Doctoral School of
Management and Business
Administration

RÉSUMÉ OF THE PH.D. THESIS

Homolya, Dániel

Operational risk of banks and firm size

Supervisors:
Király, Júlia Ph.D.
honorary professor

Benedek, Gábor Ph.D.
assistant professor

Budapest, 2011

Institute of Finance and Accounting,
Department of Finance

RÉSUMÉ OF THE PH.D. THESIS

Homolya, Dániel

Operational risk of banks and firm size

Supervisors:
Király, Júlia Ph.D.
Benedek, Gábor Ph.D.

Table of contents

1. RELEVANCE OF THE TOPIC 4

2. METHODS APPLIED 9

Hypothesis 1: The "Poisson frequency-lognormal severity" model framework generally applied in operational risk measurement practice can be justified in a theoretical, stylised framework as well, and a robust estimation can be made using the observed error points. 9

Hypothesis 2: The relationship between the operational risk losses incurred in the Hungarian banking system and the institution size is positive. 9

Hypothesis 3: Sub-hypothesis A – The more profitable a financial institution is, the more effort it makes to apply more advanced operational risk methods. Sub-hypothesis B – The bigger an institution is, the more possibilities it has to apply more advanced operational risk management methods. 10

3. RESULTS OF THE THESIS 12

4. POTENTIAL APPLICATIONS OF THE RESULTS PRESENTED IN THE THESIS 17

5. MAIN REFERENCES 18

6. OWN PUBLICATIONS RELATED TO THE TOPIC OF THIS THESIS 22

The dissertation was partly supported by TÁMOP-4.2.1/B-09/1/KMR-2010-005 project.

Magyar Nemzeti Bank's (central bank of Hungary) Ph.D. programme contributed also to the work of the author.

1. Relevance of the topic

Owing to modern regulations and company internal considerations, financial institutions pay increasingly careful attention to their risks. This systematic approach to operational risk is relatively novel, given that until the 1990s; the focus had been on credit and market risks. Operational risk is defined as the risk of loss resulting from inadequate or failed internal processes, people and systems or from external events (BIS [2004]; EU [2006]; Government of the Hungarian Republic [2007]). The need for the assessment of operational risk is evident in view of the increased risk exposure stemming from the complexity of the financial institution system on the one hand, and regulatory ambitions on the other hand. In the Hungarian legal order the so-called Basel II-based risk management principles were implemented as valid from January 2008. One of the main novelties of the regulatory change is the conscious consideration of operational risk (Government of the Hungarian Republic [2007]). The set of Hungarian academic publications, research papers in the field of operational risk is rather limited, for this reason one of the aims of this thesis is to enrich research on operational risk related to operational risk of the Hungarian banking sector.

Management of operational risks has become one of the new central issues in both Hungarian and international financial institutional practice in the recent past. Substantial losses stemming from operational risk events (for instance the recently exposed cases of fraud (e.g. the fictitious transactions carried out by Jérôme Kerviel, incurring losses of several billion euros for Société Générale, Bernard Madoff's embezzlement of clients' wealth worth tens of billions of dollars or misrepresentation affair related to Goldman Sachs revealed in H1 2010), inadequate compliance with lending standards on the subprime mortgage market, the fraud perpetrated by Nick Leeson at Barings Bank in the mid-1990s (for details on the case, see Jorion [1999]) or the 9/11 terrorist attacks against the WTC in 2001) have contributed to increased attention being focused on this topic. Although the financial and economic crisis emerged in 2007 highlighted the role of credit and market risk, some events emphasized operational risk. It is undeniable that while "the outside world" may be blamed for losses resulting from financial risks, major part of the operational risks related to the own operation is in connection with the institution's internal operation, therefore the responsibility of the individual institution may be bigger in this respect.

On the one hand, the documents issued by various regulatory bodies serve as a literature source for operational risk management (pl. BIS[1] [2004], CEBS[2] [2006a], BIS [2009a], BIS [2009b], CEBS [2009], BIS [2011a], BIS [2011b]). The other important source is the academic literature, which can be divided into two on the basis of being methodology- or management-oriented (e.g. Cruz [2002] versus Davies [2006], Davies [2007]). The related literature on methodological issues is often too formalised, and this less practice-oriented approach results in some deficiencies as well in many cases. Regarding methodology, procedures using distribution based models (LDA – Loss Distribution Approach) and scenario based models (SBA – Scenario Based Approach) can be distinguished, while certain authors recommend a mixture of the two. Due to the current practical relevance, the business importance, and the continuous development of the topic, in addition to the literature (articles, academic papers, books), it is by all means important to follow the lectures, presentations, and conference materials published by financial institutions. Besides the relative diversity of the international literature, domestic literature is quite poor, it is limited to only a few studies in addition to the supervisory (HFSA) materials, guidelines. (Amongst these studies, the articles that appeared in Hitelintézeti Szemle 2007, Issue 4 (Scientific Bulletin of Hungarian Banking Association) are especially significant[3,4]).

The number of published comprehensive surveys regarding the international operational risk management practice is limited. This may be due to the "young age" of operational risk management.

One part of international surveys analyse the capital requirement and the recorded losses (e.g. BIS [2002], BIS [2009a]), while the other part tries to apprehend the best practices (e.g. BIS [2006], BIS [2009b]). The aforementioned surveys conclude that applied operational risk management practice is in line with the recommendations regarding the advanced method of regulation. The best practice amongst the institutions is risk management based on the four

[1] BIS is the abbreviation for Bank for International Settlements. The Basel Committee on Banking Supervision (BCBS) operates attached to this institution (not in terms of same organisation, buti n terms of location).

[2] CEBS is the abbreviation for Committee of European Banking Supervisors. Under the European supervisory reform that took place in 2011, European Banking Authority (EBA) became the successor organisation of CEBS.

[3] Available on the Internet in Hungarian, but abstracts are available in English: http://www.bankszovetseg.hu/bankszovetseg.cgi?p=hatodikevf&r=&l=eng&v=7492926929 (date of download: 01.08.2010.)

