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Gonzalo Camba-Méndez – European Central Bank; gonzalo.camba-mendez@ecb.int
Konrad Kostrzewa – Narodowy Bank Polski, Financial Stability Department; konrad.kostrzewa@nbp.pl
Anna Mospan – Narodowy Bank Polski, Domestic Operations Department, and a PhD student at Łódź University of Technology; anna.mospan@nbp.pl
Dobromił Serwa – Narodowy Bank Polski, Financial Stability Department, and Warsaw School of Economics; dobromil.serwa@nbp.pl

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Abstract

We analyze the market assessment of sovereign credit risk in an emerging market using a reduced-form model to price the credit default swap (CDS) spreads thus enabling us to derive values for the probability of default (PD) and loss given default (LGD) from the quotes of sovereign CDS contracts. We compare different specifications of the models allowing for both fixed and time varying LGD, and we use these values to analyze the sovereign credit risk of Polish debt throughout the period of a global financial crisis. Our results suggest the presence of a low LGD and a relatively high PD for Poland during a recent financial crisis. The highest PD is in the months following collapse of Lehman Brothers. The derived measures of sovereign risk are strongly linked with the level of public debt and with another measure of PD from a structural model. Correlations between our PD values and the CDS spreads heavily depend on the maturity of the sovereign CDS.

Keywords: sovereign credit risk, CDS spreads, probability of default, loss given default, Poland

JEL Classification: C11, C32, G01, G12, G15

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 against 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 depends heavily upon it. In this paper we analyze the sovereign credit risk of an emerging market, Poland, by means of 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. Nevertheless, its markets were still affected by the global financial turbulence brought by the collapse of Lehmann Brothers in September 2008 and also by the sovereign debt crisis in the eurozone throughout the years 2011-2012. This suggests that Poland may serve as a natural laboratory for studying the transmission of risk to a local emerging market and also to analyze the market assessment of sovereign risk. In this context, it is worth recalling that Poland was also the only European economy that recorded positive GDP growth throughout these recent crises.

There are a number of studies that analyze the effects of financial spillovers and financial contagions as well as the effects of news and announcements on the sovereign risk of emerging markets. However, only a few works measure the sovereign risk of an emerging market using term-structure models that enable an estimation of the probability of default (PD) and even more rarely the loss given default (LGD). We provide more details on these past works in the literature review section. Our contribution to the literature rests on estimating the time varying PD and LGD simultaneously using the term structure of sovereign credit default swap (CDS) contracts. Moreover, we compare model specifications where only the PD is identified and the LGD is assumed known with models allowing both PD and LGD to be identified simultaneously.

We use information contained in the term structure of CDSs to evaluate the market perception of sovereign credit risk at different time horizons. The pricing formula for CDS spreads allows us to disentangle the PD from the 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 the PD and LGD remains empirically challenging, it is in principle a valuable piece of information that functions as an early warning for financial crises and other values that predict financial defaults. In line with some of the recent literature, we use models that allow separate identification of the PD and the LGD embedded in sovereign debt. The models used here 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 describe the underlying dynamics of the PD and LGD. This approach is in line with Doshi (2011) and it ensures that the values of both the PD and LGD remain between zero and one. We estimate two main types of models: 1) models that assume the consistency of the LGD in time and across maturities with a changing PD in time and across maturities, and 2) models where both the LGD and PD are permitted to change in time and across maturities.

Our empirical analysis found 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 PD values, however, reacted strongly to the unfolding of the subprime crisis in the U.S. and to the failure of Lehman Brothers. When looking at the term structure of the CDS spreads, we see that movements of the original CDS over short maturities are strongly driven by changes in the short-term PD values. By contrast, movements of the original CDS over longer maturities are more closely associated with developments in the LGD values. 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 within Europe. This suggests that at the peak of tensions, investors were likely not seriously concerned about the solvency of the Polish government (i.e., the LGD remained low), but more concerned about their ability to find enough liquidity to honor their payments in times of turmoil (i.e., the PD went up).

Our measures of sovereign credit risk are correlated with the level of sovereign debt and with another measure of risk derived from an alternative structural pricing model estimated by Konopczak (2014). Correlation of the PD and LGD with the CDS spreads is also positive but heavily depends on the maturity of the sovereign CDS. These results suggest that market expectations regarding sovereign risk follow dynamic developments in economic fundamentals.

The remainder of this 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, and related methods to identify the PD and LGD from market CDS spreads are discussed here. Section 3 describes our method to estimate the model-implied PD and LGD values. Section 4 discusses the empirical results and the final section presents the conclusions that can be drawn.

2. Literature Overview

Using credit default swaps (CDS) as an indicator of sovereign credit risk has been studied by numerous researchers and has been applied in different countries and economic areas. Sovereign CDS spreads and sovereign bond spreads were previously a matter of wide debate concerning which instrument is more suitable for credit risk evaluation. Both instruments have been used as substitutes in credit risk analysis; however, the application of CDS contracts has been rising considerably.

The spread between the bond yield of a sovereign prone to default and a sovereign with a prime credit rating is not solely driven by credit risk but also by other factors such as liquidity conditions, term premia, and currency risk. In contrast, and at least a priori, the premium paid for the protection that a CDS contract offers should be more directly linked to the risks associated with a sovereign default and should thus serve as a more accurate measure to gauge the market perception of sovereign credit risk rather than sovereign bond yield spreads. Fontana and Scheicher (2010) argue that movements in sovereign bond yield spreads during the financial crisis also reflected liquidity distortions, limited arbitrage operations amid increasing risk aversion, and the official interventions of the ECB, all of which were less apparent in the CDS market. Furthermore, a recent work by the IMF (2013) suggests that CDS spreads reveal new information more rapidly during periods of financial stress than sovereign bond yield spreads. Pan and Singleton (2008) also found that the CDS spreads of various emerging market economies co-varied with several economic measures of global event risk, financial market volatility, and macroeconomic policy.

