Pricing sovereign credit risk of an emerging market

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Abstract: We analyze the market assessment of sovereign credit risk in an emerging market. A reduced-form model to price the CDS spreads enables us to derive probabilities of default (PD) and loss given default (LGD) from the quotations of sovereign CDS contracts. We compare different specifications of the models allowing for the fixed and time-varying LGD and use them to analyze sovereign credit risk of Polish debt in the period of a global financial crisis. Our results point to the presence of a low loss given default and a relatively high probability of default for Poland during the recent financial crisis. The highest probability of default has been observed in the months following collapse of the Lehman Brothers bank. We also find that correlations between the PDs and the CDS spreads are not very high and they heavily depend on the maturity of the sovereign CDS.

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1. Introduction

A thorough evaluation of sovereign credit risk is an important element in the decision making process of international investors. Sovereign credit risk is commonly used as a measure of the resilience of a country to stand economic shocks. Furthermore, a deterioration of the sovereign credit risk spreads quickly to the premia demanded for holding locally traded financial instruments, and equally hampers liquidity conditions in domestic markets. The market assessment of sovereign credit risk is also crucial for central governments, as the price of sovereign debt and the ability to raise funds from private investors, heavily depends on it. In this paper we analyze the sovereign credit risk of an emerging market, Poland, by means of some recently proposed econometric techniques.

Poland is an interesting market to consider because it is a relatively large economy in Central and Eastern Europe that was successfully transformed from a centrally planned economy to a market-based economy. Poland did not suffer from the macroeconomic and financial imbalances that characterized many emerging and developed economies in the years before the global financial crisis. Its markets were nonetheless affected, first by the global financial turbulences which were brought by the collapse of Lehmann Brothers in September 2008, and second, by the sovereign debt crisis in the Eurozone in the years 2011-2012. This suggests that the case of Poland may serve as a natural laboratory for studying contagion in financial markets. In particular, for studying the transmission of shocks from turbulent global financial markets to calm domestic markets with sound underlying fundamentals. In this context, it is worth recalling that Poland was also the only European economy which recorded positive GDP growth throughout this recent crisis.

In this paper we use the information contained in the term structure of credit default swaps (CDS) to evaluate markets perception of sovereign credit risk. The pricing formula for CDS spreads allows disentangling the probability of default (PD) from the loss given default (LGD) associated with holding debt over a certain time horizon. Indeed, we are not only interested in studying the time-varying estimates of sovereign credit risk, e.g. the level of the PD curve, but also the projections of this risk at different horizons, i.e. the slope of the PD curve.

While separate identification of PD and LGD remains empirically challenging, it is in principle a valuable information for early warning models of financial crises and other methods to predict financial defaults. In line with some of the recent literature, we use models which allow separate identification of the probability of default (PD) and the loss given default (LGD) embedded in sovereign debt. The models used are similar to those recently developed by Pan and Singleton (2008) and Doshi (2011). In contrast with the model of Pan and Singleton which used affine functions, our models employ quadratic functions of unobservable factors to model the underlying dynamics of PD and LGD. This approach is in line with Doshi (2011) and it ensures that both PD and LGD are bounded between zero and one. We estimate two main types of models. First, models which assume that the LGD is constant in time and across maturities while the PD is allowed to change in time and across maturities. Second, models where both LGD and PD are allowed to change in time and across maturities.

In our empirical analysis, we find that market participants did not envisage large potential losses in the event of a default on Polish sovereign debt. Our LGD estimates for Poland did not exceed 5% and did not display large fluctuations during the crisis years of 2008-2012. The probabilities of default, however, reacted strongly to the unfolding of the subprime crisis in the US and to the failure of Lehman Brothers. When looking at the term structure of the CDS spreads, it transpires that movements of the original CDS over short maturities are strongly driven by changes in the short-term PDs, while for longer maturities, changes in CDS spreads are more closely associated with the developments in LGDs. This fact is important because the CDS spreads for Polish sovereign debt have been less volatile during the crisis than the spreads of several other developed and emerging markets in Europe. This suggests that, at the peaks of tensions, investors were possibly not seriously concerned about the solvency of the Polish government (LGD remained low), but rather about their ability to find enough liquidity to honor its payments at times of turmoil (PD went up).

The remainder of the paper is organized as follows. Section 2 presents an overview of studies related to analyses of sovereign CDS contracts for emerging markets in Central and Eastern Europe. Related methods to identify PD and LGD from market CDS spreads have also been discussed. Section 3 describes our method to estimate the model-implied PDs and LGDs. Section 4 discusses empirical results and the final section concludes.

2. Literature Overview

The use of credit default swaps (CDS) as an indicator of sovereign credit risk has been studied by numerous researchers and has been applied for different countries and economic areas. However, there are only a few analyses of these instruments for emerging countries of Central and Eastern Europe (CEE). Some of the studies are provided directly for the CEE countries while other studies include the CEE countries as a part of a more aggregated group.

Most of the studies analyzed financial spillovers and contagion between the sovereign CDS of different countries. Kisgergely (2009) examined daily values of CDS contracts of 46 advanced and emerging countries from 2006-2009 period. This study focused on estimation and interpretation of the global component and its role in explaining the dynamics of sovereign CDS premium. The results suggest that the global component determined about 90 per cent of the volatility of sovereign CDS spreads during the financial crisis compared with the 57 per cent explanatory power before the financial turbulence. Interdependence among sovereign CDS spreads of Central European countries during the recent Greek and Hungarian financial crises was examined by Kliber (2011). This author employed volatility (GARCH and stochastic volatility) models on values of CDS spreads for the 2008-2011 period. The analysis revealed evidence of contagion effects to the Central Europe from outside of this region.

Adam (2013) investigated linkages between sovereign CDS spreads of the economies in Asia, Europe, the Middle East and Africa, and Latin America using daily pricing data during the period from 2008 to 2012. This author employed the financial spillover index of Diebold and Yilmaz (2009) and found that shocks were transmitted from downgraded countries and they varied over time. Beirne and Fratzscher (2013) analyzed the factors of sovereign risk for 31 countries, including Poland, the Czech Republic and Hungary. They found evidence of fundamental contagion and herding contagion. Fundamental contagion was interpreted as an increase of financial market sensitivity to economic fundamentals in all analyzed economies. Meanwhile, herding contagion denoted financial spillovers beyond fundamental links between markets. Herding was present only in a few markets during the crisis.

Afonso, Furceri and Gomes (2012) investigated the reaction of sovereign bond yields and CDS spreads on negative and positive rating announcements in twenty four countries of the European Union (EU) including Poland. They showed the increased response of CDS spreads to negative rating events after Lehman Brothers bankruptcy. These authors also considered differences in reactions to rating news between the countries located in the Eurozone and those outside the Eurozone. They found spillover effects in the direction from lower rated countries to higher rated countries.

The works most related to our research are those of Gapen et al. (2008), Plank (2010), and Longstaff et al. (2011). The former study applied contingent claim analysis to investigate sovereign risk of twelve emerging markets including Poland. Then the implied risk of default of each country was compared with quotations of the sovereign CDS spreads. Gapen et al.

