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MEASURING SYSTEMIC RISK IN THE POLISH BANKING SYSTEM
BY MEANS OF THE RISK-BASED BALANCE SHEETS METHOD

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Abstract

The complex connections, spillovers and feedbacks of the global financial crisis remind how important it is to improve the analysis of risk modeling. This article introduces a new framework for mitigating systemic risk by using a risk-adjusted balance sheet approach. In this regard, the analysis of individual banks in Poland shows potential risk which could threaten all the financial system. Traditional banking models do not adequately measure risk position of financial institutions and cannot be used to understand risk within and between balance sheets in the financial sector. A fundamental subject is that accounting balance sheets do not indicate risk exposures, which are forward-looking. The paper concludes new directions for measuring systemic risk by using Merton's model. It shows how risk management tools can be applied in new ways to measure and analyze systemic risk in the Polish banking system.

Introduction

In the face of the financial crisis threats the way of measuring and assessing financial institutions risk of insolvency which takes into account its non-linear nature becomes particularly important. For market participants and the institutions responsible for the economic policy, the information regarding the likelihood of company insolvency and the amount of the associated risk premium is an important part of decision making. This issue is all the more important that we deal with systemic risk which by definition occurs when the instability of a single entity, or the entire financial system crisis, leads to bankruptcy of many financial institutions. In the case of systemic risk the problems of escalating payment mechanism are growing incredibly fast.

Traditional methods of measuring credit risk are mainly based on the study of the balance sheets which are unobservable in nature, and do not depend on changes in the financial market (changes in market participants' expectations and the flowing information from them). Therefore, in this article the author proposes the use of Merton's model which is mainly used for option pricing as a way to assess the risk of insolvency of the company. The essence of this method is the connection of information coming from the company's balance sheet and market data, containing a part of market participants' future expectations. In particular, it seems important to use option pricing methodology which takes into account the information contained in the market prices about the increasing risks in the financial system.

Estimation of the implied unobservable variable based on other observable market values is a technique which is often used in finance. This approach assumes that the expressed in prices opinion of a wide range of the liquid market participants contains all the information about the given entity. It does not mean at all that the market price may be overestimated / underestimated in different periods of time. However, the price seems to be the best possible source of market participants' expectations[1]. The valuation of insolvency risk basing on Merton's model has been successfully used by *CreditMetrix* (KMV method) and was developed by Stephan Kealhofera, John McQuowna and Oldrich Vasićka[2]. This approach is widely used in developed markets (USA, North and West European financial systems). Lastly, it is commonly used to assess the default risk born by the systemic financial market participants.

The model assumes determination of the likelihood of losing solvency by the entity. This approach provides the methodology to combine balance sheet information with widely used risk management tools to build marked-to-market balance sheets that better reflect underlying risk. The risk adjusted balance sheets use the option pricing model to value the liabilities which are estimated as claims on stochastic assets. Prototypical for this approach is an option – the right to

sell or buy the underlying asset at a specified exercise price by the expiration date. A PUT is an option to sell, CALL is an option to buy; but the value of each is contingent on the underlying asset price to be sold or bought. It can be used to derive a set of risk indicators, including distance-to-default that can serve as barometers of risk for financial sector vulnerability. In addition, in KMV method the credit risk assessment of a company is relatively frequently updated and does not require the existence of a liquid market for credit derivative instruments. It seems that a firm basis of KMV method in the theory of finance and a small number of assumptions affect the estimates to increase its reliability and versatility[3].

The paper is organized as follows: Section 1 gives a brief overview about market insolvency risk measure and Merton model used in literature; Section 2 presents the data and methodology; in Section 3 includes the results of the CCA model in estimating systemic risk in selected commercial banks in the Polish financial market; Section 4 contains the conclusion.

1. Literature review

The problem of increasing systemic risk in the economy is widely presented in the literature. Especially a lot on this subject can be read in the IMF reports[4].

The concept of credit risk measurement methods using KMV has a wide range of applications. American studies[5] are used by central banks to support the analysis and management of financial risk management. The main analytical tool is the risk-adjusted balance sheet which shows the sensitivity of the company's assets and liabilities to external "shocks" on the national and international level. Traditional approaches may have a problem with the analysis of how risks can accumulate gradually and then suddenly erupt in times of crisis. The KMV model approach is designed to overcome any "non-linearity" in the assets and liabilities, and between institutions. Simulations and stress tests, using risk-adjusted balance sheets are managing systemic risk.

