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Estimating Spillover Risk Among Large EU Banks

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Abstract

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The paper examines the scope for cross-border spillovers among major EU banks using information contained in the stock prices and financial statements of these banks. The results suggest that spillovers within domestic banking systems generally remain more likely, but the number of significant cross-border links is already larger than the number of significant links among domestic banks, adding a piece of empirical evidence supporting the need for strong cross-border supervisory cooperation within the EU.

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Contents	Page
I. Introduction	3
II. Methodology and Data	5
A. Theoretical Underpinnings.....	5
B. Data	6
C. Empirical Model.....	9
III. Results.....	15
IV. Conclusions.....	17
References.....	25
Tables	
1. Major EU Exchange-Listed Banks	7
2. Stock Market Indices and Government Bond Yields	8
3. Significant Co-Exceedances among Large EU Banks, May 2000–April 2007	16
Figures	
1. EU Banks: Changes in Distance-to-Default	10
3. EU Banks: Distribution of Changes in Distances-to-Default	11
2. EU Banks: Binomial Logit Exceedances in the 10th Percentile Left Tail.....	13
Appendices	
I. Spillover Risk Among Large EU Banks—Detailed Mapping.....	18
II. Calculating Distance to Default	22
Appendix Tables	
A.1. May 30, 2000 to April 30, 2007 (Full Sample Period)	18
A.2. May 30, 2000 to November 30, 2003 (First Sub-Period)	19
A.3. December 1, 2003 to April 30, 2007 Sub-Sample (Second Sub-Period).....	20
A.4. November 9, 2005–April 30, 2007 (The Latest Part of the Second Sub-Period)	21

I. INTRODUCTION

Large cross-border banks are emerging in Europe, and have a substantial market share. European banking integration is gaining momentum in terms of cross-border flows, market share of foreign banks in several domestic markets, and cross-border mergers and acquisitions of significant size (Schoenmaker and Oosterloo, 2005; Dermine, 2005). There is a growing number of large banks that have similar strategies, tend to have the same clients among trans-national firms, and engage significantly in cross-border business (Tieman and Čihák, 2007). The bulk of this business is in wholesale markets, which are now relatively well-integrated. This is in contrast with retail markets, where there is considerable scope for further integration (Decressin, Faruquee, and Fonteyne, 2007).

Cross-border banking linkages have become increasingly commonplace.² A mapping exercise of European Union (EU) banking groups with significant cross-border activity carried out by the Banking Supervision Committee of the European System of Central Banks reveal that some 46 large, complex financial institutions hold about 68 percent of EU banking assets. Of these, 16 key cross-border players account for about one third of EU banking assets, hold an average of 38 percent of their EU banking assets outside their home countries, and operate in just under half of the other EU countries (Trichet, 2007).³

An important concern relating to the increased role of large banks is their impact on financial stability. This study contemplates two main questions: (i) to what extent are the large EU banks exposed to similar (market-wide) shocks, affecting all of them simultaneously; and (ii) what is the scope for spillover of idiosyncratic shocks from one bank (or a group of banks) to other banks. The aim of this paper is to model the cross-border banking linkages in the EU and determine the potential for spillovers among the major European banks, using information captured in banks' stock prices and financial statements. Our key objective is to identify potential risk concentrations among Europe's systemically important banks, by distinguishing between the impact of common and idiosyncratic shocks.

The broader context for our study is the ongoing discussion on an appropriate financial stability framework for the EU, and in particular, the issue of finding the right balance between EU-level and nationally-based prudential frameworks (see, e.g., Čihák and Decressin, 2007). If, for example, most of the spillovers are still among banks within individual EU countries, it would provide empirical support for relying on nationally-based prudential frameworks. If, on the other hand, there are substantial cross-border spillover

² See Chan-Lau, Mitra and Ong (2007) for a detailed discussion on avenues of cross-border banking linkages.

³ Further information on the mapping exercise can be found in European Central Bank (2006).

links, it would present a strong argument for focusing on the EU-level cross-border arrangements for dealing with financial stress in major EU banks.⁴

This paper contributes to the literature by presenting a mapping of spillover risks among major EU banks, on an individual basis.⁵ Much of the existing literature on financial soundness in EU banks does not cover spillover effects and focuses instead of banks' responses to common shocks. For example, Decressin (2007) employs accounting data to analyze the extent to which the performance of large European banks is influenced by country-level shocks versus common, EU-level shocks. Similarly, Tieman and Čihák (2007) study the relationship between performance of large European banks and the extent of their cross-border diversification, but do not analyze the spillover patterns among these institutions.

The approach in this paper is similar, yet differentiated from, two other studies. First, Chan-Lau, Mitra and Ong (2007) use a very similar methodology for a sample of major global banks, while we focus specifically on large EU banks, thus enabling us to contribute to the discussion on the financial stability framework in the EU. Second, Gropp, Lo Duca, and Vesala (2007) analyze cross-border contagion for a sample of European banks from 1994–2003. The differences from that paper include both the methodology—we focus on individual, bank-to-bank mapping, rather than on country-level “portfolios” of banks and we use a different approach to calculate spillover risk—and the sample, with our paper incorporating major banks from the whole EU.

Although this paper uses individual bank data, it should be emphasized that the focus is not on the specific nature of links between individual banks per se. Rather, we are interested in these large banks because of the risks of spillovers which can turn a single large bank failure into a chain of failures and potentially, a systemic crisis. In this context, aggregate results could very likely obscure important links among institutions. We are therefore trying to map the risks within EU banking system from a bank-by-bank perspective.

Our findings suggest that spillovers within domestic banking systems in the EU are generally more likely. However, there are numerous cases of significant cross-border spillover effects, highlighting the need for strong cross-border supervisory cooperation in the region. The

⁴ This does not necessarily imply the need for an all-encompassing centralized framework. In particular, our analysis focuses on large banks (because they account for a sizeable portion of EU banking assets, and have clear systemic implications for EU financial stability); it does not cover smaller banks that tend to be less active across country borders and are not likely to pose substantial risks for EU-wide financial stability. The arguments for the EU-level cross-border arrangements are stronger for large banks than for small ones (see e.g. Čihák and Decressin, 2007).

⁵ Our references to the EU throughout this paper include the 25 countries that were members prior to 2007. Bulgaria and Romania, which entered only in January 2007, are not covered in this analysis.

structure of the paper is as follows. Section II discusses the methodology and the input data. Section III presents and discusses the results. Section IV concludes.

II. METHODOLOGY AND DATA

The scope for cross-border spillovers among the major European banks can be examined using the Extreme Value Theory (EVT) framework. EVT analyzes co-dependence between extreme events (“co-exceedances”), specifically those of extreme negative (left-tail) realizations of banks’ soundness measures. The soundness measure chosen in this analysis is the distance-to-default (DD), defined as the difference between the expected value of assets at maturity and the default threshold, which is a function of the value of the liabilities. A higher DD is associated with a lower probability of bank default. It is generally a useful proxy for default risk if stocks are traded in liquid markets.