(2008) found strong correlation between their measure of sovereign risk and other market based measures, including sovereign CDS spreads and probabilities of default derived from sovereign CDS.

Plank (2010) also analyzed sovereign credit risk in a framework of macroeconomic fundamentals. The author built a structural model explaining CDS spreads for six emerging countries (Poland, Czech Republic, Hungary, Russia, Romania, and Turkey). Using this model, he derived the measure of probability of default dependent on a country's access to external capital flows and its ability to repay external debt. The probability of default was then used to price sovereign CDS contracts for each country.

Longstaff, Pan, Pedersen, Singleton (2011) investigated factors explaining sovereign risk in a number of emerging markets including Poland. They used an affine term-structure model of CDS spreads to derive a 'distress' risk premium associated with unpredictable variation in the arrival rate of credit events. The 'distress' risk premium was interpreted as 'compensation for unforecastable distress risk, an unexpected increase in the probability that a sovereign issuer will experience a credit event'.

Our research applies a methodology strongly related to other analyses of the CDS markets not necessarily linked to the CEE region. Pan and Singleton (2008) measured both the probability of default (PD) and the loss given default (LGD) in a number of emerging markets using the affine term-structure model of sovereign CDS spreads. In their paper, the LGD was assumed to be fixed in time. The model of Pan and Singleton (2008) was often applied in subsequent research (e.g., Longstaff, Pan, Pedersen, Singleton, 2011).

Doshi (2011) applied a similar reduced-form model to investigate corporate credit risk. This author identified the PD and LGD with the use of senior and subordinate credit default swaps. Both the PD and the LGD were allowed to vary in time. Changes in PD and in LGD were described by autoregressive processes of some unobservable factors. A quadratic specification of these factors has been employed, in contrast to the linear specification in Pan and Singleton (2008). The quadratic specifications of asset pricing models have also been investigated for instance by Leippold and Wu (2002), Ahn, Dittmar and Gallant (2002), Ang, Boivin, Dong, Loo-Kung (2011). The approach to compute a time-varying LGD is consistent with empirical observations of historical sovereign defaults and historical spreads (e.g., Trebesch, Papaioannou and Das, 2012).

Finally, Camba-Méndez and Serwa (2014) built a reduced-form model analogous to Doshi (2011) and investigated changes in the PD and in the LGD for seven markets in the euro area during the sovereign debt crisis in 2011-2012. Their approach to identify the two measures of sovereign risk was different from that of Doshi (2011), and it was based on the term structure of the CDS contracts, as suggested by Christensen (2007). Camba-Méndez and Serwa analyzed macroeconomic and institutional factors explaining changes in PD and LGD, as well as spillovers of sovereign risk between European markets. Their model and the identification approach are also used in our study to analyze the sovereign risk on the Polish market. We also explore the specifications of the CDS model with the fixed LGD, as in Pan and Singleton (2008), where investors either know the level of LGD or they assume that it remains constant in time.

3. Pricing sovereign CDS spreads

In this section we have described the model used to price the risk of a sovereign default. This model has been used to derive the probability of default and the loss given default from the CDS spreads quoted on the market. The main element of our model is the pricing formula of sovereign CDS spreads. Sovereign credit default swap is a financial contract developed to let compensate investors in the event of a sovereign default. In the financial terminology such an event is called a 'credit event'.

Credit event is the focus point within the terms of the CDS contract. Credit event is defined as a sudden and significant destructive change in borrower's creditworthiness, often accompanied by deterioration of the credit rating. The list of typical events included in a sovereign CDS contract are failure to pay, obligation acceleration, repudiation/moratorium or debt restructuring. The sovereign credit event does not embrace "default" as there is no operable international court that applies to sovereign issuers (Pan and Singleton, 2008, p. 2348).

The two parties of the CDS contract are the 'protection buyer' and the 'protection seller'. The protection buyer pays a premium to the protection seller each quarter up to the termination date of the CDS contract. The expected value of the discounted payments equals approximately (O'Kane and Turnbull, 2003):

$$PB_t = E_t^Q \left\{ S_t \cdot 0.25 \sum_{i=1}^{N} D(t+i)\left[1_{(\tau > t+i)} + 0.5\left(1_{(\tau > t+i-1)} - 1_{(\tau > t+i)}\right)\right] \right\} \quad , \qquad (1)$$

where S_t is the annualized premium (spread) paid by the protection buyer, N is the number of contractual payment dates until the contract matures; $1_{(\cdot)}$ is an indicator function equal to one when its argument is true and zero otherwise; τ is defined as a time of the credit event (default). If the credit event occurs during the interval $(t+j-1, t+j)$, the protection seller makes a payment LGD. If the credit event does not occur the protection seller makes no payment at all. The expected value of the payment equals:

$$PS_t = E_t^Q\left\{\sum_{j=1}^{M} D(t+j)LGD_{t+j-1}^Q 1_{(t+j-1<\tau<t+i)}\right\} \quad , \tag{2}$$

where M is the number of periods to the termination of the CDS contract. The no-arbitrage condition assumes that $PB_t = PS_t$. Therefore, the value of the spread S_t may be written as:

$$S_t = \frac{E_t^Q\{\sum_{j=1}^{M} D(t+j)LGD_{t+j-1}^Q 1_{(t+j-1<\tau<t+i)}\}}{E_t^Q\{0.25\sum_{i=1}^{N} D(t+i)[1_{(\tau>t+i)} + 0.5(1_{(\tau>t+i-1)} - 1_{(\tau>t+i)})]\}} \quad . \tag{3}$$

The expression $E_t^Q\{1_{(\tau>t+i)}\}$ denotes the survival probability of the obligor up to time $t+i$ and $E_t^Q\{LGD_{t+i}^Q\}$ is the expected loss given default at time $t+i$. We model both expressions with the use of the homogenous Poisson processes with time-varying intensity parameters. The intensity parameters are defined as quadratic functions of some exogenous factors x and z to ensure that the PD and LGD stay in the range between zero and one:

$$E_t^Q\{1_{(\tau>t+i)}\} = E_t^Q\left\{exp\left(-\sum_{h=0}^{i} x_{t+h}^2\right)\right\} \quad , \tag{4}$$

$$E_t^Q\{LGD_{t+i}^Q\} = E_t^Q\{exp(-z_{t+h}^2)\} \quad . \tag{5}$$

Probability of default between time t and $t+i$ is defined as one minus the survival probability, $PD_{t+i}^Q = 1 - E_t^Q\{1_{(\tau>t+i)}\}$. We further assume that both factors x and z follow an autoregressive process:

$$\begin{pmatrix} x_t \\ z_t \end{pmatrix} = \begin{pmatrix} m_x \\ m_z \end{pmatrix} + \begin{pmatrix} a_x & 0 \\ 0 & a_z \end{pmatrix}\begin{pmatrix} x_{t-1} \\ z_{t-1} \end{pmatrix} + \begin{pmatrix} u_t \\ v_t \end{pmatrix} \quad , \tag{6}$$

where the error terms are normally distributed:

$$\begin{pmatrix} u_t \\ v_t \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{xx} & \sigma_{xz} \\ \sigma_{xz} & \sigma_{zz} \end{pmatrix}\right) \quad .$$

We can deduce from equations (3), (4) and (5) that the spread S_t is a function of the factors x_t and z_t. The fit of the pricing model is never perfect and we can write the pricing equation as:

$$s_t = f(x_t, z_t) + e_t \quad , \tag{7}$$

where we express the spread in log terms, $s_t = \log(S_t)$, to account for large volatility of this variable, especially during financial crises.