However, the use of CDS contracts to measure sovereign credit risk is not free from controversy. CDS are traded over-the-counter (OTC), and it has been argued that since there are few rules governing trading or regulation of information dissemination on the OTC market, transparency in these markets was quite low. Furthermore, the magnitude of the trading in some of these markets, relative to the size of the trading in sovereign debt, was small. This prompted some to suggest that speculative trading in the CDS market could be used to manipulate sovereign bond yields beyond bounds justified by economic fundamentals. In a recent study of several eurozone countries, Camba-Méndez and Serwa found that macroeconomic and institutional developments were only weakly correlated with developments in CDS markets during the recent financial crisis, whereas financial contagion appeared to have a non-negligible effect. On a more positive tone, and while transparency could still be improved further, regulatory improvements at the European Union level have reduced the potential for speculative CDS trading.[1]

In financial modeling, the credit risk of an asset has two main dimensions: the PD and LGD. Using information from sovereign CDS spreads, a market's perception of the PD of a country and the loss incurred should that country default (i.e., the LGD) could both be inferred. However, and while feasible from a theoretical perspective, a separate identification of the PD and LGD remains empirically challenging (cf. Pan and Singleton, 2008). This has prompted researchers to adopt the assumption of a constant LGD value over the sample. This strategy was regarded as satisfactory for many years but has now become more open to criticism. A fixed LGD is at odds with empirical observations of historical sovereign defaults and historical spreads that suggest the LGD varies with time (Trebesch et al., 2012). An obvious explanation for a time varying LGD is that both the default rate and the LGD are strongly influenced by the business cycle. The same adverse economic conditions that cause defaults to rise—such as a recession—can cause recoveries to fail. Recent episodes of debt restructuring may also suggest that the structure of the debt (i.e., its maturity, type of holder, and currency profiles) may have an impact on both the PD and LGD. This impact may or may not be as evident on the PD and LGD as the impact of the business cycle.

A growing number of research papers in recent years have been written about the main drivers underlying the development of CDS spreads in the emerging markets of Central and Eastern Europe. Most of these studies focused primarily on financial spillovers and contagion across countries and found evidence of contagion effects within Central and Eastern European countries from outside of the region, especially during the global financial crisis (Kisgergely, 2009; Kliber, 2011; Adam, 2013; Beirne and Fratzscher, 2013). Some of these early studies also found that sovereign rating announcements had a significant impact on CDS spreads, as was especially the case after the collapse of Lehman Brothers (Ismailescu and Kazemi, 2010; Afonso et al., 2012). However, in contrast with the economic literature for developed economies and non-Central and Eastern European emerging economies, most of these studies used the CDS spreads and did not attempt to estimate the values for PD and LGD embedded in those spreads. A notable exception is Gapen et al. (2008), who applied a contingent claim analysis to study twelve emerging markets, including Poland. They then compared the implied risk of default measures of each

[1] The European Market Infrastructure Regulation (EMIR) was introduced in August 2012 to provide financial regulators and supervisors with more information on trading in derivatives.

country with quotations of sovereign CDS spreads. The authors found a strong correlation between their measure of sovereign risk and other market based measures, including sovereign CDS spreads and PD values derived from a sovereign CDS. They did, however, assume that the LGD remained constant throughout the entire sample. Another notable exception was Plank (2010) who employed a structural economic model to derive the PD of six emerging countries (Czech Republic, Hungary, Poland, Russia, Romania, and Turkey). Their measure hinged on the country's access to external capital flows and its ability to repay external debt. The PD estimated from the economic model was then used to price sovereign CDS contracts. Once more, the LGD was fixed over the course of the sample and assigned the value commonly adopted when dealing with emerging markets (i.e., 75%). Finally, Konopczak (2014) built another structural model to estimate the PD for Poland. He used detailed information on the term-structure of Polish debt and the Black-Scholes formula to derive this measure of sovereign risk.

In contrast with these studies for Central and Eastern European economies, we will compute time varying estimates of both the PD and LGD based on the CDS spreads. We are not aware of any studies investigating estimates of LGD for sovereign debt of a Central and Eastern European country. Our modeling strategy builds upon earlier studies of quadratic term structure models of sovereign CDS spreads. In particular, we adopt a similar reduced-form term-structure model applied by Camba-Méndez and Serwa (2014) to price senior sovereign CDS spreads for some eurozone countries. This model was a simplified version of the model proposed in Doshi (2011) to study corporate credit risk. Both these models rely on a quadratic specification of unobserved factors (in contrast to a linear specification) in the affine term structure modeling strategy of Pan and Singleton (2008). The quadratic specifications of asset pricing models were also investigated, for instance, by Ahn et al. (2002), Leippold and Wu (2002), Ang et al. (2011). Camba-Méndez and Serwa (2014) did not employ a joint modeling strategy for senior and subordinate CDS contracts as Doshi (2011) had done. In the work of Doshi (2011), joint modeling of senior and subordinate contracts was necessary in order to separately identify PD and LGD. However, Camba-Méndez and Serwa showed that separate identification of the PD and LGD simply from isolated sovereign senior CDS contracts of different maturities was feasible for several eurozone countries. Feasibility was assessed using the model specification strategies proposed by Pan and Singleton (2008) and Christensen (2007).

We provide estimates of the time varying PD and LGD of Poland in our empirical analysis. Moreover, we check the robustness of our model in identifying both the PD and

LGD simultaneously. In addition, we follow Pan and Singleton (2008) and Longstaff et al. (2011) in considering the specification of the model with a constant level of the LGD, assumed to be known or estimated alongside of other parameters. Moreover, we test to what extent these estimates, which represent the financial markets' perception of sovereign credit risk, correlate with economic fundamentals and other measures of sovereign risk.

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 PD and LGD from the CDS spreads quoted on the market. The main element of our model is the pricing formula of sovereign CDS spreads. A sovereign credit default swap is a financial contract developed to compensate investors in the event of a sovereign default. In financial terminology, such an event is called a credit event.

