8.523	01/13/2004	05/20/2014	66.74	94.65	6.00	16.44
GGB 5 1/2 08/20/14	5.50	12.500	01/28/2009	08/20/2014	67.20	97.76	6.07	16.78
GGB 3.7 07/20/15	3.70	9.584	02/22/2005	07/20/2015	61.82	89.59	6.06	14.71
GGB 6.1 08/20/15	6.10	8.000	02/02/2010	08/20/2015	69.87	99.90	6.09	14.56
GGB 3.7 11/10/15	3.70	0.375	11/10/2005	11/10/2015	64.16	88.87	6.10	13.27
GGB 3.6 07/20/16	3.60	7.550	01/18/2006	07/20/2016	59.58	87.05	6.14	13.69
GGB 5.9 04/20/17	5.90	5.000	04/07/2010	04/20/2017	66.78	97.65	6.32	13.58
GGB 4.3 07/20/17	4.30	10.840	01/17/2007	07/20/2017	59.24	88.24	6.36	13.50
GGB 4.6 07/20/18	4.60	7.732	05/13/2008	07/20/2018	60.86	88.80	6.38	12.50
GGB 6 07/19/19	6.00	15.500	03/11/2009	07/19/2019	63.23	96.79	6.46	13.09
GGB 6 1/2 10/22/19	6.50	8.023	01/14/2000	10/22/2019	65.08	100.26	6.46	13.15
GGB 6 1/4 06/19/20	6.25	5.000	03/11/2010	06/19/2020	65.32	97.86	6.53	12.43

The table shows the outstanding bonds included in the sample. The sample period is 04/01/2010 – 05/31/2010.

Table 2: Pricing Errors per Bond

Issue	Average pricing error	Standard deviation	c_0	T-value	c_1	T-value	R^2
GGB 6 09/29/10	0.97	0.87	0.00	0.08	0.55	17.33	0.88
GGB 2 01/11/11	1.20	0.33	0.01	0.26	0.82	23.18	0.93
GGB 3.8 03/20/11	-0.21	0.86	0.01	0.14	1.23	18.67	0.90
GGB 5.35 03/30/11	-0.13	0.33	-0.01	-0.19	0.90	22.12	0.92
GGB 5.35 05/18/11	0.93	0.78	-0.03	-0.33	1.04	20.73	0.91
GGB 5.35 05/31/11	1.44	0.82	-0.03	-0.36	0.76	17.13	0.88
GGB 3.9 08/20/11	1.12	0.69	0.02	0.22	1.11	22.90	0.93
GGB 4.4 12/19/11	0.09	0.45	-0.01	-0.15	0.85	26.90	0.95
GGB 2 01/11/12	0.12	0.55	-0.01	-0.09	0.89	27.69	0.95
GGB 4.3 03/20/12	-0.63	1.05	0.02	0.22	1.18	38.52	0.97
GGB 5 1/4 05/18/12	0.16	0.68	0.00	-0.01	1.22	41.08	0.98
GGB 5 1/4 06/20/12	0.50	0.46	0.00	0.03	0.88	31.90	0.96
GGB 4.1 08/20/12	-0.08	0.95	0.03	0.29	1.14	36.06	0.97
GGB 4.6 05/20/13	-0.28	0.84	-0.01	-0.07	1.15	32.95	0.96
GGB 7 1/2 05/20/13	-0.75	0.80	0.03	0.25	1.05	30.24	0.96
GGB 4 08/20/13	-0.48	0.81	0.02	0.27	1.05	39.95	0.98
GGB 4.52 09/30/13	-0.63	0.62	-0.02	-0.28	0.85	36.61	0.97
GGB 6 1/2 01/11/14	-0.71	0.63	0.00	0.01	0.95	43.24	0.98
GGB 4 1/2 05/20/14	-0.87	0.71	-0.02	-0.32	1.09	49.32	0.98
GGB 5 1/2 08/20/14	-1.26	0.51	0.00	-0.04	1.00	63.03	0.99
GGB 3.7 07/20/15	-0.81	0.80	-0.02	-0.27	1.06	44.27	0.98
GGB 6.1 08/20/15	0.05	1.07	-0.06	-0.54	0.87	38.75	0.97
GGB 3.7 11/10/15	-1.07	1.81	-0.10	-0.63	0.69	16.03	0.87
GGB 3.6 07/20/16	-0.68	0.77	0.00	0.09	1.06	70.07	0.99
GGB 5.9 04/20/17	0.33	1.01	-0.02	-0.20	0.91	44.98	0.98
GGB 4.3 07/20/17	-1.15	0.67	0.01	0.17	1.07	62.32	0.99
GGB 4.6 07/20/18	-0.41	0.71	0.04	0.49	1.12	47.14	0.98
GGB 6 07/19/19	0.01	0.96	-0.01	-0.10	1.04	44.18	0.98
GGB 6 1/2 10/22/19	1.20	1.26	0.01	0.12	0.99	42.26	0.98
GGB 6 1/4 06/19/20	3.60	1.79	0.08	0.80	1.01	45.29	0.98

The left panel of the table shows the average and standard deviation of pricing errors over the sample period for each bond as well as the standard deviation (in euro). The right panel shows the parameter estimates, t-values and R-squared from a regression of changes in market prices on changes in model prices. The sample period is April-May 2010.