[4] As far as I know, the first overview in Hungarian language regarding operational risk was prepared by Homolya-Kiss [2001]. Marsi [2002] served as an article providing overview on operational risk related „Basel" developments as well. Furthermore, it is worth highlighting Baki-Rajczy-Temesvári [2004], which analyses operational risks from a special aspect, from the viewpoint of a central bank (i.e. central bank of Hungary).

pillars (internal data, external data, scenario analysis, business and control factors) of risk measurement.

In the literature, we only find a few examples of the correlation between institution size and risk management practice. Helbok-Wagner [2006] concludes that in the early stages of operational risk management (between 1998 and 2001), the institutions with lower profitability disclosed more detailed data regarding their operational risk profile and operational risk management practice. This phenomenon could be explained partly by enhanced need for risk management efforts and transparency of institutions with poorer profitability performance. Although OpRisk & Compliance [2008] and OpRisk & Compliance [2009] presents a database consisting of 100 banks in connection with operational risk management data and methods, these OR&C articles do not contain any detailed statistical analysis.

Hungarian banks started the systematic management of operational risk mainly as part of the Basel II process. The regulatory framework to be applied compulsorily from the 1st January 2008 (EU [2006]) allows the application of an approach based on a simpler basic indicator approach (BIA), a standardised and an alternative standardised approach (TSA + ASA), and a more complex approach (advanced measurement approach, AMA). A significant part of the Hungarian banking sector first started the collection of operational risk loss data. At first, the added value of risk management was hard to release; therefore emphasis was mainly on regulation and IT initially. Modelling based risk management is in operation only in a few institutions at the moment. Due to the fact that the Hungarian banking sector is typically under foreign ownership, the domestic institutions try to approach operational risk systematically by using the guidelines of parent banks and principles of the "European" "best practice" (HFSA [2005]).

Relatively few comprehensive analysis has been published on the operational risk practice of domestic banks to date. The referred Issue 4 of Hitelintézeti Szemle in 2007 (Scientific Bulletin of Hungarian Banking Association), Issue 4 represents an extensive work, but it focuses mainly on individual experiences. As far as I know, the operational risk methods used in the Hungarian banking system has been analysed comprehensively exclusively by Homolya [2009a]. The article concluded that the "most advanced" approach for the domestic banking system is the standard approach at present; the major banks (i.e. banks with higher total assets) use this method like a "foyer" of the advanced measurement approach. As it is

shown by the analysis later in this thesis, several banks made a step ahead from this approach in the past period.

An important initiative of the members of the Hungarian banking system is the HunOR Hungarian Operational Risk Database, which started its operation under the aegis of the Hungarian Banking Association in 2007. Under this data consortium, 12 banks representing more than 50 per cent of the balance sheet total of the complete banking sector share data with each other anonymously on operational risk loss events having an effect of more than HUF 50,000 incurred loss. This initiative means a huge advantage for the participating banks, as it makes it possible to explore operational risk events specific to Hungary, and creates the possibility of a comparison with institutions likely to be close to each other regarding their operational risk profile. HunOR started its operation so as to have all operational risk loss events after the 1st January 2007 recorded into the database. (The importance of the HunOR database is discussed in more detail in Homolya-Szabolcs [2008].)

The measurement of operational risk is dominated by LDA modelling based on realised losses, which examines the already occurred risk events. In my research, I first analyse whether process based modelling on the one hand confirms, with the application of a simulation method, the frequency (Poisson) and severity (lognormal) assumptions frequently used in operational risk modelling, and on the other hand it presents the analysis of a high-frequency database containing operational failures of ATMs[5]. This is not a typical approach in the methodology articles on operational risk.

Second, I examine the relationship between losses and the size of the institutions. Although several articles have been published in international literature analysing a comparison between operational risk losses and institution size to discover the scalability of losses between institutions, but no authors have yet prepared such a survey for the loss data of Hungarian banks. The literature analysing the operational risk data of foreign banks (e.g. Na et al. [2005], Dahen – Dionne [2007, 2010]) concludes the significance of the relationship between cumulative losses and institution size (primarily gross income). However, in these analyses, researchers conclude that the decisive role in the relationship between cumulative losses incurred in the given period and institution size is played by frequency. I analyse this

[5] This analysis has already been published in Homolya-Benedek [2008].

correlation in this thesis for the Hungarian banking system as a first analysis[6] in the relevant literature.

The third issue examined in this study is the relation between the selected operational risk management and capital requirement allocation method and the financial data of the institution (mainly profitability). Although there exist pieces of the literature (e.g. BIS [2009a], BIS [2009b]) which present overall best practices, but these do not analyse the underlying driving mechanisms. Therefore, as far as I know, my analyses prepared on the international, and on the domestic (i.e. Hungarian) samples are novelties[7].

[6] I published the results of the analysis presented in this thesis in Homolya [2011].

[7] I have already published certain interim results in my own previous publications (Homolya [2009]).

2. Methods applied

In the thesis I examine three hypothesis to be overviewed bellow with the analysis methods applied.

Hypothesis 1: The "Poisson frequency-lognormal severity" model framework generally applied in operational risk measurement practice can be justified in a theoretical, stylised framework as well, and a robust estimation can be made using the observed error points.

Because of the rare nature of high impact operational risk events, process based simulation methods may imply added value for loss event forecast. I test the correctness of the Poisson-lognormal model framework most commonly used in operational risk modelling, by assuming a mean-reverting process and using stochastic simulation. The reason I test this very process is, that Poisson is the most frequently used framework in modelling the frequency of operational risk events, and, although the divergence of methods is stronger in the case of severity, lognormal distribution may be considered the most common (BIS [2009b]). Different trajectories of the stylised process are simulated by different parameter settings assuming that in case of hitting critical levels or intervals there is an operational risk failures. Goodness of fit for operational risk distributions of this framework are tested by standard statistical methods (e.g. K-S Z). After the hypothesis test, I analyse, on a sample containing ATM errors, how much the stochastic process back-estimated from errors help adequate risk estimation. The analysis is based on estimation methods presented in the theoretical literature and simulations based on them.

Hypothesis 2: The relationship between the operational risk losses incurred in the Hungarian banking system and the institution size is positive.