A credit event is the focal point within the terms of the CDS contract and is defined as a sudden and significant destructive change in a borrower's creditworthiness, often accompanied by deterioration of their credit rating. The list of typical events included in a sovereign CDS contract include 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 a 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 is approximated by the following expression (O'Kane and Turnbull, 2003):

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

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, and τ is the 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, the 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 until 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 follows:

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

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

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

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

The PD 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 as follows:

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

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 so 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 the large volatility of this variable, especially during financial crises. The expression $f(x_t, z_t)$ is also a logarithm of formula (3).

Our identification and estimation approach relies on the whole term structure of CDS spreads. Therefore, we employ ten CDS contracts with maturities between one year and ten years. Thus, the same factors x_t and z_t enter into 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 the termination date of the contract. To simplify the 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, and $\mathbf{B} = \begin{bmatrix} \beta_x & 0 \\ 0 & \beta_z \end{bmatrix}$ 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, they all have the same finite variance σ_{ee};, and $\mathbf{I}$ is the identity matrix.

The procedure to derive the PD and LGD from quotes of financial instruments for each period and all maturities is as follows. 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 $t = 1, 2, \ldots, T$. The starting values for these factors (x_0 and z_0, respectively) are needed to begin the filtering process. The PD and LGD values are then computed for $t = 1, 2, \ldots, T$ and $i = 1Y, 2Y, \ldots 10Y$ using equations (4) and (5).

The parameters are usually not known a priori and thus 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 estimate of parameters in the model, and the full set of unknown parameters is defined as $\boldsymbol{\theta} = [\alpha_x \quad \alpha_z \quad \beta_x \quad \beta_z \quad \sigma_{xx} \quad \sigma_{zz} \quad \sigma_{xz} \quad \sigma_{ee} \quad x_0 \quad z_0]$. The 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 a robustness check, we investigate three specifications of our model. The first specification is the most general model with the time varying PD and time varying LGD, described by formula (9). We call this specification the TVLGD model. The second specification also uses the time varying PD; however, the LGD is assumed to be constant over time and its value is estimated along with other parameters in the model. We call this specification the CONSTLGD model. The third specification of the model is the same as the second, yet the constant LGD is not estimated and is instead fixed at some specific level known by market participants. We call this specification the FIXEDLGD model. Both the second and the third specifications 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 (e.g., 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 for ten contracts with maturities ranging from one to ten years. Missing observations, both 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 eurozone 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^* at three alternative values: 0.25, 0.50, and 0.75. The first and the third 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 choose to further estimate a model with a fixed LGD of 0.50 because this is approximately the average loss rate observed in historical sovereign defaults (cf. Moody's Investors Service, 2011; Cruces and Trebesch, 2013).

The parameters governing the dynamics of the unobservable factor x_t are very similar across all of the models. The parameter α_x is close to zero and β_x is close to one for all models, and 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 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. However, considering that the estimated value of the LGD according to our CONSTLGD model is 0.05, well below the value of 0.75 that is commonly adopted when modeling emerging markets, this is not longer that surprising. Interestingly, 0.05 is approximately the average value of the LGD estimate in the TVLGD model over the entire sample.

4.3. Separate identification of PD and LGD

We have attempted to determine whether the Polish PD and LGD can be satisfactorily identified. This assessment has been conducted by means of the graphical analysis employed by Christensen (2007). Figure 1 shows different combinations of the 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 tension in the Polish sovereign debt market. Figure 1 shows that the CDS spreads react very differently (over different maturities) to changes in both the PD and LGD. Only one PD and LGD combination pair provides a perfect fit for all observed CDS spreads, suggesting that a separate identification of both the PD and LGD is feasible. This is most clearly shown in the chart for March 2013 when the PD was well below 90%.

Despite all of this, it should be noted that the model-implied CDS spreads do not fit the observed spreads perfectly without any error. Thus, when assessing the identifiability of the parameters, it is sensible to report combinations of the PD and LGD that 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 PD and LGD pairs that fit the CDS spreads within that margin of error is very narrow. Therefore, it is not surprising that the mean absolute value of the errors is relatively small (around 4.5 basis points). We thus check for identifiability under more rigorous conditions.

We also examine the combination of the PD and LGD measures within a larger margin of error. In particular, we examine 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 colored 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 great estimation results with relatively small estimation errors to satisfactorily separate the PD from the LGD. The contour plot shown in Figure 2 for the date June 2010 appears at first sight less than satisfactory. However, the domain over which the LGD is allowed to change remains relatively narrow, ranging from 1.0% to 2.5%.

4.4. PD and LGD estimates

The estimation results shown above suggest that the TVLGD better captures 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 in the case of Poland. The identification analysis shown above further suggests that a 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 remain 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. 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 PD than on the LGD.

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 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. We can see that the TVLGD model displays higher PD than the CONSTLGD model for much 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 remains below the constant LGD in the CONSTLGD model for most of the sample.

The highest risk of a sovereign default was recorded toward 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%.[2] 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

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

sharp increase of PD took place at the end of 2011, and 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 throughout 2011 and reached their peak in mid-2012. However, once more the level of the LGD was quite 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 in the Polish sovereign debt market at the peak of tensions 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.

The LGD increased above the 5% mark during the European sovereign debt crisis. This might be due to a contagion effect from the eurozone sovereign debt crisis that 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.

4.5. Correlation of PD and LGD with other measures of sovereign risk

The estimated PD and LGD values should be correlated with other measures of sovereign risk. Correlation between our time varying LGD estimates and the ratio of Polish public debt to GDP is 0.74 (cf., Figure 7). This suggests that investors take into account the level of debt when they assess potential losses caused by some sovereign debt crisis. In turn, the PD values from the most general TVLGD model had a small negative correlation with the public debt ratio (e.g., -0.10 for the PD values with a one-year maturity and -0.19 for the PD values with a 5-year maturity). However, the PD values from the CONSTLGD model have a positive correlation of 0.53 with the debt ratio, which indicates that changes in the PD assume the effect of debt on CDS spreads when the LGD is fixed.