John McQuown[6], who commented on the application of market variables to estimate the probability of default, wrote that "financial accounting has not evolved into a coherent conceptual picture of the economics of the firm, especially when distress threatens default, so the most accurate measure of default probabilities requires the use of prices".

The overview of the theoretical and empirical aspects of systemic risk measurement and management has enabled the author to determine what was missed in previous studies and is the structural default risk modeling that is reasonable in the Polish financial system. However, the using of multitude of methods caused unequivocal conclusions. There is no doubt that the

cause of it is the randomness of economic phenomena that cannot be properly described by a statistical model.

According to Schuermann[7], accounting balance sheets do not indicate risk exposures which are forward-looking and express market risk. He has been working on linking the default risk of corporations with macroeconomic models. He underlines that the main risk is that we leave out the default risk in the financial sector in our models. Gray and Jobst[8] pointed out that study of financial volatility had not been well served by economic theory.

To manage and mitigate risk in the financial sector new analytic tools and additional regulations are needed. Recent work has shown that financial sector risk indicators, such as the systemic expected losses or system default risk from Merton's model, have big predictive power for the GDP and the output gap[9].

2. Data and methodology

In its basic concept of credit risk assessment Merton's model is based on the assumption that the equity owners of the company which is financed with external capital have a call option on the value of its assets. Shareholders' claims on contributed capital can be met only after the settlement of all remaining liabilities. At the time of company liquidation, shareholders will receive the difference between the value of assets and obligations of the company. Thus, in some studies, the method is called *Contingent Claim Analysis* (CCA).

In order to understand the individual institutional exposure to systemic risk in times of crisis, the method of the CCA and its technique of using risk-based balance sheets of financial institutions are worth analyzing. The CCA method assumes that the total market value of bank assets at any time T is equal to the sum of the market value of equity E and its "risky" debt D at time T. The term of "risky debt" is due to the fact that there is always a chance of company insolvency. The regulation of payment of "risky debt" depends on the quality of bank assets, therefore being a claim against the assets of uncertain value. This type of claim is known as a conditional claim.

At the time of bankruptcy shareholders receive payment in the amount of $A - B$, if $A > B$, or do not receive anything if $A < B$, where A is the market value of the assets, B – the liabilities (without equity). Similarly, we can compare the situation of a shareholder to that of a holder of a call option on the assets of the company. Exercise of the option occurs when it is in-the-money, which means $A > B$, while in the opposite situation, when the option is out-of-the-money, the shareholder does not exercise it (the situation of loss of the ability to pay where $A \leq B$).

The KMV method we describe the relation between the value of assets and the capital of the analyzed subject, derived from the theory of option pricing model (Black-Scholes)[10].

$$E_T = \max [A_T - B, 0] \tag{1}$$

where E_T – value of equity at the time T.

Assets take a random distribution and may fall below the value of liabilities which is equal to the level of a bank failure B (often referred to as the "default point" or "distress barrier"). Using the Black-Scholes-Merton model, the value of equity can be expressed as an implied call option on the bank assets with an exercise price equal to the level of B, which is expressed by the formula (1)[11]:

$$E_T = A_T N(d_1) - Be^{-rT} N(d_2) \tag{2}$$

where:

E_T – option value equal to the value of the bank capital at the time T,

A_T – value of the underlying bank assets at the time T,

B – exercise price equal to the value of liabilities,

r – risk free rate,

T – time to maturity option,

$N(d_i)$ – value of the distribution function for a standardized normal distribution equal to the argument d_i, where $I = 1, 2$

$N(d_2)$ – probability of exercising a call option,

$1 - N(d_2) = N(-d_2)$ – probability of losing the ability to pay,

$d_1 = [\ln(A_T/B) + (r + \sigma_A^2/2)T](\sigma_A\sqrt{T})^{-1}$,

$d_2 = d_1 - \sigma_A\sqrt{T}$,

σ_A – bank assets volatility.