A generally valid principle in the case of operational risks is that despite a given risk type is not present in the loss database of a bank; we cannot unequivocally regard the given risk as if it was non-existent. These are the types of risks in the case of which it is common to use expert estimates and scenario analyses, and to consider loss data originating from external databases.

To utilise external data we need to explore correlations that reveal the relationship between the characteristics reflecting institution size and the loss parameters, as a result of which adequate scaling techniques may be applied (regarding the benefits related to sharing

operational risk data Voit [2007] provides a good overview).For international data, the literature (e.g. Na et al. [2005], Dahen – Dionne [2007, 2010]) empirically supports the correlation between institution size and operational risk loss, but no such estimate has yet been made on a domestic (Hungarian banking sector) sample.

I apply descriptive statistics and standard linear regressions for aims of analysis.

Hypothesis 3: Sub-hypothesis A – The more profitable a financial institution is, the more effort it makes to apply more advanced operational risk methods. Sub-hypothesis B – The bigger an institution is, the more possibilities it has to apply more advanced operational risk management methods.

The fundamentals of my research hypothesis are the examination of the elements of risk management cycles (identification, measurement, monitoring and management) and decision options (unidentified risks versus identified risks, acceptable risks versus unacceptable risks). It is worth examining what are the common characteristics of the financial institutions applying more advanced operational risk approach.

Under the new CRD Directive framework (being compatible with Basel II) obligatory for every financial institution in the European Union from the 1st January 2008, it is required to separately allocate capital for operational risk based on the simpler BIA or TSA approaches or according to the advanced AMA approach based on modelling. Institutions started their preparation and introduced the methods to be used. However, in the literature, I did not find any analysis on what features characterise the institutions that use more advanced methods. My intuition is that the more successful an institution is, the more advanced risk management methods it uses. The analysis of this hypothesis may be important to understand what might inspire institutions to apply more advanced risk management methods.

The operational risk management method's state of advance can be measured by examining which approach is selected by the institution from the three regulatory approaches (BIA: 1 – least advanced; TSA: 2 – moderately advanced; AMA: 3 – most advanced).

Profitability indicators: we can measure profitability with the return on assets (ROA) and the return on equity (ROE).

Table 1 Methodological framework for analysing hypothesis 3

Dependent variable	**Independent variable**	**Immediate variables**	**Methodology**	**Way of analysis**
State of operational risk approach applied	Profitability	– Proxy for the complexity of operational risk approach (BIA:1- TSA:2- AMA:3) – Profitability: ROA and ROE	– Collection of individual institutions' data based on annual reports – Regression analysis, test of coefficients, cluster analysis – As dependent variable is ordinal, instead of standard linear regression logistic regression should be applied	– Inductive (sample based conclusion for general terms)

In addition to profitability other aspects may be important regarding the selection of operational risk approach (size based on total assets, liquidity, etc.); therefore I include these variables as well in my analysis.

3. Results of the thesis

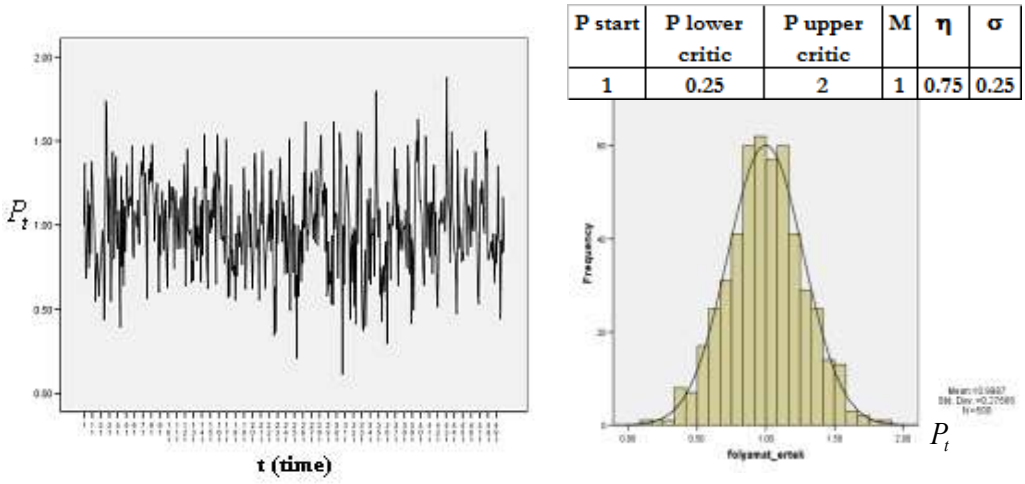
In connection with my first hypothesis the Ornstein–Uhlenbeck process (the so-called OU process) were used in our model, which is popular in financial mathematics (because of its relative simplicity). The Ornstein–Uhlenbeck-process can be defined by the following differential equation: $dP_t = \eta \quad M - P_t \cdot dt + \sigma \quad dz$ (for sake of illustration see *Figure 1*)

where: P_t : value of P at time t; η : speed factor of mean reversion, M: equilibrium rate of process P; performance level process is to revert to this point, and this is the restarting point following a catastrophe; σ : standard deviation parameter dz: Wiener-process with mean of 0, and standard deviation of 1, ρ : correlation factor (ρ) is defined for a dual process; it represents the alignment of the two processes. (In this case the stochastic elements of the processes are the following: the stochastic element of the first process is σ·dz, while the stochastic element of the second process is $\sigma \cdot (\rho \; z + \sqrt{1 - \quad} \; dy)$, where dy and dz are independent, identical, standard normally distributed Wiener-processes.