Since we aim to verify the usefulness of our PD values as measures of sovereign risk, we also compare our estimates of PD with the PD values derived from the pricing model of sovereign risk presented by Konopczak (2014).[3] This author has estimated a structural model employing detailed data on the term structure of Polish sovereign debt and has used the Black-Scholes formula to derive the PD at the horizon equal to the average residual maturity of Polish debt. The average maturity of debt denominated in foreign currencies has slightly exceeded five years in this sample. Therefore, we have fitted our model-implied PD values for the five-year CDS contracts to the estimate of PD values in Konopczak (2014). We observe the best match between the PD values when our estimated PD values come from the CONSTLGD model (correlation equal 0.75). However, the PD values from the TVLGD model are also positively correlated with the alternative measure of risk (correlation equal 0.45). These results are attractive because the measure of risk presented by Konopczak is more closely related to the real fiscal environment in Poland while our measures focus on expectations of international market participants (cf., Figure 8).

4.6. Correlation of PD and LGD estimates with CDS spreads

Another interesting question is whether changes in CDS spreads very closely mirror changes in the PD. If the correlation of the PD and LGD values with CDS spreads was high, economic analysis could be directly conducted with CDS spreads rather than with the computationally-expensive model-implied PD and LGD values. If, on the other hand, a large portion of the movement in CDS spreads is associated with changes in the LGD that are not one-to-one related to changes in the PD, the use of model-implied PD and LGD values would be preferable. Figure 9 presents the correlation between our model-implied estimates of the PD and the CDS spreads as well as correlations between the model-implied estimates of the LGD and CDS spreads for the various maturities of CDS contracts (we focus on the TVLGD model here). We find that the correlations between PD values and the CDS spreads are not very high and are heavily dependant on the maturity of the sovereign CDS. Short-term contracts are much more closely linked to the model-implied PD values than longer-term contracts. For higher maturities, the LGD values are more strongly correlated with the spreads than with the PD values. This finding is related to the high PD values observed for long-term CDS contracts in Figure 9. When the PD values are close to one, the LGD values affect CDS spreads much more than the PD values do. In contrast, the CONSTLGD and FIXEDLGD models generate PD values that are strongly correlated with the CDS spreads (cf., Figure 10).

[3] Michał Konopczak kindly provided data on the PD values estimated with his pricing model.

5. Conclusions

We have estimated the reduced-form model to price sovereign CDS contracts for Polish debt and have achieved a superior fit between the model and the data. Our approach has enabled us to identify the PD values and expected LGD values, with both measures observed at different periods and with various expectation horizons. We have found that the LGD has varied at very low levels, around 5%, and the two-year PD has changed from 20% in the calm period between 2004 and 2007 to levels above 80% in the early 2009 (i.e., the most dramatic time of the crisis in Poland). The probability of a crisis decreased to initial levels in subsequent periods. 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., a 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 confirmed the robustness of our results by comparing estimated PD and LGD values with the level of Polish sovereign debt and another measure of sovereign risk derived from an alternative model with stronger links to economic fundamentals. The results suggest that market expectations closely follow the developments of the macroeconomic situation in Poland. Interestingly enough, the sovereign debt affects the expected LGD more strongly than the expected PD.

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

Our modeling framework has several potential applications. Monetary and fiscal authorities may use our model 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 also plays an important role as a factor in explaining changes to the price of locally traded assets. Hence, the PD and the expected LGD may be key elements in models explaining asset prices in particular markets.

Problems encountered by identifying the PD and the LGD suggest that market participants have only limited access to information about 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.

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Appendix

Figure 1: Identification of the TVLGD model.