Our identification and estimation approach relies on the whole term structure of CDS spreads. We employ ten CDS contracts with maturities between one year and ten years. Thus, the same factors x_t and z_t enter equation (7) to fit ten CDS contracts with different maturities:

$$s_{i,t} = f_i(x_t, z_t) + e_{i,t} \quad , \tag{8}$$

where $i = 1Y, 2Y, \dots 10Y$ denotes termination date of the contract. To simplify notation, we define vectors $\mathbf{s}_t = [s_{1Y,t} \quad s_{2Y,t} \quad \cdots \quad s_{10Y,t}]'$, $\mathbf{e}_t = [e_{1Y,t} \quad e_{2Y,t} \quad \cdots \quad e_{10Y,t}]'$, and $\boldsymbol{f}(\mathbf{x}_t) = [f_{1Y}(x_t, z_t) \quad f_{2Y}(x_t, z_t) \quad \dots \quad f_{10Y}(x_t, z_t)]'$.

Our final model takes the following form:

$$\begin{cases} \mathbf{s}_t = \boldsymbol{f}(\mathbf{x}_t) + \mathbf{e}_t \\ \mathbf{x}_t = \boldsymbol{\alpha} + \mathbf{B}\mathbf{x}_{t-1} + \mathbf{u}_t \end{cases} , \tag{9}$$

where $\mathbf{x}_t = [x_t \quad z_t]'$ is the vector of unobservable factors following the autoregressive processes; $\boldsymbol{\alpha} = [\alpha_x \quad \alpha_z]'$ is the vector of constant terms; $\mathbf{B} = \begin{bmatrix} \beta_{\boldsymbol{x}} & 0 \\ 0 & \beta_{\boldsymbol{z}} \end{bmatrix}$ is the matrix of autoregressive coefficients. We assume that the vector of pricing errors $\mathbf{e}_t$ is normally distributed, $\mathbf{e}_t \sim N(\mathbf{0}, \sigma_{ee}\mathbf{I})$. The errors are linearly independent and they all have the same finite variance σ_{ee}; **I** is the identity matrix.

The procedure to derive the PD and the LGD from quotations of financial instruments for each period and all maturities is the following. When all parameters in model (9) are known the ‘unscented’ Kalman filter is applied to estimate the values of the unobservable factors x_t and z_t for $t = 1, 2, \dots, T$. The starting values for these factors (x_0 and z_0, respectively) are needed to start the filtering process. The PDs and the LGDs are then computed for $t = 1, 2, \dots, T$ and $i = 1Y, 2Y, \dots 10Y$ with the use of equations (4) and (5).

The parameters are usually not known *apriori* and they need to be estimated simultaneously with the unobservable factors x_t and z_t. We apply the nonlinear least squares method to find the estimates of parameters in the model. The full set of unknown parameters is defined as $\boldsymbol{\theta} = [\alpha_x \quad \alpha_z \quad \beta_{\boldsymbol{x}} \quad \beta_{\boldsymbol{z}} \quad \sigma_{xx} \quad \sigma_{zz} \quad \sigma_{xz} \quad \sigma_{ee} \quad x_0 \quad z_0]$. Technical details of this filtering and estimation approach can be found in Doshi (2011) and in Camba-Méndez and Serwa (2014).

For the sake of comparison and robustness check, we investigate three specifications of our model. The first specification is the most general model with the time-varying PD and the time-varying LGD, described by formula (9). We denote that specification as the TVLGD model. The second specification also uses the time-varying PD. However, the LGD is assumed to be constant in time and its value is estimated along other parameters of the model. We name this specification the CONSTLGD model. The third specification of the model is the same as the second one, but the constant LGD is not estimated and it is fixed at some specific level known by market participants. We name this specification the FIXEDLGD model. Both the second and the third specification imply that the equation explaining z_t is excluded from the formula (6) and the LGD_t^Q is fixed (or estimated) at some level, say, LGD^*.

4. Empirical results

4.1. Data

We use euro-denominated CDS contracts on Polish sovereign debt from Thomson Reuters. In particular, we employ end-of-month observations from January 2004 to January 2014 of ten contracts with maturities ranging from one to ten years. Missing observations, across time and across maturities, have been linearly interpolated from adjacent observations. The risk-free interest rates used to compute the discount factors in the pricing formula of the CDS contracts, have been taken from the euro area yield curve provided by the European Central Bank.

4.2. Parameter estimation results

Estimation results are presented in Table 1. The FIXEDLGD model has been estimated setting the parameter LGD^* to three alternative values: 0.25, 0.50, and 0.75. The former and latter values are commonly chosen by market practitioners when modelling CDS spreads for either emerging markets ($LGD^* = 0.75$), or developed markets ($LGD^* = 0.25$). We further choose to estimate a model with a fixed LGD of 0.50 because this is approximately the average loss rate observed in historical sovereign defaults, see e.g. Moody's Investors Service (2011) and Cruces and Trebesch (2013).

The parameters governing the dynamics of the unobservable factor x_t are very similar across the various models estimated. For all models the parameter α_x is close to zero and $\beta_{\boldsymbol{x}}$ is close to one, i.e. the data generating process of x_t resembles a random walk. The same applies to the data generating process for z_t in the TVLGD model. The best estimation results, in terms of R^2, correspond to the TVLGD model. This is of course to be expected, as the other models are restricted versions of the TVLGD model. Interestingly, the CONSTLGD model performs much better than the FIXEDLGD model. This comes of course at no surprise, when noticing that the estimated value of the LGD according to our CONSTLGD model is 0.05, well below the value of 0.75 which is commonly adopted when modeling emerging markets. Interestingly, 0.05 is approximately the average value of the LGD estimate of the TVLGD model over the sample.

[Insert Figure 1 here]

4.3.Separate identification of PD and LGD

We also study whether the Polish PD and LGD can be satisfactorily identified. This assessment has been conducted by means of the graphical analysis employed in Christensen (2007). Figure 1 shows different combinations of PD and LGD that would allow the model-implied CDS spreads to perfectly match the observed CDS spreads on four given dates. The dates chosen are February 2009, June 2010, September 2011, and March 2013, which correspond with periods of tensions in the Polish sovereign debt market. Figure 1 shows that the CDS spreads react very differently, over different maturities, to changes in PD and LGD. Only one PD and LGD combination pair provides a perfect fit of the observed CDS spreads, suggesting that separate identification of PD and LGD is feasible. This is most clearly shown in the chart for March 2013 when the PD was well below 90%.