The differential equation of the first process is therefore: $dP_t = \eta \quad \cdot M_P - P_t \cdot dt + \sigma \quad \cdot dz$

The second differential equation is: $dR_t = \quad \cdot M_R - R_t \cdot dt + \quad \cdot (\rho \; z + \sqrt{1 - \quad} \; dy)$

Figure 1 Characterisation of basic OU process with given parameterisation[8]



Source: Author's calculations (process values, histogram of output values (Y axis is frequency) and parameterisation)

[8] In the latter part of the thesis, more figures showing simulation results are presented. On the figures, small tables are indicating parameter settings with the following notions: Pstart indicates the initial value of the process, P-lower critic: lower threshold value, P-upper critic: upper threshold value M: equilibrium value, η: speed of reversion, σ: standard deviation parameter

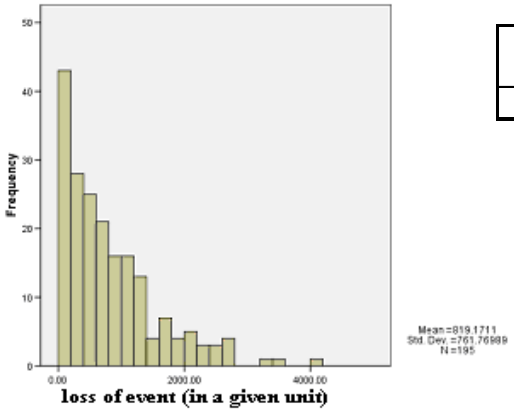
In a stylised model framework analysed by simulation methods I concluded that the frequency distribution of operational risk losses can be properly approximated by Poisson distribution (*Table 2*); while in the case of loss severity distribution, lognormal distribution did not show appropriate fit, while the more fat tailed Pareto distribution provided appropriate goodness of fit (*Figure 2*). Therefore, only one part of my hypothesis proved to be true. The distribution of the first hitting time often present in the related mathematical literature shows complexity in our empirical analyses. We analysed the possibilities of a model-based forecast, and discovered that a method built from historical data on a small sample may result in biased values (over- or underestimation).

Table 2 Goodness of fit to the Poisson distribution with different limitation parameters

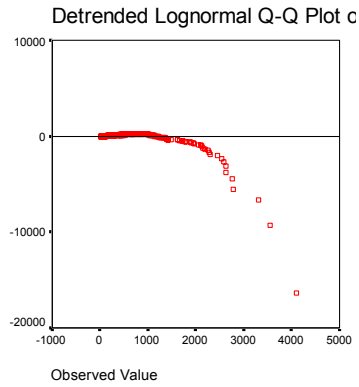
P-lower critic	P-upper critic	K–S Z	Significance (2-tailed)
0.25	2	2.129	0
0.5	1.5	0.406	0.996
0.5	∞	0.794	0.554

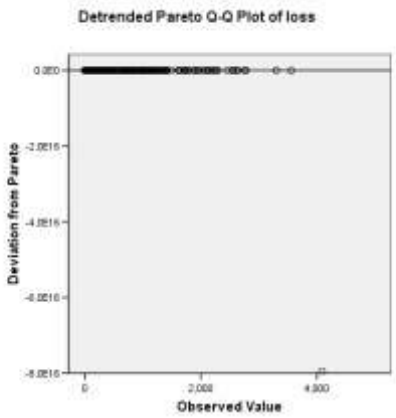
Source: Author's calculations

Figure 2 Severity distribution and its fit to lognormal and Pareto distribution



P-start	P-lower critic	P-upper critic	M	η	σ
1	0.5	1.5	1	0.75	0.25



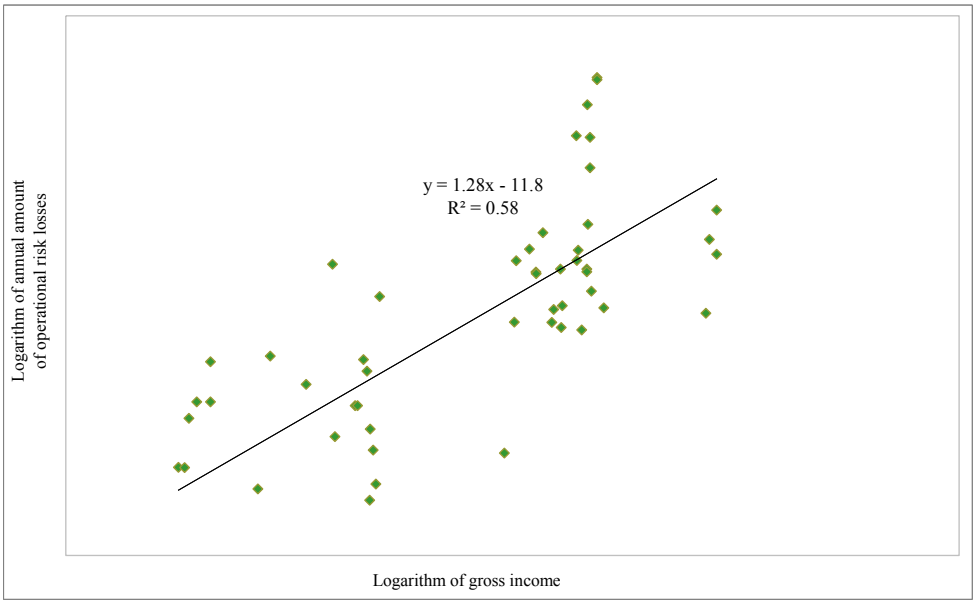


Source: Author's calculations

The model estimated for ATM errors present a proper methodological foundation; however, the back-estimation of the latent risk process may only take place when there is high error frequency. Back-estimation of the error process from the observed errors requires further analysis.

In connection with my second hypothesis, I concluded that my empirical analysis supports that similarly to the foreign banking sectors and banking groups already analysed in the literature, the correlation between gross income-based institution size and the total operational risk losses incurred in a given period is significant in the domestic banking sector as well. The small sample of institutions limits the possibility to draw solid conclusions from the presented analysis; nevertheless, I ended up with forward-looking results. According to the analysis, mostly the relationship of the institution size with the frequency parameter can be regarded as strong, and that with the loss size less strong. In addition, the size of the individual losses is affected less by institution size, and more by business line or loss type.

Figure 3 Relationship between the logarithms of banks' yearly operational risk losses and gross income



Source: MNB.

In connection with my third hypothesis, I concluded that amongst both the international and the domestic banks, the larger institutions are more inclined to use more advanced operational risk management methods, while there is no significant relationship with profitability.