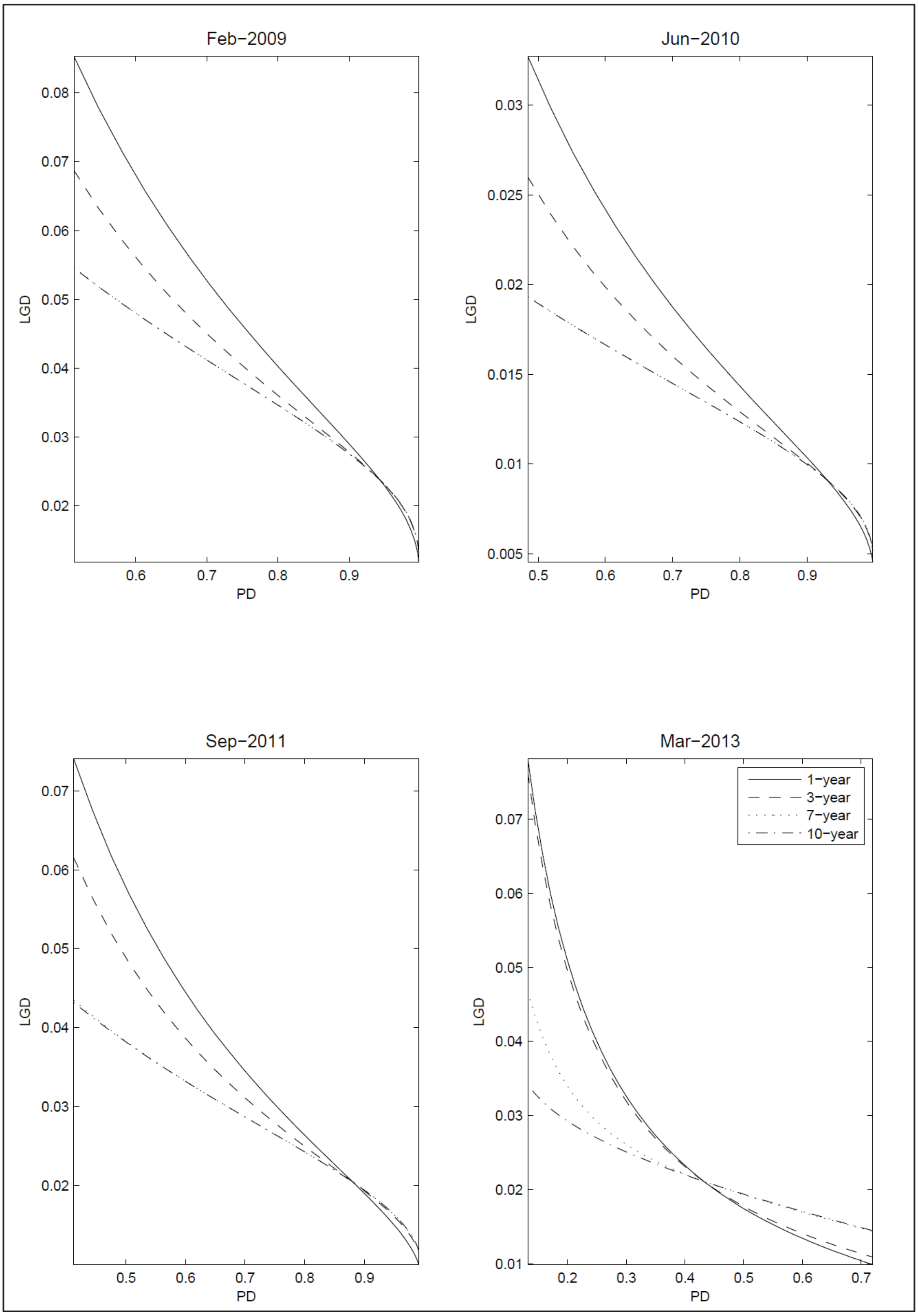


Figure 2: Identification of the TVLGD model.