A. Theoretical Underpinnings

The theoretical literature has focused on contagion among banks through their interbank market linkages. For example, Allen and Gale (2000) show that an “incomplete” market structure, with only unilateral exposure chains across banks, is the most vulnerable to contagion. In contrast, a “complete” structure, with banks transacting with all other banks, is less at risk of contagion. A “tiered structure” of a “money center” bank (or banks), where all banks have relations with the center bank, but not with each other, is also susceptible to contagion (Freixas, Parigi, and Rochet, 2000). In both papers, contagion is found to arise from unforeseen liquidity shocks, i.e., banks withdrawing interbank deposits from other banks. Alternatively, contagion could arise from credit risk in the interbank market, namely deposits at other banks not being repaid.⁶

There may be spillovers even in the absence of explicit financial links between banks. In the presence of asymmetric information, difficulties in one bank may be perceived as a signal of possible difficulties in others, especially if market participants perceive opacity in banks’ balance sheets, and other publicly available information may be uninformative (Morgan, 2002). If a liquidity shock hits one bank, depositors may effect a run on other banks as well—even if those banks are perfectly solvent—if they fear that there may be insufficient liquid assets in the banking system (Freixas, Parigi and Rochet, 2000; Čihák, 2007). Cifuentes, Ferrucci, and Shin (2004) have proposed that there may be spillovers through fire sales of illiquid assets. If banks use fair value accounting to value at least some of their illiquid assets at imputed market prices, and the demand for illiquid assets is less than

⁶ Čihák (2007) shows how this could be modeled.

perfectly elastic, sales by distressed institutions may depress the market prices of such assets. Prices could fall, inducing a further round of sales and so forth.

This present paper does not explore the exact nature of the links among financial institutions. Rather, market-based data is applied to establish potential linkages between individual banks. The results are intended to represent “spillover maps,” which could be helpful in the allocation of limited surveillance and supervisory resources. Specifically, it could help focus cross-border collaboration and supervision among the EU supervisory authorities.

B. Data

Our data sample comprises 33 largest listed EU banks, accounting for about a half of total EU banking system assets. We originally selected the top 50 largest banks in the EU, and added the biggest bank in each EU country that would otherwise not have a representative in this category. We then refined the sample to include only banks for which good quality and sufficient data are available, which reduced the sample to 33 banks. Balance sheet data for the individual banks are obtained from Bureau van Dijk Electronic Publishing – BankScope, while their financial prices are available from Bloomberg LP (Table 1).⁷

The sample period, determined by data availability, is May 30, 2000 to April 30, 2007. The data for 6 banks—Bank Austria Creditanstalt (Austria), Credit Agricole (France), Deutsche Postbank (Germany), HBOS (United Kingdom), National Bank of Greece (Greece), PKO (Poland)—are only available from later dates. Thus, only 27 banks are tested for the full sample period (the “main sample”); the other banks are subsequently added to the main sample as their data become available, and we rerun the tests for each expanded sample.

We use four control variables to account for common shocks affecting the local real economy, and domestic, regional and global markets. Specifically, we incorporate changes in the slope of the local term structure (between one- and ten-year government bonds) to represent developments in the domestic real economy;⁸ the stock price return volatility in the domestic stock market index to capture local market influences; the price return volatility in the Morgan Stanley Capital International (MSCI) All-Country Europe Index (ACEI) returns and the MSCI All-Country World Index (ACWI) returns to account for regional and global market shocks, respectively. These variables are constructed using data obtained from Bloomberg LP (Table 2).

⁷ The EU adopted a regulation requiring public companies to convert to IFRSs beginning in 2005. All publicly traded EU companies were required to prepare their consolidated accounts using IFRS from 2005. Thus, the BankScope balance sheet data from 2005 onwards incorporate IFRS requirements.

⁸ See, for example, Bernard and Gerlach (1998), Estrella (2005) and Estrella and Hardouvelis (1991).

Table 1. Major EU Exchange-Listed Banks

Major Banking Groups	Nationality	Stock Ticker	Currency	Date of Availability			Distance-to-Default
				Standard Deviation of Returns	Stock Market		
					Capitalization	Risk-Free Rate	
Erste Bank der Oesterreichischen Sparkassen AG	Austria	EBS AV	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
	Austria	BACA AV	EUR	From 8 July, 2004	From July 9, 2003	ρ	From 8 July, 2004
	Fortis Group	FORB BB	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
KBC Group-KBC Groep NV / KBC Groupe SA	Belgium	KBC BB	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Dexia SA	Luxembourg	DEXB BB	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Danske Bank A/S	Denmark	DANSKE DC	DKK	ρ	From May 30, 2000	ρ	From May 30, 2000
BNP Paribas	France	BNP FP	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Crédit Agricole S.A.	France	ACA FP	EUR	From December 16, 2002	From December 14, 2001	ρ	From December 16, 2002
Société Générale	France	GLE FP	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Natixis	France	KN FP	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Deutsche Bank AG	Germany	DBK GR	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Commerzbank AG	Germany	CBK GR	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Deutsche Postbank AG	Germany	DPB GR	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
National Bank of Greece	Greece	ETE GA	EUR	From June 23, 2005	From June 23, 2004	ρ	From June 23, 2005
National Savings and Commercial Bank of Hungary (OTP Bank)	Hungary	OTP HB	HUF	ρ	From May 30, 2000	From August 1, 2000	From August 1, 2000
Bank of Ireland	Ireland	BKIR ID	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Allied Irish Bank PLC	Ireland	ALBK ID	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
UniCredito Italiano SpA	Italy	UC IM	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Intesa Sanpaolo	Italy	ISP IM	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
ING Group -- ING Groep NV	Netherlands	INGA NA	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
ABN Amro Holding NV	Netherlands	AABA NA	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
PKO BP	Poland	PKO PW	PLN	From November 9, 2005	From November 10, 2004	ρ	From November 9, 2005
Santander Central Hispano Group-Banco Santander Central Hispano	Spain	SAN SM	EUR	ρ	From May 30, 2000	ρ	From May 30, 2000
Banco Bilbao Vizcaya Argentaria SA	Spain	BBVA SM	EUR	ρ	From May 4, 2000	ρ	From May 4, 2000
Nordea Bank AB / Nordea Group	Sweden	NDA SS	SEK	ρ	From May 30, 2000	ρ	From May 30, 2000
Skandinaviska Enskilda Banken AB	Sweden	SEBA SS	SEK	ρ	From May 30, 2000	ρ	From May 30, 2000
Svenska Handelsbanken	Sweden	SHBA SS	SEK	ρ	From May 30, 2000	ρ	From May 30, 2000
Barclays PLC	United Kingdom	BARC LN	GBP	ρ	From May 17, 2000	ρ	From May 17, 2000
HSBC Holdings PLC	United Kingdom	HSBA LN	GBP	ρ	From May 17, 2000	ρ	From May 17, 2000
Royal Bank of Scotland Group PLC (The)	United Kingdom	RBS LN	GBP	ρ	From May 17, 2000	ρ	From May 17, 2000
HBOS PLC	United Kingdom	HBOS LN	GBP	From September 11, 2002	From September 10, 2001	ρ	From September 11, 2002
Lloyds TSB Group PLC	United Kingdom	LLOY LN	GBP	ρ	From May 17, 2000	ρ	From May 17, 2000
Standard Chartered PLC	United Kingdom	STAN LN	GBP	ρ	From May 17, 2000	ρ	From May 17, 2000