In the model, the variables E, B, T, r are directly observable, but the market value of bank assets (A) and its volatility (σA) are not directly observable. Therefore, in order to estimate the market value of the asset and its variability the relationship[12] was used as well.

$$\sigma_E E = N(d_1) \sigma_A A \tag{3}$$

where σ_E – volatility of the bank equity.

With equations (2) and (3) we can calculate the market value of bank assets (A) and its volatility (σ_A) by successive iterations by comparing the two equations to zero.

$$A_T N(d_1) - Be^{-rT} N(d_2) - E_T = 0 \tag{4}$$

$$N(d_1) \sigma_A A - \sigma_E E = 0 \tag{5}$$

Minimizing the value of the expression (6) estimate the value of assets and volatility:

$$[A_T N(d_1) - Be^{-rT} N(d_2) - E_T]^2 + [(N(d_1) \sigma_A A - \sigma_E E]^2 \rightarrow min \tag{6}$$

The estimated value is a market asset value, as assessed by investors. Let us assume that the relevant bank has a simple structure of financing (equity and foreign liabilities with maturity T). The bank's loss of the ability to pay occurs when at the time T the value of the assets is smaller than the liabilities. It follows that the loss of solvency is a function of the capital structure, the volatility rate of return on assets and the current market value of assets. When marking the probability to lose the ability to pay by the bank P_{def} we get:

$$P_{def} = Pr\ [V \leq V_{def}] = Pr\ [lnV \leq V_{def}] \tag{7}$$

When estimating the probability of losing the ability to pay in the KMV model defined by (7), we assume that the random variable – the return on assets adopts normal distribution, and therefore can be represented as a cumulative normal distribution of P_{def}. It means that we can find such a value of a normally distributed variable Z where the decline in the value of assets below its level will mean that bank has lost its ability to pay:

$$P_{def} = Pr[\ln A_0 + (\mu - \frac{\sigma_A^2}{2})t + \sigma_A \sqrt{t} Z_t \leq \ln A_{def}] \tag{8}$$

After the appropriate transformations we can determine the probability as:

$$P_{def} = Pr\left[\frac{\ln\left(\frac{V_0}{V_{def}}\right) - \left(\mu - \frac{\sigma_A^2}{2}\right)t}{\sigma_A\sqrt{t}} \geq Z_t\right] = Pr\left[Z_t \leq -\frac{\ln\left(\frac{V_0}{V_{def}}\right) - \left(\mu - \frac{\sigma_A^2}{2}\right)t}{\sigma_A\sqrt{t}}\right] = N(-d_2) \tag{9}$$

where:

P_{def} – probability of the bank failure,

V_0 – market assets value,

V_{def} – limit of the assets value resulting in bankruptcy,

σ_A – asset volatility,

μ_A – the actual expected rate of return on assets,

t – time to option expiration.

The algorithm (9) is defined in literature as a DtD – Distance to Default, the number of standard deviations between the expected value of assets and the level of causing the loss of ability to pay. Using the procedure of estimating the likelihood by means of the KMV estimator turns out to be a better credit risk estimator than the actual statistics of rating agencies – such conclusions were reached in the studies by Kealhofer, McQuown and Vasicek[13]. The distribution of assets at time T of the selected barrier solvency is presented in the Figure 1.
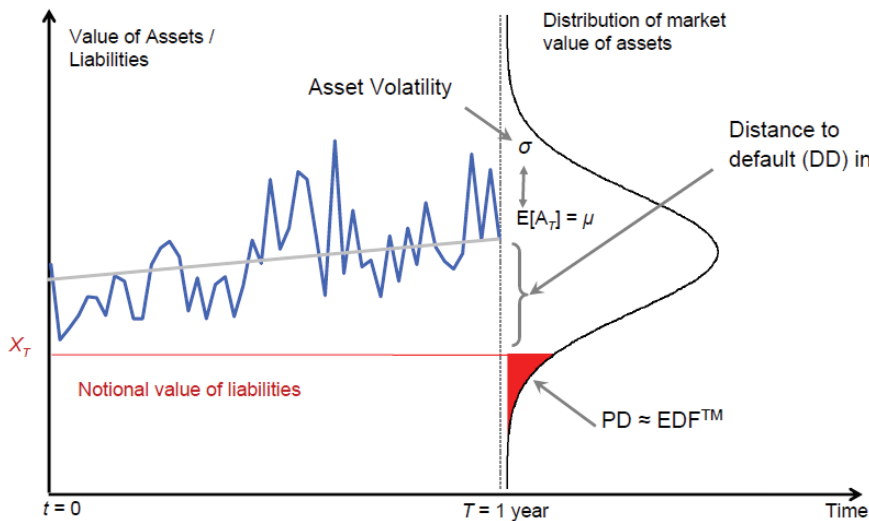

Fig. 1. Distribution of assets and the process of finding the probability of default

Source: Gray, Malone (2008), p. 21.