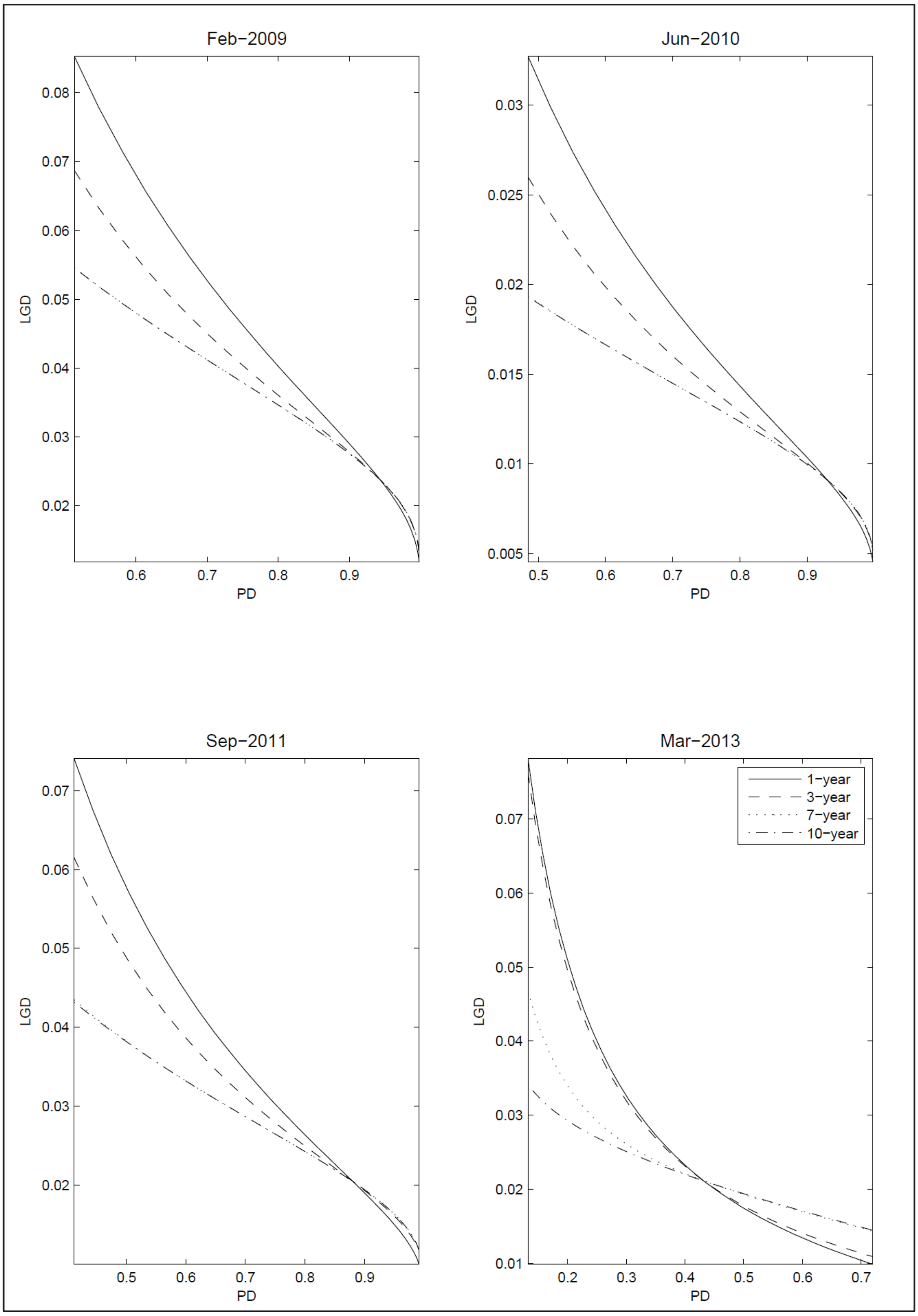
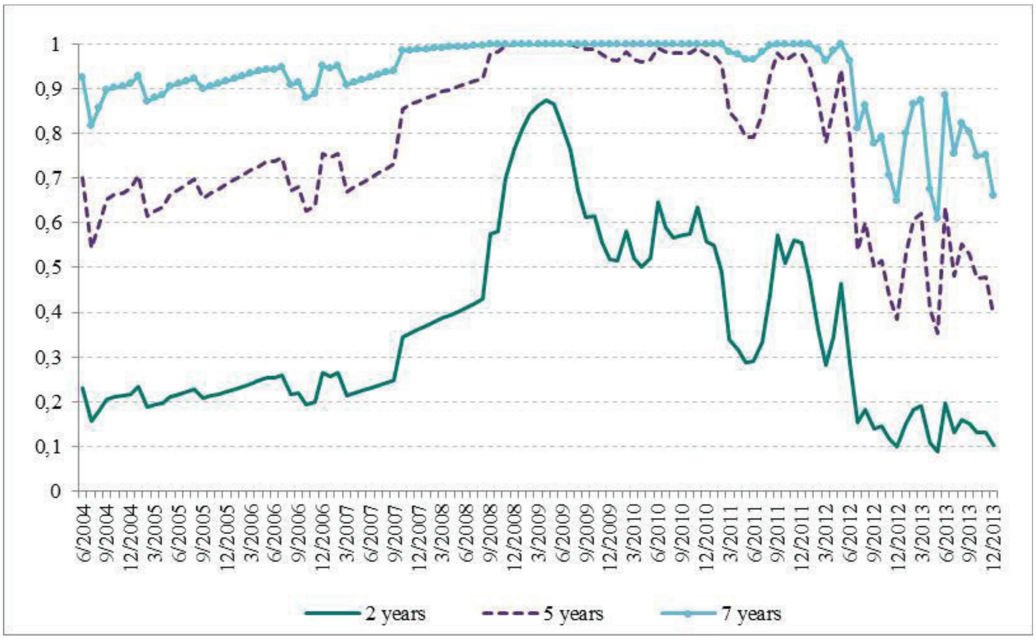
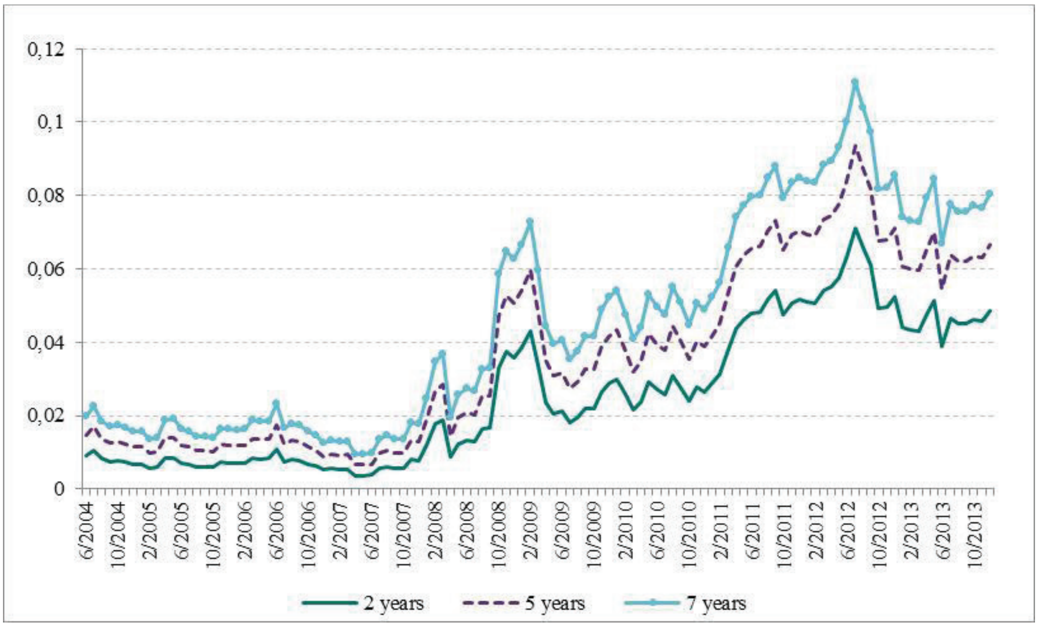


Figure 3: Term structure and time fluctuations of probability of default values in the TVLGD model.



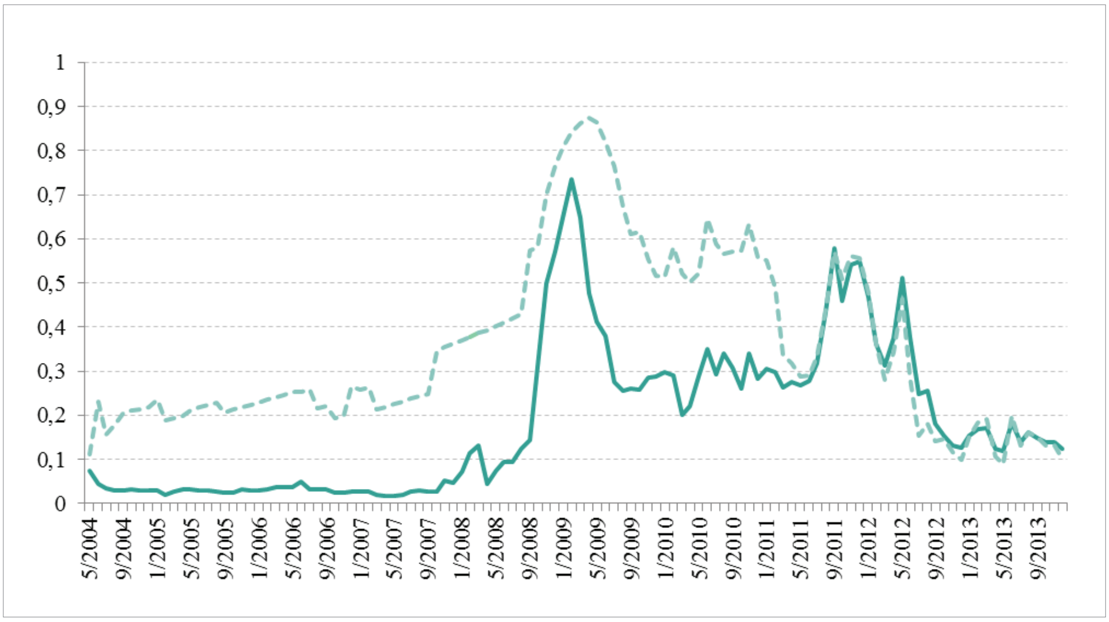
Note: The x-axis describes the dates of observation, the y-axis describes probability of default, and the z-axis describes time to maturity of the contract.