Despite this, it should be noted that the model-implied CDS spreads do not fit the observed spreads perfectly but with some error. Thus, when assessing identifiability of the parameters, it is sensible to report the combinations of PD and LGD which provide model-implied CDS spreads not departing from the true values by more than the average absolute estimation error (Christensen, 2007). Such combinations are shown in Figure 2. Interestingly, the possible set of combinations of the PD and LGD pairs that fit the CDS spreads within that margin of error is very narrow. This is not surprising as the mean absolute value of the errors is relatively small (around 4.5 basis points). We thus check identifiability under more rigorous conditions.

[Insert Figure 2 here]

In particular, we also examine the combination of PD and LGD within a larger margin of error, and in particular, the largest average absolute error across maturities on the four chosen dates, at times of major market turmoil, i.e. around 11 basis points in our estimation results. This is shown in Figure 2 in the darker color area. The area of plausible combinations is understandably wider. However, even for that wide margin of error, plausible combinations remained contained for three of the dates plotted in Figure 2 thus suggesting that the very good estimation results, with relatively small estimation errors allows to satisfactorily separate PD from LGD. The contour plot shown in Figure 2 for the date June 2010 appears at first sight less satisfactory. However, the domain over which LGD is allowed to change remains relatively narrow, ranging from 1.0 percent to 2.5 percent.

4.4. PD and LGD estimates

The estimation results shown above suggest that the TVLGD captures better the dynamics of CDS spreads, and that constraining the value of the LGD is not statistically justified. Furthermore, the standard value adopted by market practitioners to fix the value of LGD when modelling the CDS of emerging economies (0.75), is not a reasonable modelling assumption for the case of Poland. The identification analysis shown above, further suggests that separate identification of PD and LGD is empirically tractable for Poland. Therefore, in what follows, we will focus our analysis primarily on the TVLGD model, although references to the CONSTLGD model will be made for comparison.

The term structure of the PDs and LGDs over the sample period is shown in Figures 3 and 4 respectively. It appears that the slope of the LGD curve has been rather flat for most of the sample, and only when the crisis in the Eurozone erupted, was the slope of the LGD curve slightly more pronounced. This is in contrast with the slope of the PD curve. The uncertainty related to future periods increases the market assessment of risk and, when judged by the slope of the curve, it appears to have a larger effect on the PDs than on LGDs.

[Insert Figure 3 here]

[Insert Figure 4 here]

The model-implied time series of PDs derived from the two-year CDS contracts are shown in Figure 5. We present results from the two-year year contracts for the sake of parsimony and clarity. The standard horizon for predictions made with early warning models is also 24 months because the current economic fundamentals still have some effect on the risk of future crises in such a short horizon. It can be observed that the TVLGD model displays higher PDs than the CONSTLGD model for most of the sample. This relationship becomes intuitive when the PDs are compared with the corresponding LGDs presented in Figure 6. The time-varying LGD generated by the TVLGD model stays below the constant LGD in the CONSTLGD model for most of the sample.

The highest risk of a sovereign default was recorded towards the end of 2008 and early 2009 following the collapse of Lehman Brothers. The PD for the two year maturity reached values close to 90%.[1] At that time, and amid increased outflows of speculative capital, the Polish currency also depreciated by more than 30% against the euro and other major currencies. The inter-bank market was frozen and the stock market recorded record losses. The slowdown of the global economy must have also contributed to the increase in PD. The LGD also increased following the collapse of Lehman Brothers, but the recorded increases in LGD were always contained and the LGD never exceeded 5%. The second sharp increase of PD took place at the end of 2011, and it was associated with the financial turmoil in Greece and in particular the discussions associated with the Greek debt restructuring. This effect is equally noticeable in the estimates of LGD which increased steadily during 2011 and reached its peak in mid-2012. However, once more the level of the LGD was relatively low.

In this context, it is worth recalling that Poland did not suffer from the macroeconomic and financial imbalances that characterized many emerging and developed economies in the years that preceded the global financial crisis. The muted impact on the LGD at the peak of tensions in the Polish sovereign debt market, suggests that investors were possibly not seriously concerned about the solvency of the Polish government. The potential of the economy to generate high income in the long-term was judged positively. However the ability of the central government to find enough liquidity to honor its payments at times of turmoil (e.g., a delay in the payment of coupons) was seriously questioned.

During the European sovereign debt crisis the LGD increased above the 5% mark. This might be due to a contagion effect from the euro area sovereign debt crisis which may have led to a broad reassessment of sovereign credit risk in Europe at large. A formal analysis of this issue is left for future research.

[Insert Figure 5 here]

[Insert Figure 6 here]

4.5. Correlation of PD and LGD estimates with CDS spreads

Another interesting question is whether changes in CDS spreads mirror very closely changes in PD. If the correlation of PDs and LGDs with CDS spreads was high, economic analysis could be directly conducted with CDS spreads rather than with the computationally-costly model-implied PDs and LGDs. If, on the other hand, a large part of the movement in CDS spreads is associated with changes in the LGD which are not one-to-one related to

[1] In interpreting the magnitude these PDs, one should keep in mind that these are risk-neutral PDs. They are usually higher than 'physical' PDs that control for risk premia in market quotations of CDS spreads.

changes in PD, then the use of model-implied PDs and LGDs would be preferable. Figure 8 presents the correlations between our model-implied estimates of PD and the CDS spreads, as well as the correlations between the model-implied estimates of LGD and CDS spreads for the various maturities of the CDS contracts (we focus on the TVLGD model here). We find that correlations between the PDs and the CDS spreads are not very high and they heavily depend on the maturity of the sovereign CDS. Short-term contracts are much more closely linked to the model-implied PDs than longer-term contracts. For higher maturities, the LGDs are more strongly correlated with the spreads than the PDs. This finding is related to high values of PDs observed for long-term CDS contracts in Figure 8. When the PDs are close to one, the LGDs affect CDS spreads much more than the PDs do. In contrast, the CONSTLGD and FIXEDLGD models generate PDs that are strongly correlated with the CDS spreads (cf., Figure 9).

[Insert Figure 7 here]

[Insert Figure 8 here]

5. Conclusions

We have estimated the reduced-form model to price sovereign CDS contracts for Polish debt and have achieved a superior fit of the model to data. Our approach has enabled to identify the probabilities of default and the expected loss given default, both measures observed at different periods and with various expectation horizons. We have found that the LGD has varied at the very low levels, around five percent, and the two-year PD has been changing from twenty percent in the calm period between 2004 and 2007 to the levels above eighty percent in the early 2009, i.e. the most dramatic time of the crisis in Poland. In subsequent periods the probability of the crisis has decreased to initial levels. We interpret these results as evidence that the most likely scenario of a sovereign credit event in Poland would be associated with some temporary liquidity problems (e.g. delay in a coupon payment) rather than a full-blown sovereign default with a major debt restructuring. In general, this research has helped us to better understand the role of the time-varying expected losses in the pricing of sovereign risk.

We have also found that the market CDS spreads in Poland are good approximations for model-implied probabilities of default for short-term expectation horizons, but they are poor approximations for long-term expectations. This finding may be an effect of large uncertainty of market participants regarding the sovereign default risk in a distant future. In general, early warning models to predict financial crises are also most effective in the short-term horizons, up to 24 months.