Table 3 Bank size and profitability indicators versus state of advance in a correlation matrix based on Kendall tau-b measure (international sample)

	Sample of 2008 (end-of-2007 data)		**Sample of 2009 (end-of-2008 data)**	
	State of advance (0= simple, 1=advanced)	State of advance including aspiration	State of advance (0= simple, 1=advanced)	State of advance including aspiration
Tier 1 capital (mUSD)	0.2706	0.1317	0.35	0.28
Total assets (mUSD)	0.3627	0.2101	0.37	0.27
Return on Average Assets (ROAA) (%)	-0.0542	-0.0564	-0.03	0.02
Return on Average Equity (ROAE) (%)	0.0516	-0.0147	0.00	0.04

Note: _ refers to significance at the 5% level, = refers to significance at the 1% level.

Table 4 Choice for operational risk approach and its relationship with size, profitability and capital adequacy indicators (Hungarian banking sector)

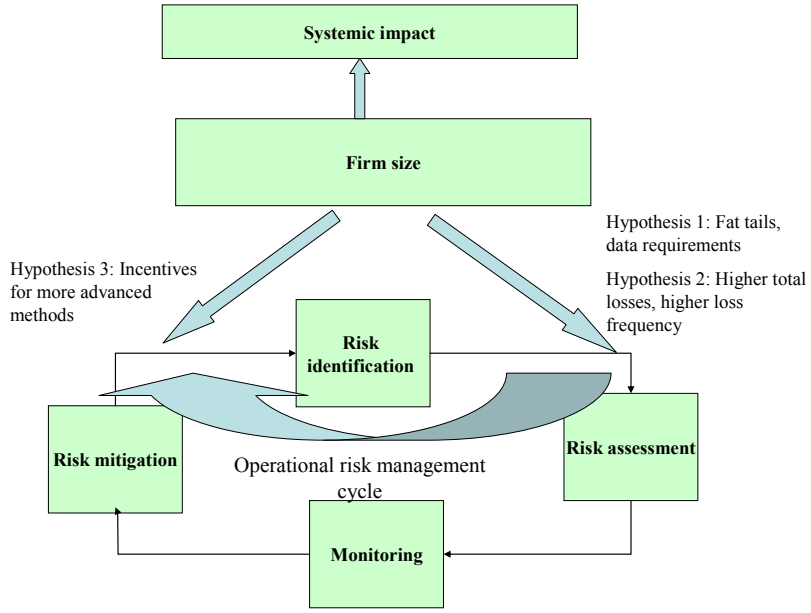
	End-of-2010		
Correlations (Kendall tau b)	OR approach's state of advance*	p	N
Capital adequacy ratio	-0.35	0.04	35
Total assets	0.54	0.00	35
ROE	0.09	0.62	0
ROA	0.28	0.11	0

Note: *BIA=0. ; TSA=1; AMA=2

Source: MNB.

Summarising the results of the thesis and the connections thereof (Figure 4), our most important result is that institution size has an important effect on operational risk exposure and method selection. That is, larger institutions may potentially incur greater total loss, at the same time, with the fixed costs related to risk management, they may be more inspired to use more advanced methods. Higher loss frequency could serve as a basis for more robust risk estimation results, however co-operation in data consortia also could support increasing robustness of estimations. Summarily these results are congruous with our basic intuitions, however, it is important to highlight that altogether, this is a favourable tendency from an operational-risk-related system risk point of view, since it is important that institutions with potentially higher system risk influence apply more conscious risk management.

Figure 4 Results regarding hypotheses discussed in this thesis and their relationship with operational risk management cycle



In today's financial and economic crisis, with the increasing financial risks, even steady operational risks further worsen the position of the credit institutions, and on top of that, the employees of the financial institutions may make more errors in stress situations. As a result of this, the interaction of various risk types may intensify, operational risk events may cause credit risk events and vice versa (some kind of endogeneity appears). Furthermore, in today's circumstances, legal risk appreciates, since the clients become more sensitive in a more difficult economic environment, therefore the legal proceedings arising from the noncompliance with the ethics of fair business conduct (e.g. the selling of too risky products to clients not informed adequately) may cause severe financial and reputation loss, worsening the banks' not so favourable profitability expectations. All this means that operational risk will continue to play an important role regarding the evaluation of the risks of the banking sector.

4. Potential applications of the results presented in the thesis

The individual results of the thesis can be utilised in different ways by the individual participants affected. The two most important participants from the aspect of the banking sector's operational risks are the banks themselves and the authorities acting as supervisors.

The results presented in the simulation model framework and the exploration of the relationships between the operational risk loss parameters and the institution size indicators in the domestic banking system may contribute to the development of the operational risk management practice of banks. The simulation model framework can provide the banks with an idea to model their risks in a more sophisticated way. The scaling relations presented on the basis of the loss data of the domestic banking system can help scale the public operational risk losses from one bank to another on the one hand, and may inspire the members of the HunOR database operating in the domestic banking system to develop the scaling practice on the other hand. The overview of the factors affecting the measurement of operational risk as well as the domestic empirical analysis can help domestic banks to develop their risk measurement. This is important because the current crisis also highlighted that the more conscious, more complex risk measurement and risk management mean competitive advantage.

My results might also be important for the authorities responsible for financial regulation, supervision. Namely, it helps to understand the driving mechanisms behind the operational risk exposure of the banking system, the result may support the analysis of operational risk on system level, and the results of the analyses justify the simpler operational risk capital allocation methods. Though the relatively short time series and the significant variance of the data do not make it possible to judge the sufficiency of the level of current operational risk capital requirement in the domestic banking system, but the described methods may improve the robustness of the analyses regarding sufficiency with the expansion of the time series. From a stability point of view, a favourable fact is that larger institutions are more inclined to use advanced methods. Since larger institutions may have higher impact on system risk, it is important that institutions more important on the banking sector level apply more advanced methods. Naturally, the positive impacts are only available if the methods used by the institutions are transparent enough, and can be extensively validated by the supervisory authorities.