Figure 4: Term structure and time fluctuations of loss given default values in the TVLGD model.



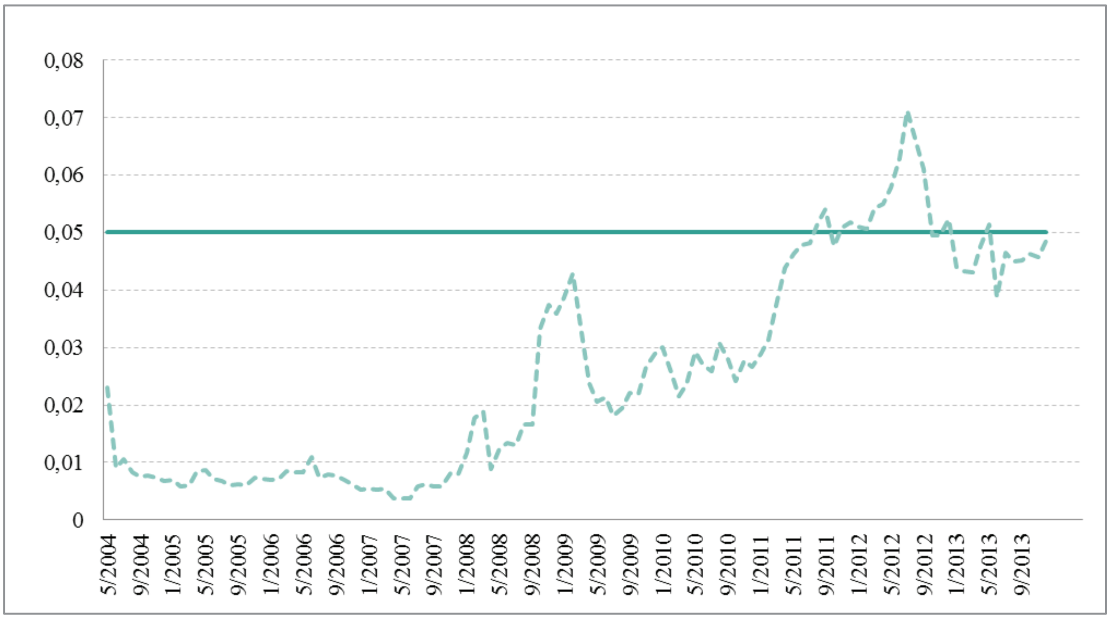
Note: The x-axis describes the dates of observation, the y-axis describes loss given default, and the z-axis describes time to maturity of the contract.

Figure 5: Probability of default values for two-year CDS contracts in the TVLGD and CONSTLGD models.



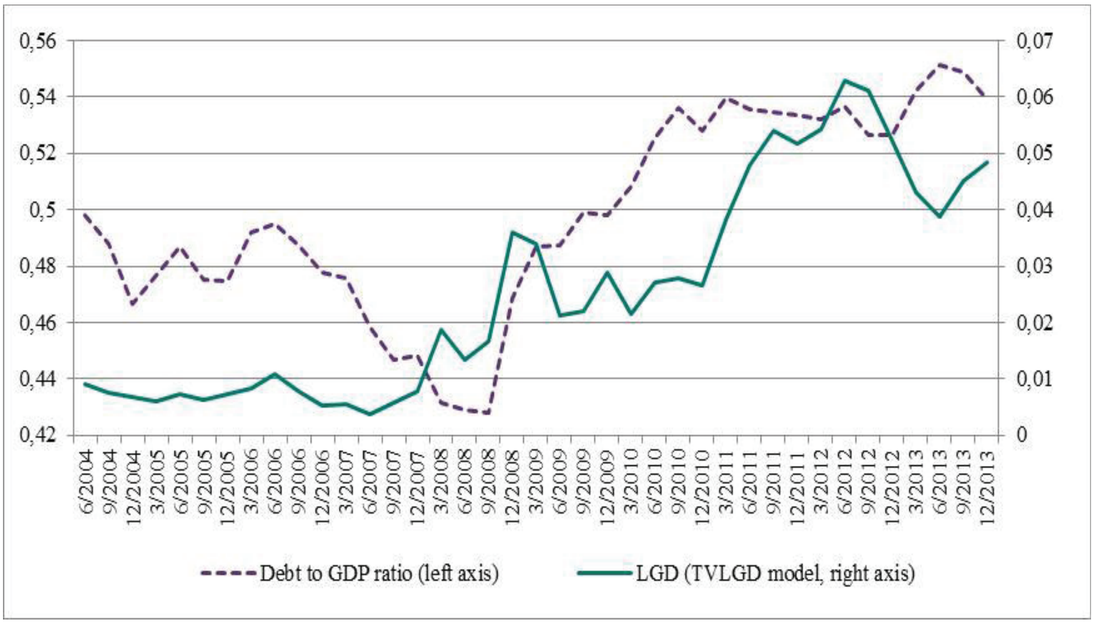
Note: The x-axis describes the dates of observation, and the y-axis describes probability of default. The dashed line corresponds to the TVLGD model and the solid line corresponds to the CONSTLGD model

Figure 6: Loss given default values for two-year CDS contracts in the TVLGD and CONSTLGD models.