Our modeling framework has several potential applications. It may be used by monetary and fiscal authorities to learn how markets assess the risk of a crisis. Financial market participants may use the model to price debt instruments in their portfolios. Sovereign risk plays also an important role as a factor explaining changes in prices of locally traded assets. Hence, the probability of default and the expected loss given default may be the key elements of models explaining asset prices in particular markets.

Problems encountered by identifying the probability of default and the loss given default suggest that market participants have only limited access to information about the future extreme financial risks. Further development of financial instruments and econometric methods are required to assess more precisely the losses of investors during sovereign debt crises. One possible extension of our model could include observable factors to help identify the PD and LGD more precisely (e.g., Longstaff et al., 2011). The comparison of the quadratic specification of the factors in the CDS models analyzed in this paper with some linear (affine) specifications proposed by Pan and Singleton (2008) would be an interesting route for future research.

References

1. Adam M. (2013). Spillovers and contagion in the sovereign CDS market, Bank i Kredyt, 44 (6), Pages 571–604.
2. Afonso, A., Furceri, D., & Gomes, P. (2012). Sovereign credit ratings and financial markets linkages: application to European data. Journal of International Money and Finance, 31(3), 606–638.
3. Ahn, D. H., Dittmar, R. F., & Gallant, A. R. (2002). Quadratic term structure models: Theory and evidence. Review of Financial Studies, 15(1), 243–288.
4. Ang, A., &Longstaff, F. A. (2013). Systemic sovereign credit risk: Lessons from the US and Europe. Journal of Monetary Economics, 60(5), 493–510.
5. Ang, A., Boivin, J., Dong, S., Loo-Kung, R. (2011). Monetary policy shifts and the term structure. The Review of Economic Studies, 78(2), 429–457.
6. Beirne J., Fratzscher M. (2013). The pricing of sovereign risk and contagion during the European sovereign debt crisis, Journal of International Money and Finance, 34, 60–82.
7. Camba-Mendez, G., Serwa, D. (2014). Sovereign credit risk in the euro area during the financial crisis, National Bank of Poland Working Paper, forthcoming.
8. Christensen, J. H. E. (2007). Joint default and recovery risk estimation: an application to cds data. Working Paper. Available at: http://www.defaultrisk.com/ppcrdrv37.htm.
9. Cruces, J., Trebesch, C. (2013). Sovereign Defaults: The Price of Haircuts, American Economic Journal: Macroeconomics, 5(3), 85–117.
10. Diebold F. X., Yilmaz K. (2009). Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets, Economic Journal, Volume 119, Issue 534, pages 158–171.
11. Doshi, H. (2011). The term structure of recovery rates. Available at SSRN.
12. Gapen, M., Gray, D., Lim, C. H., & Xiao, Y. (2008). Measuring and analyzing sovereign risk with contingent claims. IMF Staff Papers, 109–148.
13. Kisgergely K. (2009). What moved sovereign CDS spreads in the period of financial turbulence?, Report on Financial Stability, November 2009, Central Bank of Hungary.
14. Kliber A. (2011). Sovereign CDS instruments in Central Europe – linkages and interdependence, Dynamic Econometric Models, 11, Pages 111–128.
15. Leippold, M., & Wu, L. (2002). Asset Pricing under the Quadratic Class. Journal of Financial and Quantitative Analysis, 37(02), 271–295.

16. Longstaff, F. A., Pan, J., Pedersen, L. H., & Singleton, K. J. (2011). How Sovereign Is Sovereign Credit Risk?. American Economic Journal: Macroeconomics, 3(2), 75-103.
17. Moody's Investors Service (2011) Special comment: sovereign default and recovery rates, 1983-2010, Report number 132672 on May 10, 2011.
18. O'Kane, D., & Turnbull, S. (2003). Valuation of credit default swaps. Lehman Brothers Quantitative Credit Research Quarterly, 2003, Q1-Q2.
19. Pan, J., & Singleton, K. J. (2008). Default and recovery implicit in the term structure of sovereign CDS spreads. The Journal of Finance, 63(5), 2345-2384.
20. Plank, T. J. (2010). Do Macro-economic Fundamentals Price Sovereign CDS Spreads of Emerging Economies? (No. 10-5).
21. Trebesch, C., Papaioannou, M. M. G., & Das, M. U. S. (2012). Sovereign Debt Restructurings 1950-2010: Literature Survey, Data, and Stylized Facts (No. 12-203). Andrews McMeel Publishing.