On this basis we can also indicate other "warning indicators" of systemic risk:

− Critical level of assets under which the company will lose its ability to pay, i.e. the Default Point. The level has been defined as the sum of short-term liabilities and a half of long-term liabilities.

− Expected Default Frequency – EDF estimating the probability of losing the ability to pay by bank.

The proposed method of measurement of systemic risk has been used to estimate the market value of the assets of Polish commercial banks listed on the Warsaw Stock Exchange. The study was conducted for the selected seven largest commercial banks in the last ten years

(from March 2002 to June 2012). Data on the size of selected assets and liabilities come from the banks' financial statements, and market data were obtained from Reuters Eikon. As far as accuracy of the results is concerned, the variables are related to quarterly periods. General characteristics of the data used in the study are presented in Table 1.

Table 1. Data description

Bank	Number of variables in the sample (quarters)	The average value of equity (PLN million)	Average book value of assets	Market capitalisation
Bank PEKAO	42	11,989.33	99,869	30,684.84
BRE Bank	41	3,588.11	59,571	6,993.24
ING Bank	42	3,896.07	52,740	6,125.77
Millenium	42	2,555.48	33,933	4,428.91
Bank HANDLOWY	40	5,867.18	38,096	10,053.83
BOS Bank	33	828.32	9,917	1,093.32
Bank BPH	40	4,672.49	41,795	3,508.71
Total		33,396.97	335,920	62,888.63

Source: own calculation.

As the risk-free rate we adopted the Polish central bank's reference rate, while the adopted market value of equity is the capitalization of individual banks on the Warsaw Stock Exchange. The calculation of the assets market value is based on Merton's model and were calculated by means of Microsoft Excel Solver.

3. Empirical Results

The CCA models for each of the seven Polish banks were calibrated, and then the expected market value of assets was estimated for each of them. In case of each bank equity market and balance sheet information was used to calculate the key parameters of the CCA model (bank asset level, asset volatility, bank debt distress barrier and a assets volatility. One of the key systemic risk indicator are the expected losses of the banking system. All banks show the same pattern, with a low point reached in early 2009 and 2011. Financial sector indicators of this type contain forward-looking information about risk appetite channels. What is very interesting, the estimation made for individual banks shows different levels of systemic risk. The most important thing in this estimation is the information about insolvency risk in the Polish banking system, which is often viewed as safe. See Figure 2, showing the distribution of systemic risk for particular banks.
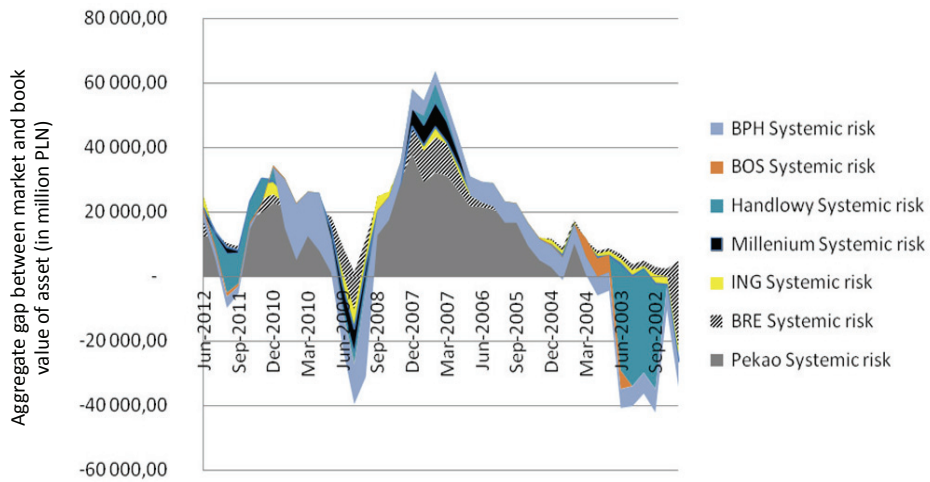
Fig. 2. Distribution of systemic risk in the Polish banking system (March 2002–June 2012)

Source: own calculation.