5. Main references

- Babbie, E. [2000]: A társadalomtudományi kutatás gyakorlata. Balassi Kiadó, Budapest
- Baki, László – Rajczy, Péter – Temesvári, Márta [2004]: A működési kockázatok mérése és kezelése a Magyar Nemzeti Bankban, MNB műhelytanulmányok 32., http://www.mnb.hu/Kiadvanyok/mnbhu_mnbtanulmanyok/mnbhu_muhelytanulmanyok/mnbhu_muh_32, letöltés ideje: 2011. július 3.
- Bankárképző [2010]: A kockázati étvágy meghatározása, 2010.04.06., http://www.bankarkepzo.hu/images/articles/576/file/Risk_appetite_Bankarkepzo_20100406.pdf
- Baxter, M.–Rennie, A. [2002]: Pénzügyi kalkulus, Typotex, Budapest [Financial Calculus. CUP, Cambridge,1996]
- Bee, Marco [2006]: Estimating the parameters in the Loss Distribution Approach: How can we deal truncated data in „The advanced measurement approach to operational risk", Risk books, London
- Bhattacharya, Kaushik [2003]: How good is the BankScope database? A cross-validation exercise with correction factors for market concentration measures, BIS Working Papers No 133, September 2003, internetes elérhetősége: http://www.bis.org/publ/work133.htm, 2009. január 2.
- Bhattacharya, Kaushik [2003]: How good is the BankScope database? A cross-validation exercise with correction factors for market concentration measures, BIS Working Papers No 133, September 2003, internetes elérhetősége: http://www.bis.org/publ/work133.htm, 2009. január 2.
- BIS [2001]: Working Paper on the Regulatory Treatment of Operational Risk, 2001. szeptember, http://www.bis.org/publ/bcbs_wp8.pdf
- BIS [2002]: The Quantitative Impact Study for operational risk: overview of individual loss data and lessons learned, 2002. január, http://www.bis.org/bcbs/qis/qisopriskresponse.pdf
- BIS [2004]: International Convergence of Capital Measurement and Capital Standards: a Revised Framework, 2004. június 26., internetes elérhetőség: http://www.bis.org/publ/bcbs107.pdf (2009. március 4.)
- BIS [2006]: Observed range of practice in key elements of Advanced Measurement Approaches (AMA), October 2006, http://www.bis.org/publ/bcbs131.htm
- BIS [2009a]: Results form the 2008 Loss Data Collection Exercise for Operational, July 2009
- BIS [2009b]: Observed range of practice in key elements of Advanced Measurement Approaches (AMA), July 2009, internetes elérhetőség: http://www.bis.org/publ/bcbs160b.pdf (2011. február 19.)
- BIS [2011a]: Principles for the Sound Management of Operational Risk - final document, http://www.bis.org/publ/bcbs195.htm (2011. július 9.)
- BIS [2011b]: Operational Risk - Supervisory Guidelines for the Advanced Measurement Approaches - final document, http://www.bis.org/publ/bcbs196.htm (2011. július 9.)

- Bouchaud, J.-P. [2001]: Power-laws in economy and finance: some ideas from physics, Quantitative Finance, vol. 1, pp. 105-112
- Bureau van Dijk [2008]: Bankscope World banking information source, internetes elérhetőség: http://www.bvdep.com/pdf/brochure/Bankscope_Brochure.pdf, 2009. január 2.
- Bureau van Dijk [2008]: Bankscope World banking information source, internetes elérhetőség: http://www.bvdep.com/pdf/brochure/Bankscope_Brochure.pdf, 2009. január 2.
- CEBS [2006a]: GL10 - Guidelines on the implementation, validation and assessment of Advanced Measurement (AMA) and Internal Ratings Based (IRB) Approaches, www.c-ebs.org
- CEBS [2006b]: Quantitative Impact Study 5 - Overview on the Results of the EU countries, http://www.c-ebs.org/documents/QIS5.pdf, letöltés időpontja: 2009. június 12.
- CEBS [2009]: guidelines on operational risk mitigation techniques, www.c-ebs.org
- Cernauskas, D. – David, G. – Tarantino, A. [2010]: VAR VAR voom, Operational Risk & Regulation August 2010
- Chernobai, A. – Jorion, Philippe – Yu, Fan [2009]: The Determinants of Operational Risk in U.S. Financial Institutions, Working Paper, http://ssrn.com/abstract=1360266
- Cruz, M. [2002]: Modelling, measuring and hedging operational risk, John Wiley & Sons, Chichester
- Dahen, H. – Dionne, G. [2007]: Scaling Models for the Severity and Frequency of External Operational Loss Data, Canada Research Chair in Risk Management Working Paper 07-01
- Dahen, H. – Dionne, G. [2010]: Scaling Models for the Severity and Frequency of External Operational Loss Data, Journal of Banking & Finance, 34. (2010) 1484- 1496
- Danielsson J. – Shin, H. S. [2002]: Endogenous risk, http://www.riskresearch.org/files/HSS-JD-02-9-22-1032695086-15.pdf
- Davies, Ellen [2006]: Operational Risk: Practical Approaches to Implementation, Risk Books. London
- Davies, Ellen [2007]: Operational Risk 2.0: Driving Value Creation in a post Basel II Era, Risk Books. London
- Ditlevsen, Susanne - Ditlevsen, Ove [2008]: Parameter estimation from observations of first-passage times of the Ornstein–Uhlenbeck process and the Feller process, Probabilistic Engineering Mechanics 23 (2008) 170–179
- Ditlevsen, Susanne–Ditlevsen, Ove [2006]: Parameter estimation from observation of first passage times of the Ornstein-Uhlenbeck Process and the Feller process, Conference paper: Fifth Computational Stochastics Mechanics Conference, Rhodos, June 2006
- Elder, James [2006]: Using scenario analysis to estimate Operational Risk Capital, London, Operational Risk Europe Conference
- Európai Unió [2006]: 2006/48/ EK irányelv (2006. június 14.) a hitelintézetek tevékenységének megkezdéséről és folytatásáról (átdolgozott szöveg), EGT-vonatkozású szöveg