Appendix

Figure 1: Identification of the TVLGD model

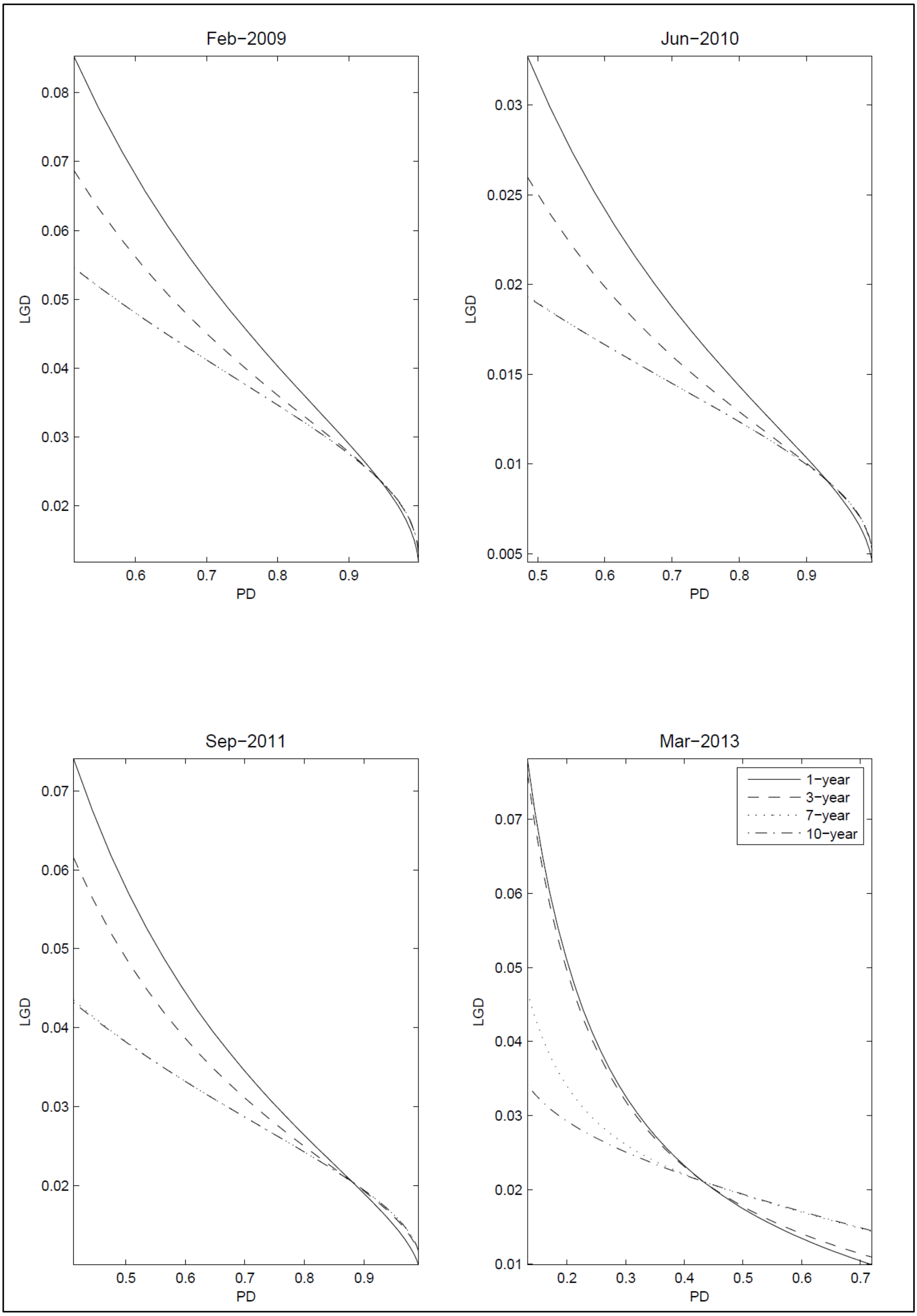


Figure 2: Identification of the TVLGD model

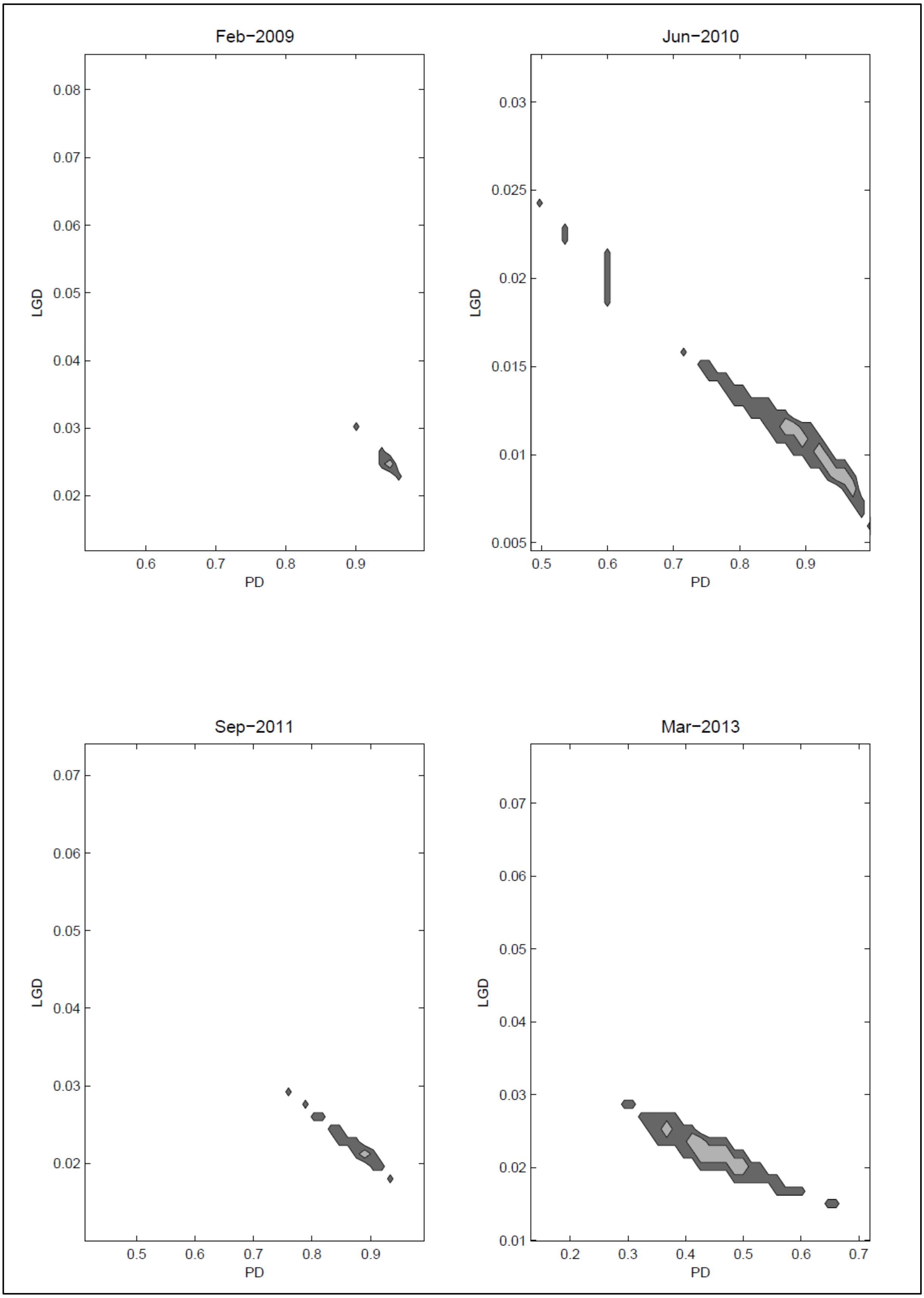
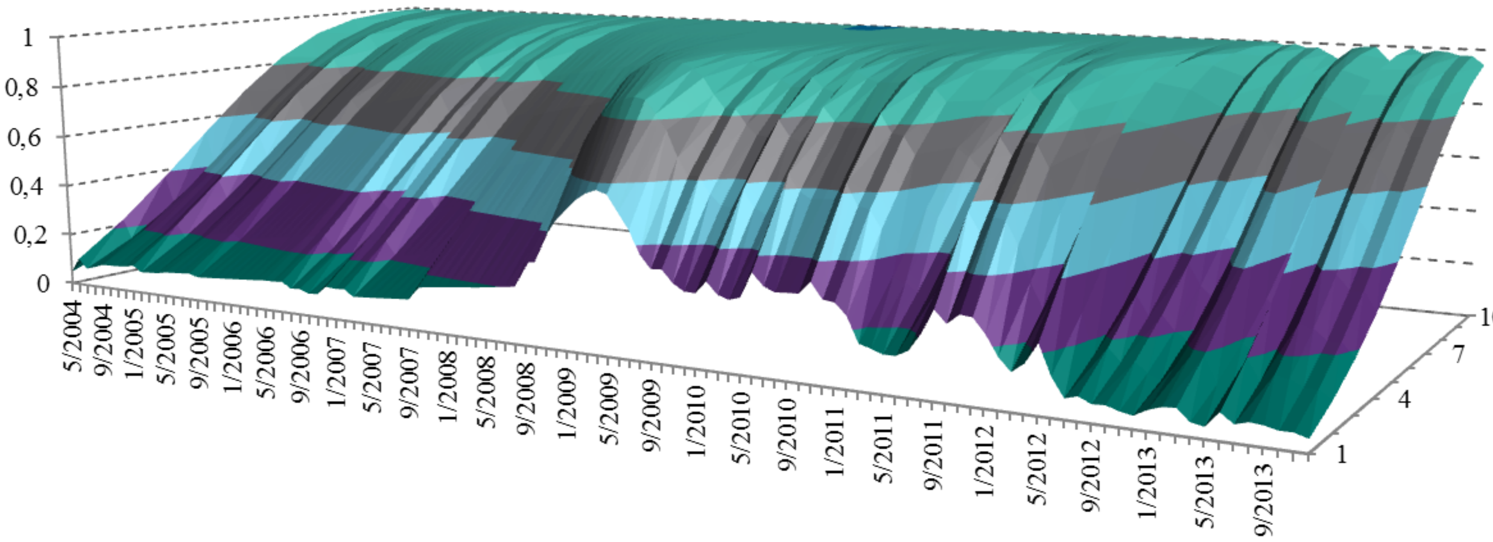
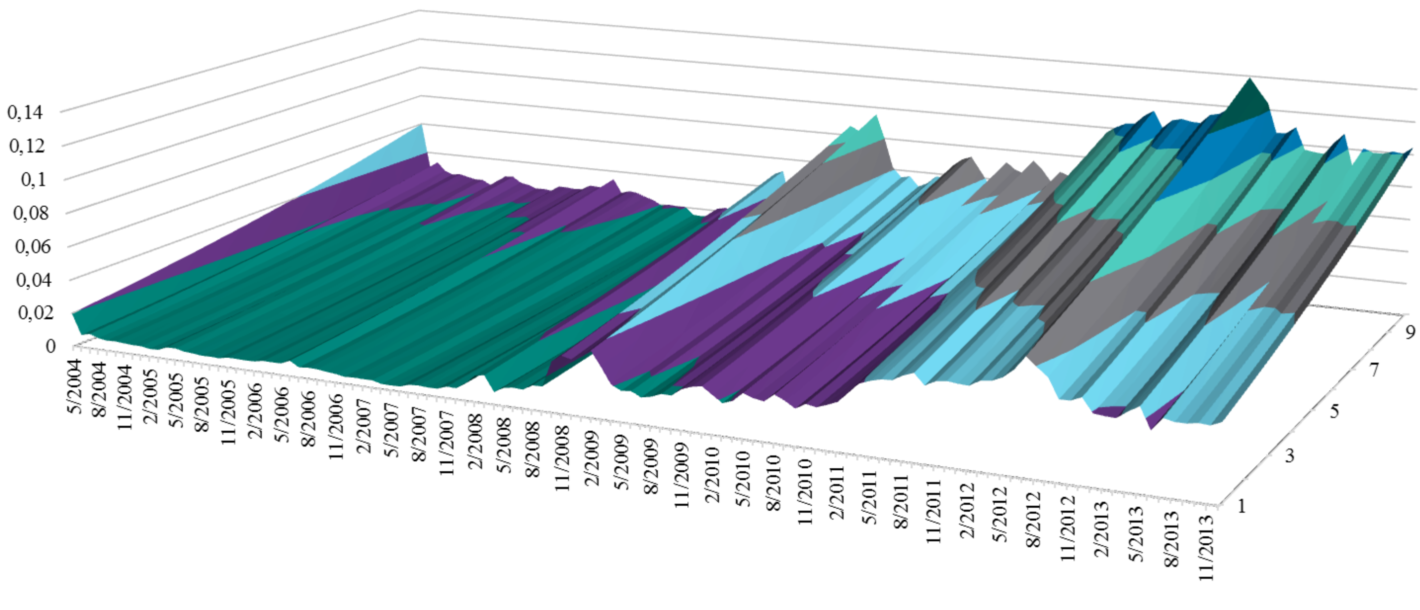