The CCA implied assets value is generally higher than the book value, but the level was negative during the global (2009) and fiscal (2011) crisis.
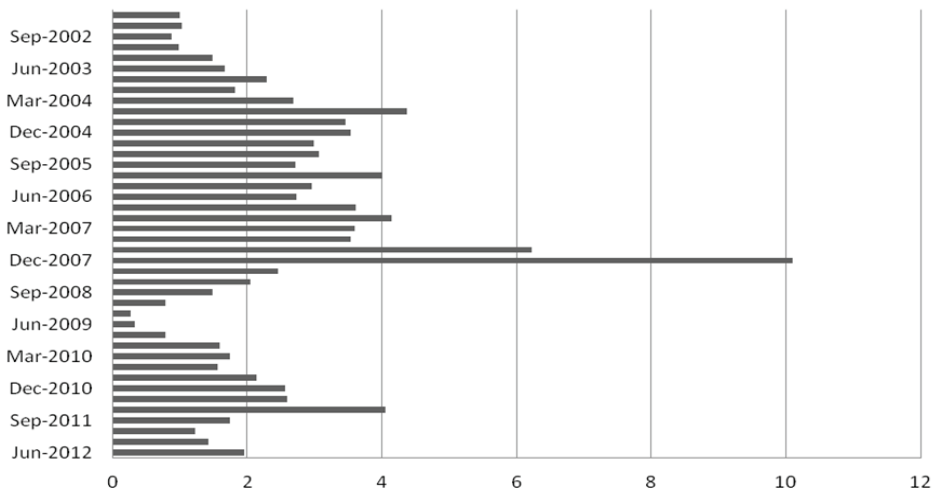

Fig. 3. The distance to the critical point (default) from the expected value, referred to as DD – distance to default and the calculated number of standard deviations

Source: own calculation.

Another estimated risk indicator is DtD – distance to default, which was estimated for an aggregated banking system. In other words, the indicator corresponds to the number of standard deviations from the current level of assets to the distress barrier. The larger the indicator, the safer the banking system. The empirical results show that it was changing over time. During the economic boom it reached its size up to 8 standard deviations, and with the growing crisis in the financial market the distance to the point of insolvency fell to one standard deviation. None of the banks reached the critical barrier, but the year of 2009 can undoubtedly be called disturbing (see Figure 3).

The periods when markets assessed suddenly higher risk for the Polish banks are easily discerned, for example, the decline in the world stock markets following the collapse of Lehman Brothers or fiscal crisis in PIIGS countries.

Conclusions

The assessment of systemic risk is not straightforward and requires significant departure from conventional statistics. This paper presented a new modeling framework which can help to analyse systemic risk by estimating the aggregated contingent liabilities of financial institutions. An example of the CCA for the Polish commercial banks showed useful insights about the systemic risk which might lead to insolvency problems. This framework can be used to analyze potential destabilizing feedback processes inside the financial sector. In fact, there is a danger of underestimating potential systemic risk, but on the other hand risk management in real-life situations based on complex modeling leads to losing the transparency of operation. In this regard, the CCA model offers a good approach to improving systemic risk management in financial sector. Looking forward, this approach could provide more information about the impact of systemic risk dynamics on economic growth and financial stability in Poland.

Notes

[1] Gray, Jobst, Malone (2010), pp. 90–110.
[2] Gątarek, Maksymiuk, Krysiak, Witkowski (2001), p. 176.
[3] Gapen (2009), pp. 20–21.
[4] IMF (2008), (2009).
[5] Gray, Malone (2011).
[6] Raport MKMV (2003).
[7] Schuermann, Pesaran, Treuler, Weiner (2006).

[8] Gray, Jobst (2009), pp. 128–131.

[9] Garcia, Gray, Luna, Restrepo (2010).

[10] Hull, Nelken, White (2003).

[11] Gray, Malone (2011).

[2] Hull (2003).

[13] Wójciak, Wójcicka (2007).

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