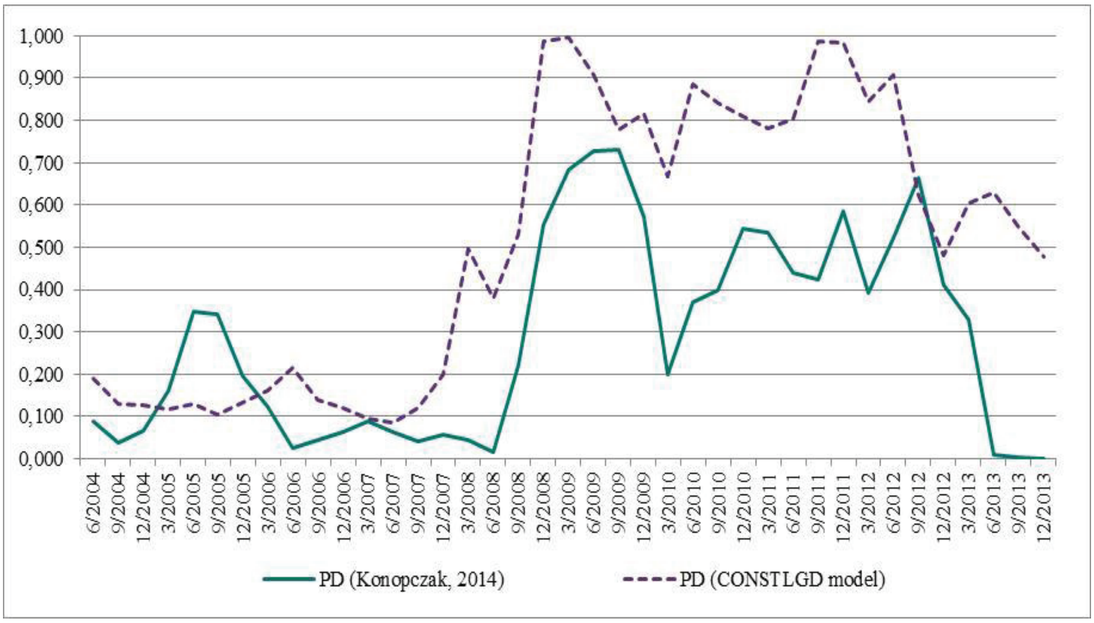
Note: The x-axis describes the dates of observation, and the y-axis describes loss given default. The dashed line corresponds to the TVLGD model and the solid line corresponds to the CONSTLGD model.

Figure 7: Loss given default values derived from the TVLGD model and the level of sovereign debt



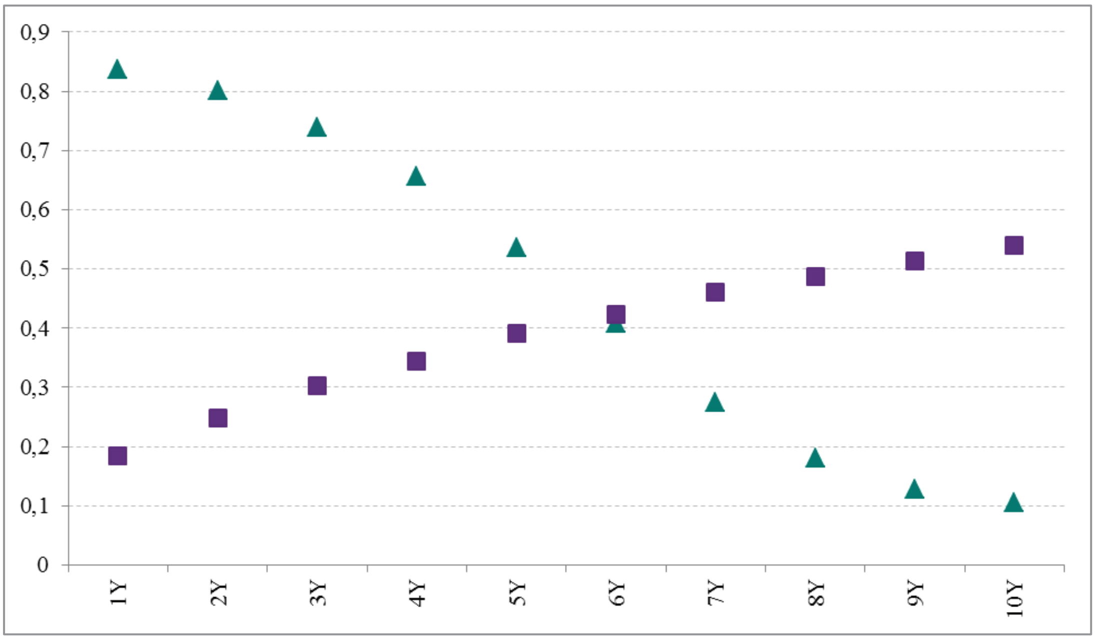
Note: The x-axis describes the dates of observation and the y-axes describe the loss given default (right axis) and the ratio of sovereign debt to GDP (left axis).

Figure 8: Comparison of probability of default values derived from the CONSTLGD model with the probability of default values derived from the structural model of Konopczak (2014).



Note: The x-axis describes the dates of observation, y axis describes probability of default. Both probabilities of default are computed for the five-year horizons.

Figure 9: Correlation between the CDS premia, probability of default values, and loss given default values in the TVLGD model.



Note: The x-axis describes years to maturity and the y-axis describes the value of the correlation coefficient. Triangles represent the correlation between CDS premia and probability of default values and squares represent the correlation between CDS premia and loss given default values.

Figure 10: Correlations between CDS premia and probability of default values in the CONSTLGD and FIXEDLGD models.

Note: The x-axis presents years to maturity and the y-axis presents the 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

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