Table 3: Relation between Bond Characteristics and Average Pricing Errors

	Model 1		Model 2	
	Estimate	**T-value**	**Estimate**	**T-value**
Intercept	0.05	0.78	-0.32	-0.44
	(0.18)		*(0.74)*	
Coupon			0.13	0.86
			(0.15)	
Issued amount			-0.09	-1.91
			(0.04)	
Maturity			0.06	0.82
			(0.07)	
Adj. R^2			0.05	

The table shows the results from a regression of average bond pricing errors on an constant (Model 1) and on a constant and the bond characteristics coupon rate, issued amount, and time-to-maturity (Model 2). Standard errors are in parentheses.

Figure 1: Price Development of the GGB 4.3 03/20/2012 Bond: April and May 2010

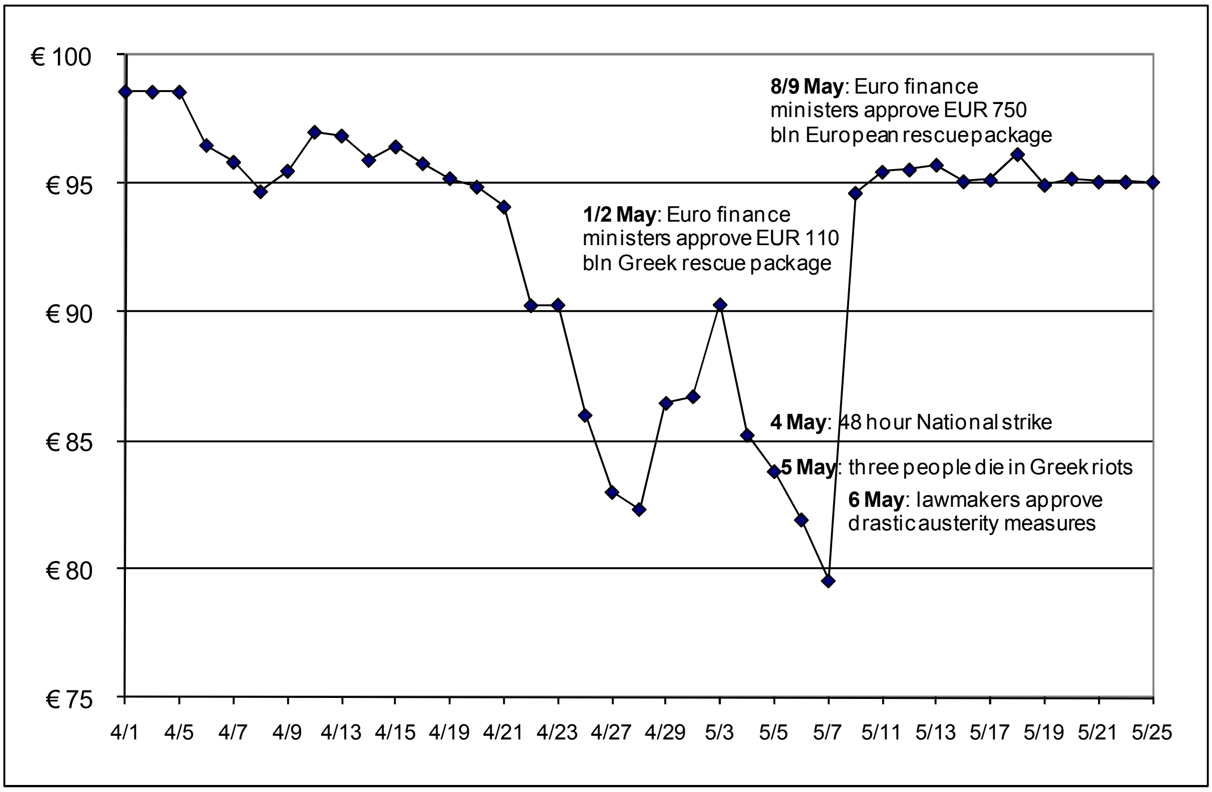
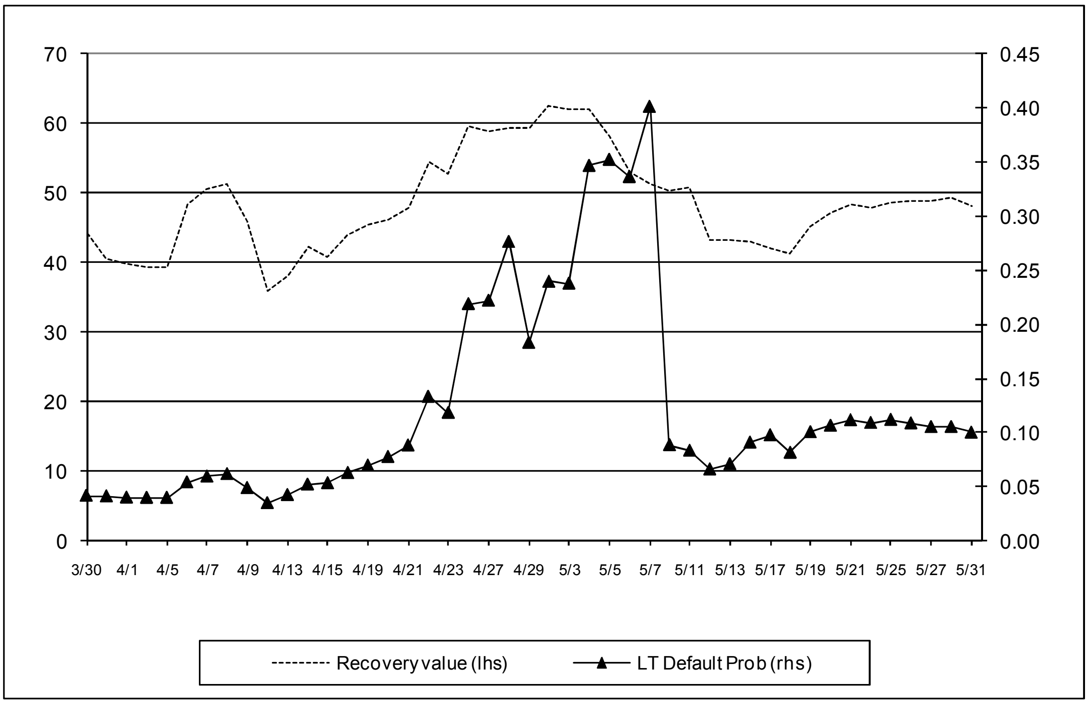
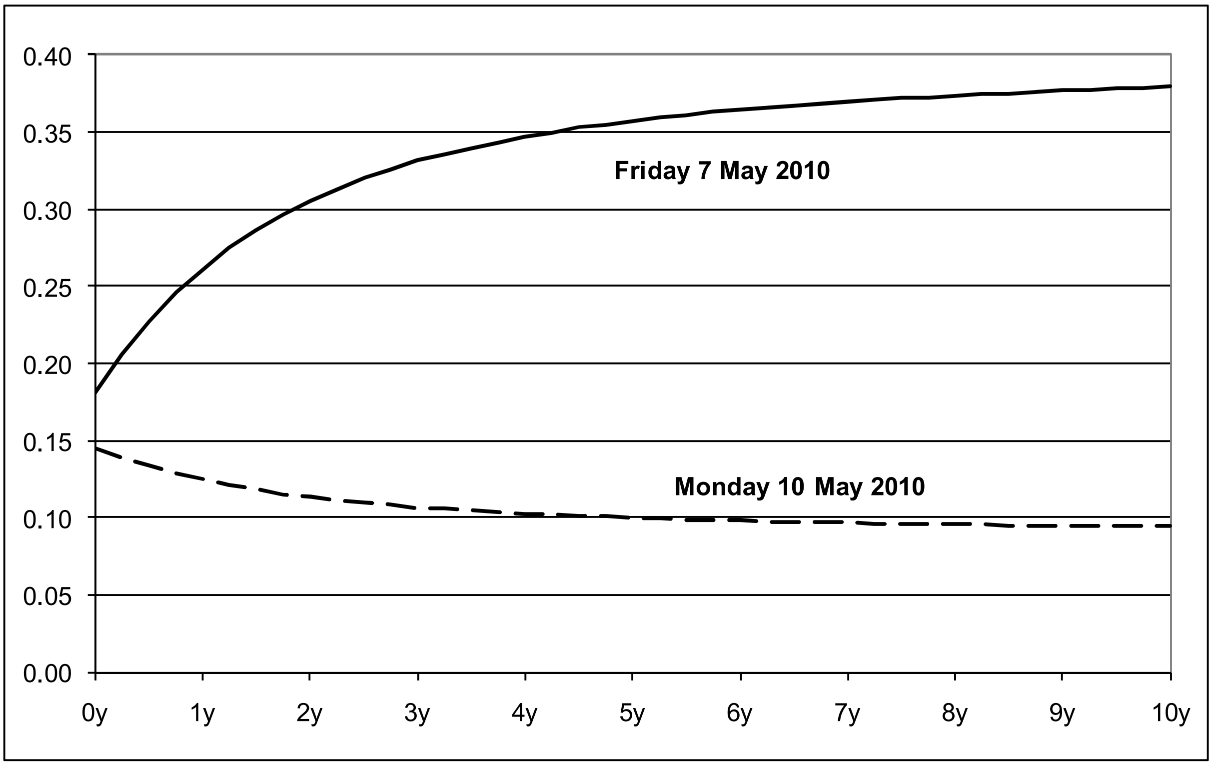


Figure 2: Estimated Long-Term Default Probability and Recovery Value



The graph shows the estimated long-term default probability, α in equation (4) (right axis), and the estimated recovery value (left axis) during April and May 2010.

Figure 3: Estimated Risk-Neutral Default Probability Term-Structures



The graph shows the risk-neutral term-structure of default probabilities as implied by the model in equation (4) on Friday 7 May and Monday 10 May, the trading day before and after the announcement of the EU rescue package.