Ω At least from May 2000.

§ At least from 1999.

Sources: Bloomberg LP and Bureau van Dijk Electronic Publishing – BankScope.

Table 2. Stock Market Indices and Government Bond Yields

Country	Stock Market			Sovereign Bond	
	Index	Currency	Bloomberg Ticker	Maturity	Bloomberg Ticker
Austria	Austria Traded ATX Index	EUR	ATX	EUR Austria sovereign zero coupon yield, 1-year EUR Austria sovereign zero coupon yield, 10-year	F90801Y F90810Y
Belgium	BEL 20 Index	EUR	BEL20	EUR Belgium sovereign zero coupon yield, 1-year EUR Belgium sovereign zero coupon yield, 10-year	F90001Y F90010Y
Denmark	OMX Copenhagen 20 Index	DKK	KFX	DKK Denmark sovereign zero coupon yield, 1-year DKK Denmark sovereign zero coupon yield, 10-year	F26701Y F26710Y
France	CAC 40 Index	EUR	CAC	EUR France sovereign zero coupon yield, 1-year EUR France sovereign zero coupon yield, 10-year	I01401Y I01410Y
Germany	DAX Index	EUR	DAX	EUR Germany sovereign zero coupon yield, 1-year EUR Germany sovereign zero coupon yield, 10-year	F91001Y F91010Y
Greece	Athens Stock Exchange General Index	EUR	ASE	EUR Greece sovereign zero coupon yield, 1-year EUR Greece sovereign zero coupon yield, 10-year	F90401Y F90410Y
Hungary	Budapest Stock Exchange Index	HUF	BUX	HUF Hungary sovereign zero coupon yield, 1-year HUF Hungary sovereign zero coupon yield, 10-year	F11401Y F11410Y
Ireland	Irish Overall Index	EUR	ISEQ	EUR Ireland sovereign zero coupon yield, 1-year EUR Ireland sovereign zero coupon yield, 10-year	F91801Y F91810Y
Italy	S&P MIB Index	EUR	SPMIB	EUR Italy sovereign zero coupon yield, 1-year EUR Italy sovereign zero coupon yield, 10-year	F90501Y F90510Y
Netherlands	Amsterdam Exchanges Index	EUR	AEX	EUR Netherlands sovereign zero coupon yield, 1-year EUR Netherlands sovereign zero coupon yield, 10-year	F92001Y F92010Y
Poland	WSE WIG 20 Index	PLN	WIG20	PLN Poland sovereign zero coupon yield, 1-year PLN Poland sovereign zero coupon yield, 10-year	F11901Y F11910Y
Spain	IBEX 35 Index	EUR	IBEX	EUR Spain sovereign zero coupon yield, 1-year EUR Spain sovereign zero coupon yield, 10-year	F90201Y F90210Y
Sweden	OMX Stockholm 30 Index	SEK	OMX	SEK Sweden sovereign zero coupon yield, 1-year SEK Sweden sovereign zero coupon yield, 10-year	F25901Y F25910Y
United Kingdom	FTSE 100 Index	GBP	UKX	GBP United Kingdom zero coupon yield, 1-year GBP United Kingdom zero coupon yield, 1-year	I02201Y I02210Y
Region	MSCI All-Country Europe Index	EUR	MXER		
World	MSCI All-Country World	EUR	MXWD		

Source: Bloomberg L.P.

C. Empirical Model

We apply a binomial logit model to the distance-to-default (DD) data within an Extreme Value Theory framework to determine spillover risk across the EU banking system. Specifically, we examine the likelihood that a sizeable negative idiosyncratic shock experienced by a large EU bank would be followed by a similarly sizeable shock experienced by another large EU bank.

Distance-to-Default and Extreme Values

The DD metric provides a market-based measure of a bank's default/solvency risk, reflecting publicly available information. The DD is attractive in that it measures the solvency risk of a bank by combining information from stock returns with information from leverage and volatility in asset values—key determinants of default risk. For this reason, it has been widely used as a market-based indicator of soundness in recent literature.⁹ The DD measure represents the number of standard deviations away from the point where the book value of a bank's liabilities is equal to the market value of its assets. An increase/decrease in the DD implies greater/lesser stability or soundness, that is, a lower/higher risk of default. That said, it should be noted that DDs are risk-neutral, that is, they do not take into account that risk preferences may be different between volatile and benign periods.

We begin by calculating the DD measure for individual banks, which is based on the structural valuation model of Black and Scholes (1973) and Merton (1974). An exposition of the method is detailed in Appendix II.¹⁰ We find that the DDs across banks exhibit some common trends over time, which suggests that they are also likely to be exposed to common shocks, in addition to idiosyncratic ones (Figure 1). Next, we derive the changes in DD (we denote the percentage change in the DD as “ ΔDD ”) from the generated series of DDs. We calculate the weekly (5 trading-day) ΔDD s, on a daily basis, for the following reasons: (i) extreme events are more significant if they are prolonged; events that last for only a day are of little concern; (ii) the use of weekly changes reduces “noise” in the data.¹¹ The ΔDD s are derived as follows:

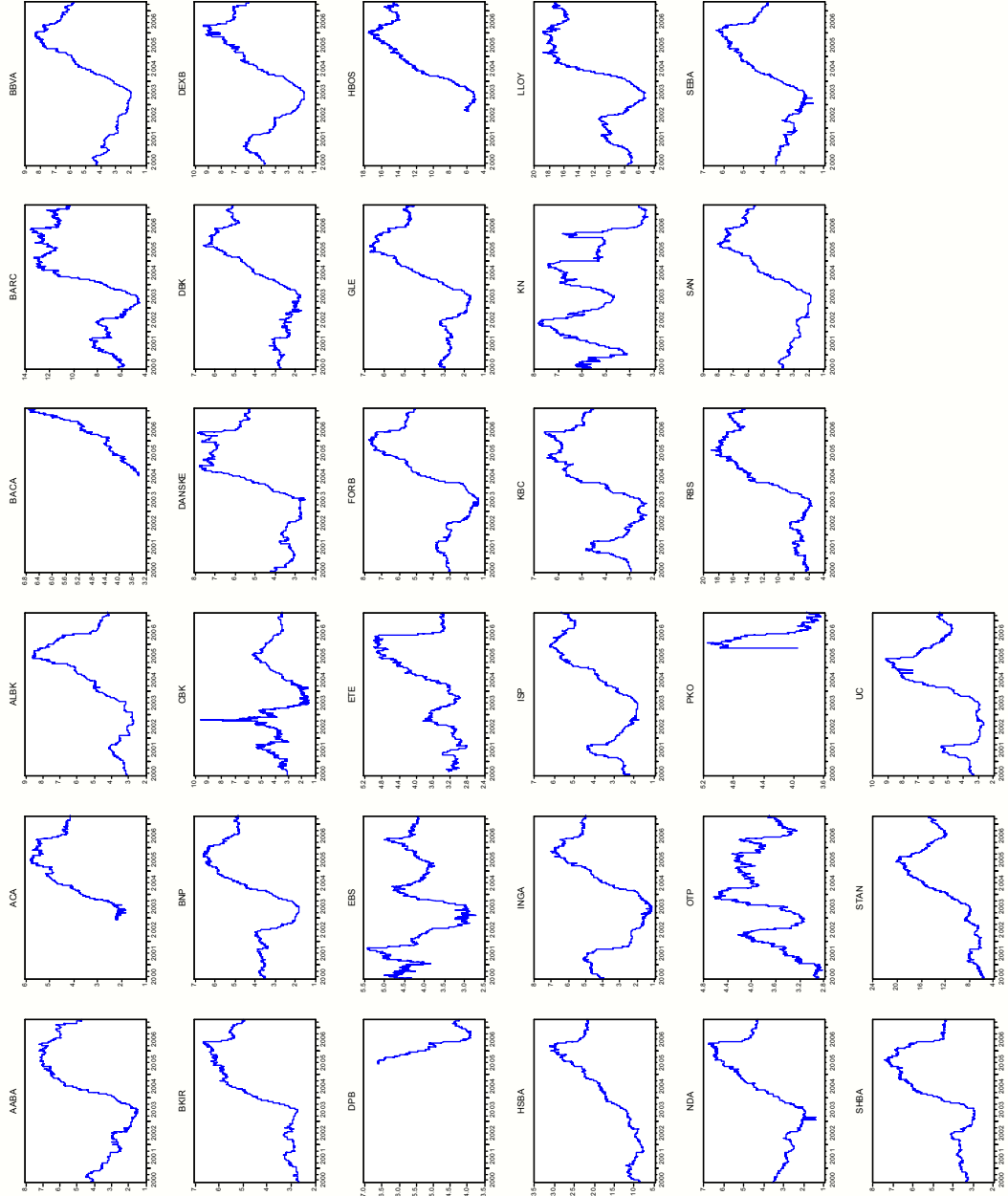
$$\Delta DD_{it} = \frac{DD_{it} - DD_{it-5}}{|DD_{it-5}|} . \quad (1)$$

⁹ See Čihák (2007) for a review of the literature.

¹⁰ This is the same method as that used in Chan-Lau, Mitra and Ong (2007).

¹¹ Stock price returns exhibit day-of-the-week effects (Chang, Pinegar, and Ravichandran, 1993; French, 1980; Jaffe and Westerfield, 1985; and Lakonishok and Smidt, 1988), while non-synchronous trading effects related to the overnight or weekend non-trading periods impact the calculation of daily close-to-close returns (Rogalski, 1984), effects of which could be “smoothed” using weekly data.

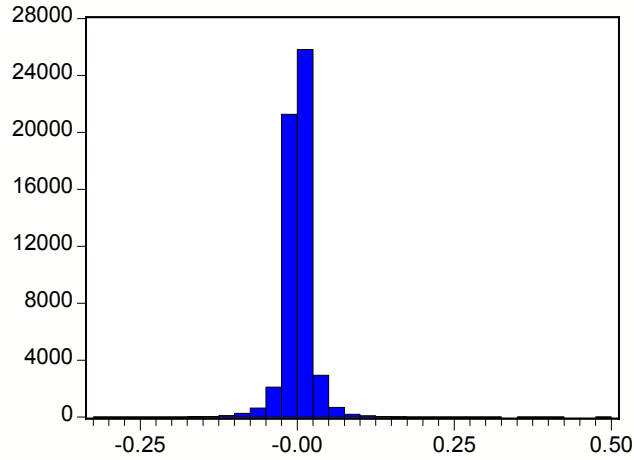
Figure 1. EU Banks: Changes in Distance-to-Default



Sources: Bloomberg LP, Bureau van Dijk Electronic Publishing – BankScope, and authors' calculations.

We then rank all ΔDD_{it} observations across all banks in our sample, and calculate the threshold, T_{10} , for the bottom 10 percent tail of the common distribution, which we define as “exceedances” or “extreme values”. The threshold for the 10th percentile left tail is calculated at -0.016 (Figure 2). The 10 percent tail is a value commonly used in the literature.

Figure 2. EU Banks: Distribution of Changes in Distances-to-Default



Sources: Bloomberg LP, Bureau van Dijk Electronic Publishing – BankScope and authors’ calculations.

Co-Exceedances

A “co-exceedance” is defined as the probability that a particular bank will experience a large negative shock as a result of shock to another bank in the sample, after controlling for common shocks. The exceedances for each bank i at time t are defined as binary variables, y_{it} , such that:

$$y_{it} = 1 \text{ if } \Delta DD_{it} < T_{10}, \text{ and } 0 \text{ otherwise,} \quad (2)$$

where T_{10} is the 10th percentile threshold in the left tail of the distribution (Figure 3). As mentioned earlier, this threshold is commonly used in the existing literature. The co-exceedances reflect all potential spillover channels, without defining explicit links between banks or specifying a particular channel of contagion.