- Finch, Steven [2004]: Ornstein Uhlenbeck process, elérés: http://algo.inria.fr/csolve/ou.pdf
- FSA [2007]: Operational Risk Appetite; Operational Risk Standing Group on 3 rd April 2007 http://www.fsa.gov.uk/pubs/international/ora_4apr07.pdf
- Gáll, József – Nagy, Gábor [2007]: A működési kockázat veszteségeloszlás-alapú modellezése (Loss Distribution Approach – LDA), Hitelintézeti szemle, 2007. 4. szám
- Gillet, R. – Hübner, G. – Plunus, S. [2010]: Operational risk and reputation int he financial industry, Journal of Banking & Finance, 34 (2010) 224-235
- Government of the Hungarian Republic [2007]: 200/2007. Government decree on management of operational risk and capital requirement, link: http://net.jogtar.hu/jr/gen/getdoc.cgi?docid=a0700200.kor (date of download: 30th July 2010.)
- Helbok, G. - Wagner, C. [2006]: Determinants of Operational Risk Reporting in the Banking Industry, , http://papers.ssrn.com/sol3/papers.cfm?abstract_id=425720
- Hitelintézeti Szemle [2007]: Működési kockázati különszám (title in English: Special issue on operational risk), Hitelintézeti szemle, 2007. évi 4. szám, elérhetőség: http://www.bankszovetseg.hu/bankszovetseg.cgi?p=hatodikevf&r=&l=&v=6907760287, letöltés időpontja: 2009. június 6. (abstracts in English: http://www.bankszovetseg.hu/anyag/feltoltott/426-428.pdf)
- Homolya Dániel - Kiss Hubert János [2001]: Bázelen innen, botrányokon túl; in Széchenyi Füzetek XIII. Sziszifusz 2001 Válogatás a Széchenyi István Szakkollégiumban készült TDK dolgozatokból pp. 49-71., Széchenyi István Szakkollégium (title in English: Before Basel, beyond scandals, Proceedings for István Széchenyi College for Advanced Studies)
- Homolya, Dániel – Benedek Dr., Gábor [2007]:: A banki működési kockázat elemzése - katasztrófamodellezés. Hitelintézeti Szemle 4., p. 358-385.. http://www.bankszovetseg.hu/anyag/feltoltott/358-385.pdf (title in English: Analysis of operational risk of banks – catastrophe modelling; abstract in English available at: http://www.bankszovetseg.hu/bankszovetseg.cgi?p=hsz2007_4_3&r=&l=eng&v=696273977)
- Homolya, Dániel – Benedek Dr., Gábor [2008]: Analysis of operational risk of banks: catastrophe modeling. ICFAI Journal of Financial Risk Management 3., p. 20-46.
- Homolya, Dániel [2009a]: The impact of the capital requirements for operational risk in the Hungarian banking system. MNB Bulletin July, p. 6-13., http://english.mnb.hu/Root/Dokumentumtar/ENMNB/Kiadvanyok/mnben_mnbszemle/mnben_szemle_cikkei/homolya_angol_0908.pdf
- Homolya, Dániel [2011]: Operational risk and its relationship with institution size in the Hungarian banking sector. MNB Bulletin June, p. 7-17., http://english.mnb.hu/Root/Dokumentumtar/ENMNB/Kiadvanyok/mnben_mnbszemle/mnben_mnb_bulletin_june_2011/homolya_ENG.pdf
- Hunyadi, L. – Mundruczó, Gy. – Vita, László [1996]: Statisztika, Aula kiadó, Budapest
- Jarrow, Robet A. [2008]: Operational risk,
- Jorion, P. [1999]: A kockáztatott érték. Panem, Budapest.

- Jorion, Philip [1999]: A kockáztatott érték, Panem Könyvkiadó
- Karlin, S.–Taylor, M. H. [1985]: Sztochasztikus folyamatok, Gondolat Kiadó, Budapest (Hungarian version of Karlin - Taylor [1975]. A First Course in Stochastic Processes. Academic Press, New York.)
- Király, Júlia [2005]: Kockáztatottérték-számítások, előadássorozat, Budapesti Corvinus Egyetem
- Klugman, S.– Panjer, H.–Wilmot, G. [1997]: Loss Models, Wiley Series in Probability and Statistics, Wiley, New York
- Kovács Erzsébet [2003]: Többváltozós adatelemzés, Budapest, egyetemi jegyzet a „Többváltozós adatelemzés" tárgyhoz
- Marsi, Erika [2002]: A működési kockázat és tőkekövetelménye., Hitelintézeti szemle. 2./ 2002. p. 50-59.
- McConnell, Patrick – Blacker, Keith [1999]: An approach to modell operational risk in banks, GARP - Operational Risk Group - 10 October 1999, link: http://www.riskmania.com/pdsdata/An%20Approach%20to%20Modelling%20Operational%20Risk%20in%20Banks.pdf (letöltés ideje: 2010. július 30.)
- Michaletzky, György [2001]: Kockázati folyamatok, ELTE Eötvös kiadó, Budapest
- Na, H.S. – Couto Miranda, L. - van den Berg, J. – Leipoldt M. [2005]: Data Scaling for Operational Risk Modelling, ERIM Report Series: ERS-2005-092-LIS
- Na, H.S. [2004]: Analysing and Scaling Operational Risk, Master Thesis, Erasmus University Rotterdam, Netherlands, http://www.tudelft.nl/live/binaries/70163a1a-37c1-4f78-8cb0-50653874a96b/doc/Heru.pdf
- OpRisk & Compliance [2008]: A new dawn for disclosure, Top 100 banks, 2008/10. pp. 26-29., Incisive Media, London
- OpRisk & Compliance [2009]: Divine Illusion, pp. 18-24, Incisive Media, London
- ORX [2007]: ORX reporting standards, URL: http://www.orx.org/lib/dam/1000/ORRS-Feb-07.pdf , 26th July 2007 (this version is not downloadable anymore)
- OTP Bank Nyrt. [2008]: Időközi vezetőségi beszámoló 2008. első kilenc havi eredmény, internetes elérhetőség: https://www.otpbank.hu/OTP_Portal/file/081113_OTP_20083Q_h.pdf, 2009. január 2.
- Panjer, Harry H. [2006]: Operational Risk: Modeling Analytics, John Wiley & Sons, New York
- Peccia [2004]: An Operational Risk Ratings Model Approach to Better Measurement and Management of Operational Risk, in Ong, K. (ed) The Basel Handbook, London: Risk Books.
- PSZÁF [2005]: Az új tőkemegfelelési szabályozással kapcsolatos felkészülésre vonatkozó kérdőívre beérkezett válaszok feldolgozása, Budapest, www.pszaf.hu
- PSZÁF [2005]: Az új tőkemegfelelési szabályozással kapcsolatos felkészülésre vonatkozó kérdőívre beérkezett válaszok feldolgozása, Budapest, korábban elérhető volt a www.pszaf.hu oldalon