Figure 3: Term structure and time fluctuations of Probabilities of Default of the TVLGD model



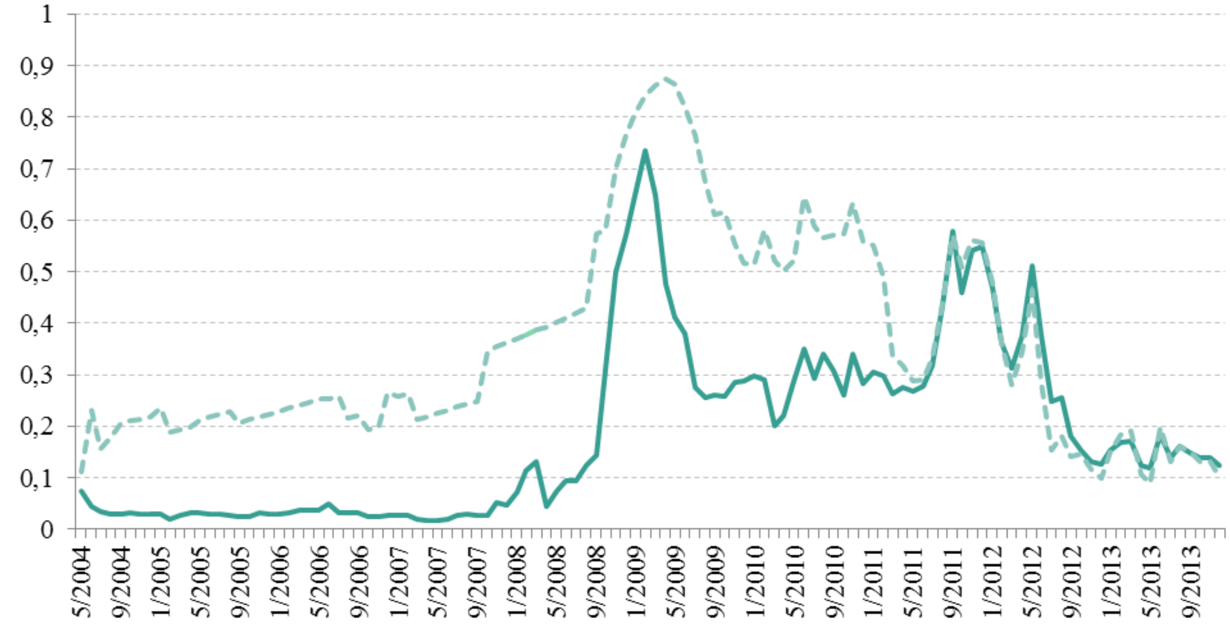
Note: x axis describes dates of observations, y axis describes probability of default, z axis describes time to maturity of the contract

Figure 4: Term structure and time fluctuations of Loss Given Default implied by the TVLGD model