We estimate the conditional probability that bank i will be in distress at time t conditional on bank j ($j \neq i$) being in distress, after controlling for other country-specific and global factors,

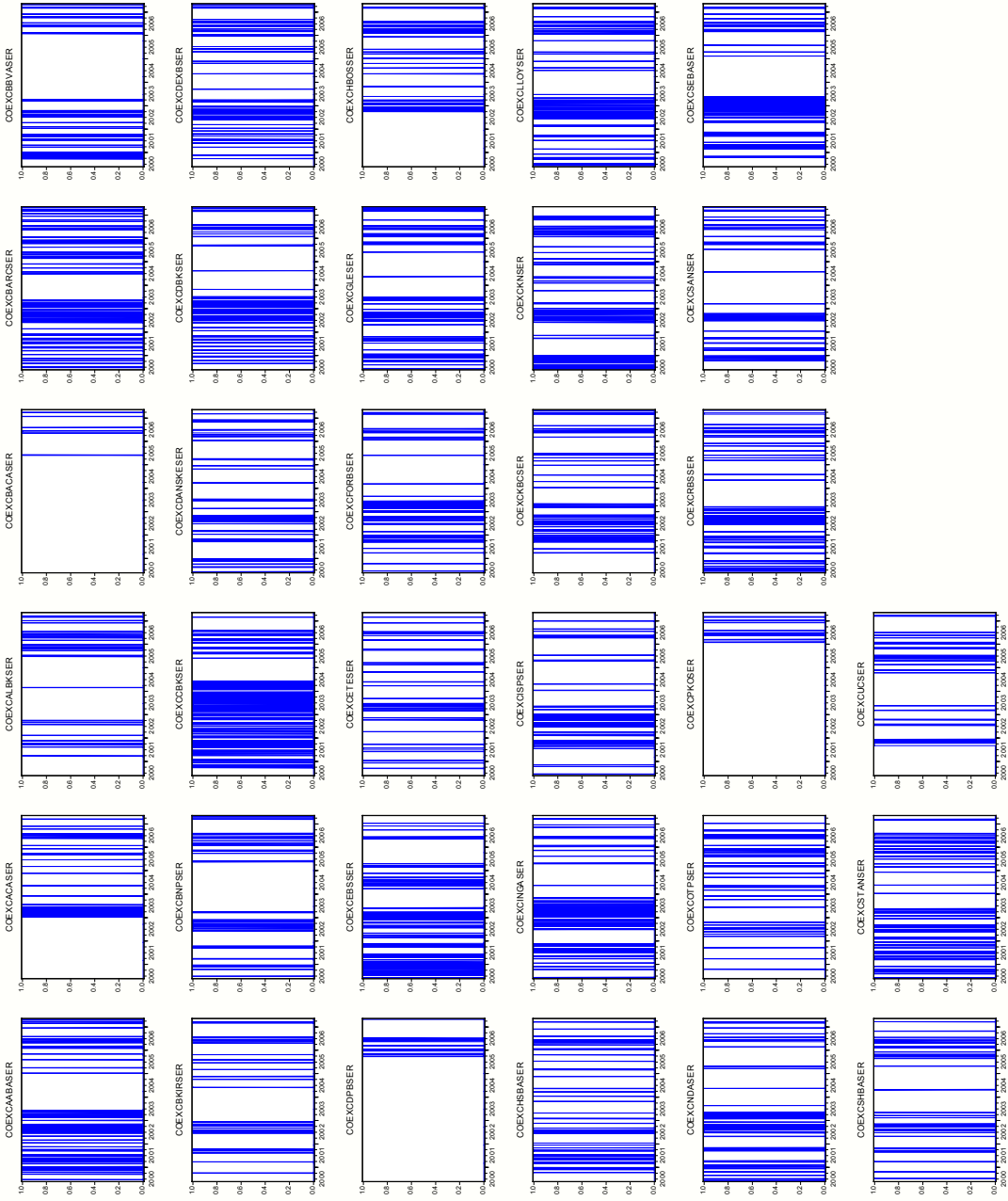
$$\Pr(y_{it} = 1 | x, \beta) = \frac{e^{\alpha_i F_{it} + \sum_{s=1}^5 \rho_{si} C_{it-s} + \gamma_j \sum_{j=1}^B C_{jt-1}}}{1 + e^{\alpha_i F_{it} + \sum_{s=1}^5 \rho_{si} C_{it-s} + \gamma_j \sum_{j=1}^B C_{jt-1}}}, \quad (3)$$

which is based on the cumulative distribution function for the logistic distribution. On the left hand side, x represents the explanatory variables F and C , and β represents the slope coefficients α , ρ , γ . The parameter α represents the sensitivity of bank i to “common shocks,” i.e., real and financial developments in its own country as well as in the European and global markets (F_{it}); ρ represents the sensitivity of bank i to extreme shocks it has experienced itself in the previous periods of up to s lags (C_{it-s}),¹² and γ represents the sensitivity of bank i to extreme shocks experienced by the rest of the banks in the sample during the previous period (C_{jt-1} , where $j \neq i$), or in other words, the “co-exceedance” of bank i with other banks in the sample. All the C variables are lagged by one period to capture the impact on bank i from developments in the other banks.¹³ The goodness of fit is given by the McFadden R^2 .

¹² This operation adjusts for any serial correlation in the residuals, which may be induced by our use of overlapping weekly ΔDDs .

¹³ The issue of non-synchronicity is not a major concern in this case, given that the stocks of the majority of banks in our sample largely trade in the same time zone (continental banks also have operations in London and some are listed on the London Stock Exchange).

Figure 3. EU Banks: Binomial Logit Exceedances in the 10th Percentile Left Tail



Sources: Bureau van Dijk Electronic Publishing – BankScope, Bloomberg LP, and authors' calculations.

Common Shocks

This sub-section describes how we have calculated the “common shocks” (F_{it}), introduced in equation (3). These shocks reflect the real and financial developments in each bank’s country as well as in the European and global markets, which are denoted

$F_{it} = f(\sigma_C, \Delta yc, \sigma_E, \sigma_W)$, as defined below.

Country-Specific Market Shocks (σ_C)

We calculate the weekly (5 trading-day) returns on each country-specific stock index by taking the weekly log-difference of the stock index in the local currency. The volatility of returns is approximated by the conditional variance estimated from a GARCH(1,1) model of the weekly returns, such that,

$$X_t = c + \varepsilon_t, \text{ and} \quad (5)$$

$$\sigma_t^2 = w + \alpha \varepsilon_{t-1}^2 + \beta \sigma_{t-1}^2, \quad (6)$$

where X_t is the weekly local currency return in the country’s stock price index and σ_t^2 is the GARCH volatility, both at time t .¹⁴ The ARCH effect is captured by the lagged square residual, ε_{t-1}^2 . We predict this period’s variance by forming the weighted average of a long term average (the constant, w), the forecast variance from the previous period (σ_{t-1}^2), and information about volatility observed in the last period (ε_{t-1}^2). This model is consistent with the volatility clustering associated with financial returns data, where large changes in returns are likely to be followed by further large changes.¹⁵ Lagrange multiplier tests show significant ARCH(1) effects for all the stock market returns used in this paper.