- Rachev, Svetlozar Todorov – Mittnik, Stefan – Fabozzi, Frank J. – Focardi, Sergio M. – Jásic, Teo [2007]: Financial econometrics: from basics to advanced modeling techniques, John Wiley and Sons
- Risk Books [2005]: Basel II handbook for practioners, Risk Books, London
- Shih, J. – Samad - Khan A. H. – Pat, Medapa [2000]: Is the Size of an Operational Loss Related to Firm Size?, Operational Risk, 2000. január, http://www.opriskadvisory.com/docs/Is_the_Size_of_an_Operational_Loss_Related_to_Firm_Size_(Jan_00).pdf (2010. július 20.)
- Székelyi Mária – Barna Ildikó [2005]: Túlélőkészlet az SPSS-hez. Többváltozós elemzési technikákról társadalomkutatók számára, Typotex, Budapest
- Veeraraghavan, M. [2004]: Stochastic processes, előadásjegyzet, http://www.ece.virginia.edu/~mv/edu/715/lectures/SP.pdf
- Voit, J. [2007]: How to Create Value from Loss Data Pooling? in Operational Risk 2.0 , Delivering Valu for Your Firm, 2007 (Risk Books)
- Wan, F. - Tuckwell, H. [1982]: Neuronal firing and input variability. J Theoret Neurobiol 1982;1:197–218.

6. Own publications related to the topic of this thesis

- Armai, Zsolt – Homolya, Dániel – Szabolcs, Gergely – Kasnyik, Klára – Kovács, Ottó [2007]: Úton az AMA-módszer bevezetéséig az Erste Bankban. Hitelintézeti Szemle 4., p. 309-323.. http://www.bankszovetseg.hu/anyag/feltoltott/309-323.pdf (title in English: On the way to AMA at the Erste Bank Hungary, abstract in English available at: http://www.bankszovetseg.hu/bankszovetseg.cgi?p=hsz2007_4_1&r=&l=eng&v=696273977)
- Homolya, Dániel – Benedek Dr., Gábor [2007]:: A banki működési kockázat elemzése - katasztrófamodellezés. Hitelintézeti Szemle 4., p. 358-385.. http://www.bankszovetseg.hu/anyag/feltoltott/358-385.pdf (title in English: Analysis of operational risk of banks – catastrophe modelling; abstract in English available at: http://www.bankszovetseg.hu/bankszovetseg.cgi?p=hsz2007_4_3&r=&l=eng&v=696273977)
- Homolya, Dániel – Benedek Dr., Gábor [2008]: Analysis of operational risk of banks: catastrophe modeling. ICFAI Journal of Financial Risk Management 3., p. 20-46.
- Homolya, Dániel – Burucs, Judit [2009]: Operational Risk Data Consortia as a Useful Tool for Operational Risk Assessment and Mitigation in the Banking Sector, IFC Russian Banking Project Research Document, http://www.ifc.org/ifcext/rbap.nsf/AttachmentsByTitle/Burucs_Article_October2009_ENG/$FILE/DrBurucs-HomolyaeENG.pdf (megjelent oroszul: Bankovske Delo 2009/10-es szám: http://www.ifc.org/ifcext/rbap.nsf/AttachmentsByTitle/Burucs_Article_October2009_RUS/$FILE/BD%2310_Buruch.pdf)
- Homolya, Dániel – Szabolcs, Gergely [2008]: Működési kockázati adatkonzorciumok és alkalmazásuk - HunOR, a hazai bankok lehetősége. Hitelintézeti Szemle 1., p. 41-66.. http://www.bankszovetseg.hu/anyag/feltoltott/homolya_0801.pdf (title in English:

Operational risk data consortia and their applicability – HunOR, the opportunity of Hungarian banks; abstract in English available at: http://www.bankszovetseg.hu/bankszovetseg.cgi?p=hsz_0801_homolya&r=&l=eng&v=696273977)

- Homolya, Dániel [2009a]: The impact of the capital requirements for operational risk in the Hungarian banking system. MNB Bulletin July, p. 6-13., http://english.mnb.hu/Root/Dokumentumtar/ENMNB/Kiadvanyok/mnben_mnbszemle/mnben_szemle_cikkei/homolya_angol_0908.pdf
- Homolya, Dániel [2011]: Operational risk and its relationship with institution size in the Hungarian banking sector. MNB Bulletin June, p. 7-17., http://english.mnb.hu/Root/Dokumentumtar/ENMNB/Kiadvanyok/mnben_mnbszemle/mnben_mnb_bulletin_june_2011/homolya_ENG.pdf

Conference presentations, reference on proceedings in the topic of this thesis (selection based on importance):

- Homolya Dániel - Kiss Hubert János [2001]: Bázelen innen, botrányokon túl; in Széchenyi Füzetek XIII. Sziszifusz 2001 Válogatás a Széchenyi István Szakkollégiumban készült TDK dolgozatokból pp. 49-71., Széchenyi István Szakkollégium (title in English: Before Basel, beyond scandals, Proceedings for István Széchenyi College for Advanced Studies)
- Homolya, Dániel – Benedek Dr., Gábor [2008]: Analysing latent factor processes causing operational risk events and empirical analysis of ATM downtimes. 2nd European Risk Conference. 2008. 09. 10-12., Milánó, Universitá Bocconi
- Homolya, Dániel – Kiss, Hubert János [2009]: Design and incentives in operational risk data consortia. Magyar Közgazdaságtudományi Egyesület Éves konferencia 2009. Design and incentives in operational risk data consortia, Budapest, Magyar Nemzeti Bank. http://konferencia.mktudegy.hu/conferences/1/program/; http://media.coauthors.net/konferencia/conferences/1/Homolya_Kiss_ORDataCons_MKE_final%20version_20091014.pdf