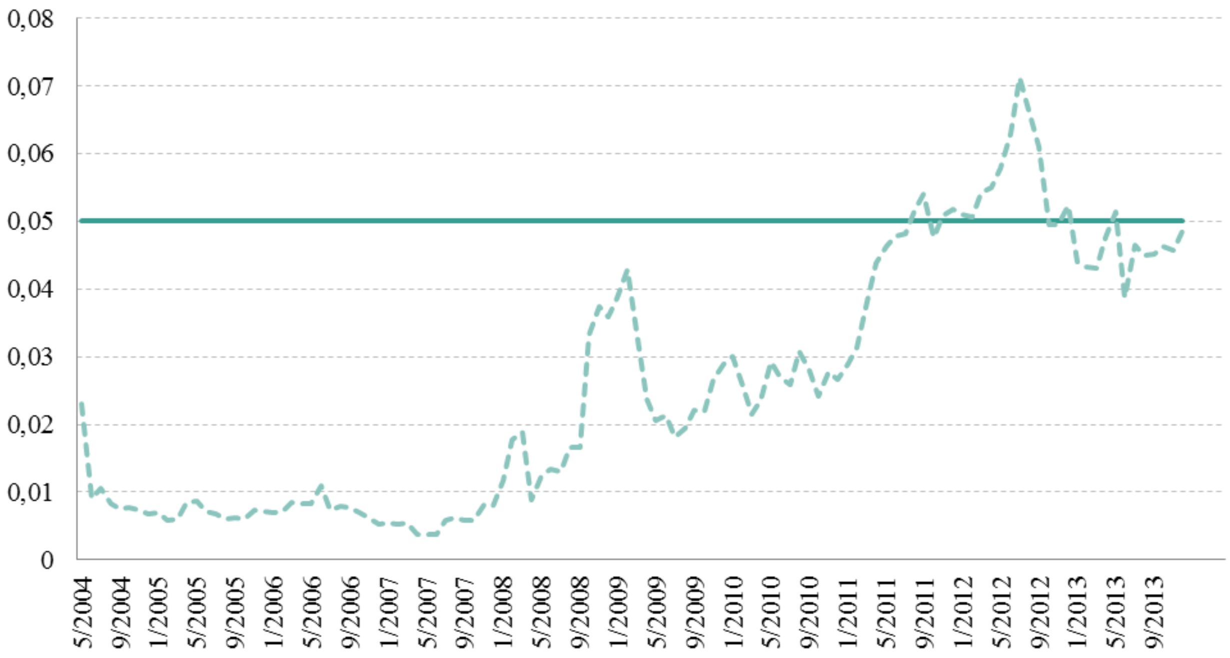
Note: x axis describes dates of observations, y axis describes loss given default, z axis describes time to maturity of the contract

Figure 5: PDs for the two-year CDS contracts implied by the TVLGD and CONSTLGD models



Note: x axis describes dates of observations, y axis describes probability of default. Dashed line corresponds to the TVLGD model and solid line corresponds to CONSTLGD model

Figure 6: LGDs for the two-year CDS contracts implied by the TVLGD and CONSTLGD models

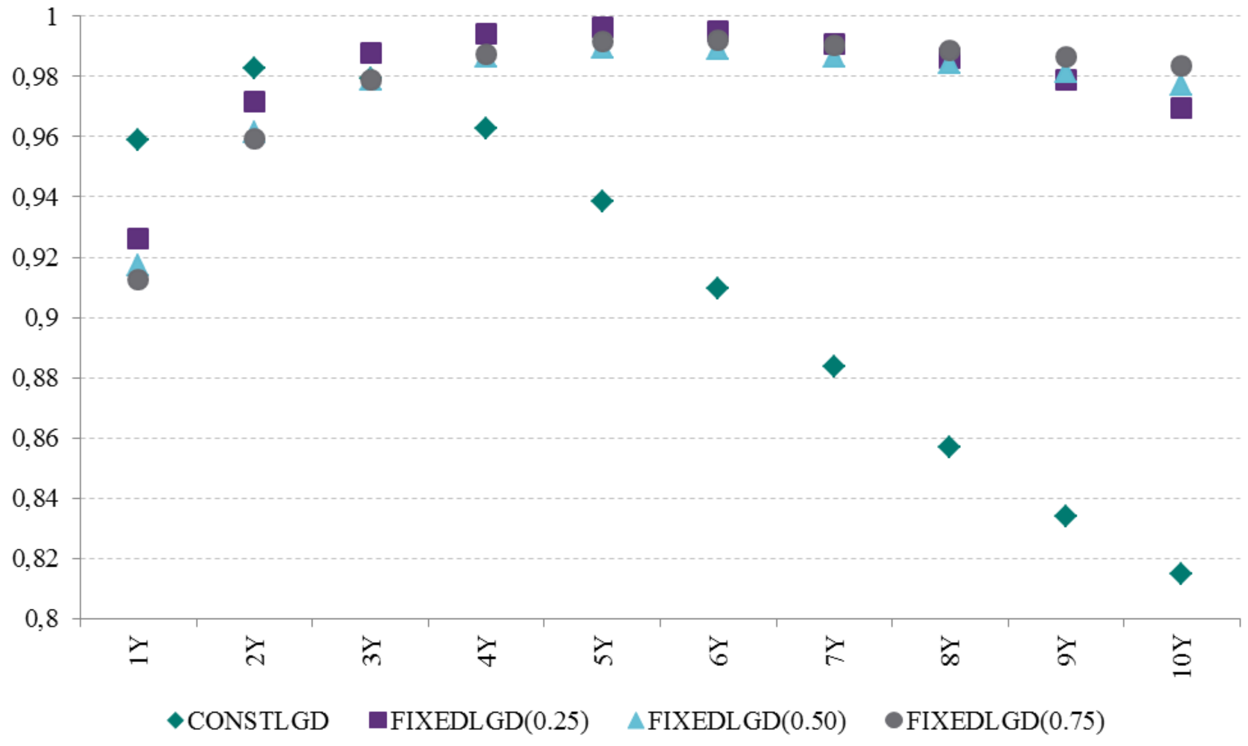


Note: x axis describes dates of observations, y axis describes loss given default. Dashed line corresponds to the TVLGD model and solid line corresponds to the CONSTLGD model

Figure 7: Correlation between the CDS premia and PDs and LGDs implied by the LGDTV model

Note: x axis describes years to maturity, y axis describes value of the correlation coefficient. Triangles represent correlations between CDS premia and PDs and squares represent correlations between CDS premia and LGDs.

Figure 8: Correlations between CDS premia and PDs implied by the CONSTLGD and FIXEDLGD models



Note: x axis years to maturity, y axis value of the correlation coefficient

Table 1: Comparison of model parameters and statistics

	LGDTV	CONSTLGD	FIXEDLGD (0.25)	FIXEDLGD (0.50)	FIXEDLGD (0.75)
α_x	7,68E-06	-1,88E-04	-9,13E-05	3,56E-05	3,29E-05
α_z	3,72E-06	x	x	x	x
β_x	1.0144	1.0176	1.0110	1.0108	1.0100
β_z	0.9985	1.0000	1.0000	1.0000	1.0000
σ_{xx}	2,93E-06	5,60E-06	5,02E-06	1,98E-06	1,35E-06
σ_{zz}	9,77E-06	x	x	x	x
$\sigma_{xz} = \sigma_{zx}$	-1,07E-07	x	x	x	x
σ_{ee}	1,37E-05	5,57E-05	3,92E-06	1,82E-06	1,72E-06
x_0	0.0212	0.0478	0.0237	0.0146	0.0122
z_0	1.3320	0.95	0.75	0.50	0.25
S.E.	0.2409	0.2760	0.2962	0.3607	0.3503
R^2	0.9557	0.9416	0.9328	0.9007	0.9060
LGD	x	0.05	0.25	0.50	0.75