Developments in the Local Real Economy (Δyc)

We use weekly (5 trading-day) changes in term structure spreads to represent expectations of changes in the business cycle in a bank’s home country. The term structure spread is calculated as the difference between a long-term interest rate (the 10-year government bond yield) and a short term rate (the 1-year government bond yield) in any one country. Thus, the *change* in yield curve slope is defined as

¹⁴ It should be noted that the use of GARCH volatility may induce errors-in-variables in the modeling process.

¹⁵ This method was developed by Ding and Engle (1994).

$$\Delta y c_t = \frac{y c_t - y c_{t-5}}{|y c_{t-5}|}, \quad (7)$$

where $y c_t$ is the term structure spread at time t .

Regional Market Shocks (σ_E)

We apply a regional (European) stock market return volatility variable to control for common shocks affecting European markets, in this case, the MSCI ACEI index.¹⁶ We denominate the index in the currency of the country in which the dependent variable bank is located. We use the same method as that for the local stock markets, and estimate the GARCH(1,1) volatility for the MSCI ACEI.

Global Market Shocks (σ_W)

We apply a global stock market return volatility variable to control for common shocks affecting global markets, in this case, the MSCI ACWI. We denominate the index in the currency of the country in which the dependent variable bank is located, and estimate the GARCH(1,1) volatility for the MSCI ACWI, as for the other indices.

III. RESULTS

Our results on the spillover risks among EU banks are summarized in Table 3. The detailed bank-by-bank results are presented in four tables in Appendix I. We derive the following main observations from our findings:¹⁷

- Spillovers among banks in the same country appear to be relatively more frequent than among banks from different countries. For the whole sample period, significant spillovers were found in about 40 percent of all possible domestic links, compared to about 9 percent of all possible cross-border links. This result is significant (at the 5 percent level), and it also seems robust over time: for all the sub-periods, the relative frequency of co-exceedances among domestic banks was higher than the relative frequency of co-exceedances among banks from different countries.

¹⁶ This is a free-float-adjusted market capitalization index, which consisted of the following 16 developed market country indices as at June 2006: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom.

¹⁷ As a side result, the tables also show the significance levels for the control variables. In many cases, the “common factors” turn out to be insignificant, but they are significant for some banks. Also, the number of significant cases is higher for the more recent sub-periods.

- The absolute number of significant cross-border spillovers in our sample was higher than the number of significant domestic spillovers. This is driven by the number of *potential* cross-border linkages among the large banks, which is much higher than the number of potential domestic linkages. So, even with the lower relative frequency, cross-border co-exceedances are more numerous than domestic co-exceedances (57 compared to 19 for the full sample). This finding may seem trivial, but it serves as a reminder that significant cross-border linkages, even if relatively less frequent than domestic linkages, may still be quite numerous, and may require more attention (e.g., in terms of supervisory time) than suggested by the relative frequencies.
- The spillover risks are spread far from evenly across the large EU banks (Tables A.1 to A.4). Some banks (e.g., OTP or Bank of Ireland) have no significant spillover impact on other banks, while others have significant impact on a number of domestic and foreign banks at the same time. Interestingly, the bank with the biggest potential for spillover is Fortis (which ranks 19 in the EU in terms of total assets), which has significant impact on eight other banks (six cross-border and two domestic). HSBC is second, with six spillover links (five cross-border and one domestic). The largest number of banks (19) have cross-border impact on between one to three other banks.
- It appears that the relative frequency of spillovers has been increasing for cross-border linkages (from 7.6 percent in May 2000–November 2003 to 8.3 percent in December 2003–April 2007 and 8.7 in November 2005–April 2007), while for domestic linkages it has been declining (from 28.6 percent in May 2000–November 2003 to 18.8 percent in December 2003–April 2007 and 18.6 in November 2005–April 2007). These changes are not significant at conventional levels, however; further research into these changes is needed as additional data become available.

Table 3. Significant Co-Exceedances among Large EU Banks, May 2000–April 2007

	Number of significant links 1/	... as percent of all possible links 2/
May 2000–April 2007		
Domestic	19	39.6
Cross-border	57	8.7
May 2000–November 2003		
Domestic	14	28.6
Cross-border	50	7.6
December 2003–April 2007		
Domestic	9	18.8
Cross-border	54	8.3
November 2005–Apr 2007		
Domestic	13	18.6
Cross-border	86	8.7

Source: Authors, based on data from Bloomberg LP; and © Bureau van Dijk Electronic Publishing - BankScope.

1/ Number of bank pairs for which co-exceedances were significant at the 5 percent level in the given period.

2/ Number of significant links (in the left column), in percent of all possible contagion channels (i.e., as a percentage of all possible domestic and cross-border pairings of banks, respectively).

IV. CONCLUSIONS

Our findings, based on market-based data and the Extreme Value Theory framework, suggest that spillovers within domestic banking systems are generally more likely. However, there is considerable potential for extreme events to spill over from one bank to another across the border. The number of significant cross-border links is already larger than the number of significant links among domestic banks, underscoring the need for greater cross-border supervisory cooperation in the EU.

When interpreting these results, two considerations need to be taken into account. First, the model is estimated over a relatively benign period in financial markets with little disruption to the financial sector; the tight market conditions of third quarter of 2007 have yet to be fully played out, and could eventually be used as an out-of-sample test of our findings. Second, some of the banking groups in our sample represent important constituents in their respective countries' stock market indices, and some are also represented in the regional and global indices, which means that some of the stock market volatility effects captured in the results could already be partly driven by the volatility in the individual bank stocks.

The analysis presented in this paper is based solely on publicly available data. Possible future research could attempt to corroborate this analysis by using supervisory data (to which we did not have access in this study). For example, information on individual bank-to-bank exposures could be used to run interbank contagion stress tests in the manner described in Čihák (2007). It could also help to provide more information as to the exact channel through which spillovers may be occurring between banks, an aspect which is outside the scope of this study.

APPENDIX I. SPILLOVER RISK AMONG LARGE EU BANKS—DETAILED MAPPING

Appendix Table A.1. May 30, 2000 to April 30, 2007 (Full Sample Period)

Country	Bank	Contagion to:																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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Source: Authors' calculations, based on data from Bloomberg L.P. and © Bureau van Dijk Electronic Publishing - BankScope.

Note: Factors in the columns are dependent on factors in the rows.

1 denote statistical significance (positive sign) on 1 and 5 percent significance level, respectively (highlighted in blue and yellow, respectively)

d denote domestic and cross-border linkages, respectively

denotes significance (negative sign) at the 5 percent level or lower.

[illegible]

Source: Authors' calculations, based on data from Bloomberg LP; and © Bureau van Dijk Electronic Publishing - BankScope.

Note: Factors in the columns are dependent on factors in the rows.

1 denote statistical significance (positive sign) on 1 and 5 percent significance level, respectively (highlighted in blue and yellow, respectively).

d denote domestic and cross-border linkages, respectively

denotes significance (negative sign) at the 5 percent level or lower.

Appendix Table A.3. December 1, 2003 to April 30, 2007 Sub-Sample (Second Sub-Period)

Country	Bank	Contagion to:																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									
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Source: Authors' calculations, based on data from Bloomberg LP; and © Bureau van Dijk Electronic Publishing - BankScope.

Note: Factors in the columns are dependent on factors in the rows.

1 denote statistical significance (positive sign) on 1 and 5 percent significance level, respectively (highlighted in blue and yellow, respectively)

d denote domestic and cross-border linkages, respectively

denotes significance (negative sign) at the 5 percent level or lower.

Appendix Table A.4. November 9, 2005–April 30, 2007 (The Latter Part of the Second Sub-Period)

Country	Bank	Contagion to:																																								
		AUT		BLG			DMK			FRA			DEU			GRE			HUN			IRL			ITL			NDL			POL			ESP			SWE			GBR		
		1	2	1	2	3	1	2	3	1	2	3	4	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3	4	5	6					
Austria	Initial shock to:																																									
	1 Erste	d																																								
	2 Bank Austria Creditanstalt	d																																								
	1 Fortis	c	c																																							
Belgium	2 KBC	c	c																																							
	3 Dexia (Luxembourg)	c	c																																							
	1 Danske	c	c																																							
Denmark	1 BNP Paribas	c	c																																							
	2 Credit Agricole	c	c																																							
	3 Societe Generale	c	c																																							
	4 Natixis	c	c																																							
Germany	1 Deutsche Bank	c	c																																							
	2 Commerzbank	c	c																																							
	3 Deutsche Postbank	c	c																																							
	1 National Bank of Greece	c	c																																							
Greece	1 OTP	c	c																																							
	1 Bank of Ireland	c	c																																							
Hungary	2 Allied Irish	c	c																																							
	1 Unicredit	c	c																																							
Italy	2 Intesa Sanpaolo	c	c																																							
	1 ING	c	c																																							
Netherlands	2 ABN Amro	c	c																																							
	1 PKO	c	c																																							
Poland	1 Santander	c	c																																							
	2 Banco Bilbao Vizcaya	c	c																																							
Spain	1 Nordea	c	c																																							
	2 SEB	c	c																																							
	3 Swedbank	c	c																																							
	1 Barclays	c	c																																							
United Kingdom	2 HSBC	c	c																																							
	3 RBS	c	c																																							
	4 HBOS	c	c																																							
	5 Lloyds	c	c																																							
	6 Standard Chartered	c	c																																							
Other factors	Constant																																									
	Change in term structure																																									
	Local market volatility																																									
	Regional market volatility																																									
	Global market volatility																																									
McFadden's R-squared		0.85	0.58	0.82	0.80	0.63	0.68	0.83	0.73	0.76	0.76	0.81	0.73	0.70	0.85	0.68	0.81	0.71	0.83	0.70	0.72	0.61	0.71	0.82	0.77	0.89	0.71	0.68	0.55	0.68	0.78	0.71	0.55	0.72								

Source: Authors' calculations, based on data from Bloomberg LP, and © Bureau van Dijk Electronic Publishing - BankScope.

Note: Factors in the columns are dependent on factors in the rows.

1 and 5 denote statistical significance (positive sign) on 1 and 5 percent significance level, respectively (highlighted in blue and yellow, respectively)

d and c denote domestic and cross-border linkages, respectively

..... denotes significance (negative sign) at the 5 percent level or lower.

APPENDIX II

CALCULATING THE DISTANCE TO DEFAULT

The distance-to-default (DD) measure is based on the structural valuation model of Black and Scholes (1973) and Merton (1974). The authors first drew attention to the concept that corporate securities are contingent claims on the asset value of the issuing firm.¹⁸ This insight is clearly illustrated in the simple case of a firm issuing one unit of equity and one unit of a zero-coupon bond with face value D and maturity T . At expiration, the value of debt, B_T , and equity, E_T , are given by:

$$B_T = \min(V_T, D) = D - \max(D - V_T, 0), \quad (\text{A.1})$$

$$E_T = \max(V_T - D, 0), \quad (\text{A.2})$$

where V_T is the asset value of the firm at expiration. The interpretation of equations (A.1) and (A.2) is straightforward. Bondholders only get paid fully if the firm's assets exceed the face value of debt, otherwise the firm is liquidated and assets are used to partially compensate bondholders. Equity holders, thus, are residual claimants in the firm since they only get paid after bondholders.

Note that equations (A.1) and (A.2) correspond to the payoff of standard European options. The first equation states that the bond value is equivalent to a long position on a risk-free bond and a short position on a put option with strike price equal to the face value of debt. The second equation states that equity value is equivalent to a long position on a call option with strike price equal to the face value of debt. Given the standard assumptions underlying the derivation of the Black-Scholes option pricing formula, the default probability in period t for a horizon of T years is given by the following formula:

$$p_t = N \left[- \frac{\ln \frac{V_t}{D} + \left(r - \frac{\sigma_A^2}{2} \right) T}{\sigma_A \sqrt{T}} \right], \quad (\text{A.3})$$

¹⁸ Models built on the insights of Black and Scholes (1973) and Merton (1974) are known in the literature as structural models.

where N is the cumulative normal distribution, V_t is the value of assets in period t , r is the risk-free rate, and σ_A is the asset volatility.

The numerator in equation (A.3) is referred to as *distance-to-default*. An examination of equation (A.3) indicates that estimating default probabilities requires knowing both the asset value and asset volatility of the firm. The required values, however, correspond to the *economic* values rather than the accounting figures. It is thus not appropriate to use balance-sheet data for estimating these two parameters. Instead, the asset value and volatility can be estimated. It is possible to solve the following equations (A.4) and (A.5) for the asset value and volatility:

$$E_t = V_t N(d_1) - e^{-rT} DN(d_2), \text{ and} \quad (\text{A.4})$$

$$\sigma_E = \frac{V_t}{E_t} \sigma_A N(d_1), \quad (\text{A.5})$$

if E_t , the value of equity; σ_E , the equity price return volatility; and D , the face value of liabilities, are known; and d_1 and d_2 are given by:

$$d_1 = \frac{\ln \frac{V_t}{D} + \left(r + \frac{\sigma_A^2}{2} \right) T}{\sigma_A \sqrt{T}}, \text{ and} \quad (\text{A.6})$$

$$d_2 = d_1 - \sigma_A \sqrt{T}. \quad (\text{A.7})$$

The parameters can be calibrated from market data:

- The time horizon T is usually fixed at one year.
- The value of equity, E_t , corresponds to the market value of the firm. The data are obtained from Bloomberg by multiplying the number of shares outstanding for a firm by the closing share price on a particular day.
- The equity volatility, σ_E , corresponds either to historical equity volatility or implied volatility from equity options. This is derived by calculating the standard deviation of daily share price returns over a one year period (around 260 days).

- The face value of liabilities, D , is usually assumed equal to the face value of short-term liabilities plus half of the face value of long-term liabilities.¹⁹ This number represents the “default barrier”. The liability data are obtained from Bureau van Dijk Electronic Publishing – BankScope. The item “Deposits and Short-Term Funding” is used to represent short-term liabilities, while the long-term liabilities are derived by deducting the short-term liabilities from the “Total Liabilities” item. To obtain daily liability data from annual balance sheets, the data is intrapolated between two year-end balances.
- The risk-free rate, r , is the one-year government bond yield, in the same currency as those of the market and balance sheet data.

Once the asset value and volatility are estimated, the default probability of the firm could be derived from equation (A.3).

¹⁹ This is based on work done by Moody’s KMV (see Crosbie and Bohn, 2003).

REFERENCES

- Allen F. and D. Gale, 2000, "Financial Contagion," *Journal of Political Economy*, 108(1), pp. 1–33.
- Bernard, Henri and Stefan Gerlach, 1998, "Does the Term Structure Predict Recessions? The International Evidence," *International Journal of Finance and Economics*, Vol. 3, No. 3, pp. 195–215.
- Black, Fisher and Myron Scholes, 1973, "The Pricing of Options and Corporate Liabilities," *Journal of Political Economy*, Vol. 81, No. 3, pp. 637–54.
- Chan-Lau, Jorge, Srobona Mitra and Li Lian Ong, 2007, "Contagion Risk in the International Banking System and Implications for London as a Global Financial Center," IMF Working Paper No. 07/74 (Washington: International Monetary Fund).
- Cifuentes, R., G. Ferrucci and H. Shin, 2004, "Liquidity Risk and Contagion," *Journal of The European Economic Association*, 3(2-3), pp 556–66.
- Čihák, Martin, 2007, "Introduction to Applied Stress Testing," IMF Working Paper No. 07/59 (Washington: International Monetary Fund).
- , 2007, "Systemic Loss: A Measure of Financial Stability," *Czech Journal of Economics and Finance (Finance a uver)*, Vol. 57 (1–2).
- , and Jörg Decressin, 2007, "The Case for a European Banking Charter," IMF Working Paper No. 07/173 (Washington: International Monetary Fund).
- Chang, Eric C., J. Michael Pinegar, and Ravi Ravichandran, 1993, "International Evidence on the Robustness of the Day-of-the-Week Effect," *Journal of Financial and Quantitative Analysis*, Vol. 28 (December), pp. 497–513.
- Crosbie, Peter and Jeffrey R. Bohn, 2003, "Modeling Default Risk," Moody's KMV.
- Decressin, Jörg, 2007, "A Bank Business Correlation Perspective on Pan-European Supervision," In Jörg Decressin, Hamid Faruquee, and Wim Fonteyne (eds.), *Integrating Europe's Financial Markets* (Washington: International Monetary Fund).
- , Hamid Faruquee, and Wim Fonteyne (2007) (eds.), *Integrating Europe's Financial Markets* (Washington: International Monetary Fund).
- Dermine, Jean, 2005, "European Banking Integration: Don't Put the Cart before the Horse," paper presented at the Federal Reserve Bank of Chicago conference on Cross-Border Banking, Regulatory Challenges, 6–7 October 2005.
- Ding, Zhuanxin and Robert Engle, 1991, "Large Scale Conditional Covariance Matrix Modeling, Estimation and Testing," *Academia Economic Papers*, Vol. 29, No. 2, pp. 157–84.

- Estrella, Arturo, 2005, "Why Does the Yield Curve Predict Output and Inflation?" *Economic Journal*, Vol. 115, No. 5, pp. 722–44.
- , and Gikas Hardouvelis, 1991, "The Term Structure as a Predictor of Real Economic Activity," *Journal of Finance*, Vol. 46, No. 2, pp. 555–76.
- European Central Bank, 2006, "EU Banking Structures," October 2006 (Frankfurt: European Central Bank). <http://www.ecb.int/pub/pdf/other/eubankingstructures2006en.pdf>.
- Freixas X., Parigi B. and J.C. Rochet, 2000, Systemic Risk, Interbank Relations and Liquidity Provision by the Central Bank, *Journal of Money, Credit, and Banking*, 32(3/2), pp. 611–40.
- French, Kenneth R., 1980, "Stock Returns and the Weekend Effect," *Journal of Financial Economics*, Vol. 8, pp. 55–69.
- Gropp, Reint, Marco Lo Duca, and Jukka Vesala, 2007, "Cross-Border Bank Contagion in Europe," Working Paper No. 175 (Frankfurt: Johann Wolfgang Goethe University).
- Jaffe, Jeffrey, and Randolph Westerfield, 1985, "The Weekend Effect in Common Stock Returns: The International Evidence," *Journal of Finance*, Vol. 40, No. 2, pp. 433–54.
- Lakonishok, Josef, and Seymour Smidt, 1988, "Are Seasonal Anomalies Real? A Ninety-Year Perspective," *Review of Financial Studies*, Vol. 1, No. 1, pp. 403–25.
- Merton, Robert. C., 1974, "On the Pricing of Corporate Debt: The Risk Structure of Interest Rates," *Journal of Finance*, Vol. 29, No. 2, pp. 449–70.
- Morgan, D., 2002, "Rating Banks: Risk and Uncertainty in an Opaque Industry," *American Economic Review* 92, pp. 874–88.
- Rogalski, Richard J., 1984, "A Further Investigation of the Weekend Effect in Stock Returns: Discussion," *Journal of Finance*, Vol. 39, No. 3, pp. 835–37.
- Schoenmaker, Dirk, and Sander Oosterloo, 2005, "Cross-Border Issues in European Financial Supervision," forthcoming in David Mayes and Geoffrey Wood (eds), *The Structure of Financial Regulation* (London: Routledge).
- Tieman, Alexander, and Martin Čihák, 2007, "European Internationally Active Large Banking Groups," In Jörg Decressin, Hamid Faruquee, and Wim Fonteyne (eds.), *Integrating Europe's Financial Markets* (Washington: International Monetary Fund).
- Trichet, Jean-Claude, 2007, "Towards the Review of the Lamfalussy Approach—Market Developments, Supervisory Challenges and Institutional Arrangements," Keynote speech by at the First CEBS Conference, London, 9 May, in: BIS Review 45/2007 (Basel: Bank for International Settlements).