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# Estimating Spillover Risk Among Large EU Banks

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# Estimating Spillover Risk Among Large EU Banks

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**Abstract**



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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Keywords: European Union, financial stability, spillovers, contagion, large banks.

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# 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, Faruqee, 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

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[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

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[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).

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[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 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Stock Market | | Risk-Free Rate | Financial Statement | Distance-to-Default | |
| | | | | Standard Deviation of Returns | Capitalization | | | | |
| Erste Bank der Oesterreichischen Sparkassen AG | Austria | EBS AV | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Bank Austria Creditanstalt AG | Austria | BACA AV | EUR | From 8 July, 2004 | From July 9, 2003 | ρ | ς | From 8 July, 2004 | 4 |
| Fortis Group | Belgium | FORB BB | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| KBC Group-KBC Groep NV/ KBC Groupe SA | Belgium | KBC BB | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Dexia SA | Luxembourg | DEXB BB | EUR | ρ | From May 30, 2000 | ρ | 1999-2005 | From May 30, 2000 | |
| Danske Bank A/S | Denmark | DANSKE DC | DKK | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| BNP Paribas | France | BNP FP | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Crédit Agricole S.A. | France | ACA FP | EUR | From December 16, 2002 | From December 14, 2001 | ρ | 1999-2005 | From December 16, 2002 | 3 |
| Société Générale | France | GLE FP | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Natixis | France | KN FP | EUR | ρ | From May 30, 2000 | ρ | 1999-2005 | From May 30, 2000 | |
| Deutsche Bank AG | Germany | DBK GR | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Commerzbank AG | Germany | CBK GR | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Deutsche Postbank AG | Germany | DPB GR | EUR | From June 23, 2005 | From June 23, 2004 | ρ | ς | From June 23, 2005 | 5 |
| National Bank of Greece | Greece | ETE GA | EUR | ρ | From May 30, 2000 | From August 1, 2000 | ς | From August 1, 2000 | 1 |
| National Savings and Commercial Bank of Hungary (OTP Bank) | Hungary | OTP HB | HUF | ρ | From May 30, 2000 | ρ | 1999-2005 | From May 30, 2000 | |
| Bank of Ireland | Ireland | BKIR ID | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Allied Irish Bank PLC | Ireland | ALBK ID | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| UniCredito Italiano SpA | Italy | UC IM | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Intesa Sanpaolo | Italy | ISP IM | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| ING Group -- ING Groep NV | Netherlands | INGA NA | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| ABN Amro Holding NV | Netherlands | AABA NA | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| PKO BP | Poland | PKO PW | PLN | From November 9, 2005 | From November 10, 2004 | ρ | 2003-2006 | From November 9, 2005 | 6 |
| Santander Central Hispano Group-Banco Santander Central Hispano | Spain | SAN SM | EUR | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Banco Bilbao Vizcaya Argentaria SA | Spain | BBVA SM | EUR | ρ | From May 4, 2000 | ρ | ς | From May 4, 2000 | |
| Nordea Bank AB / Nordea Group | Sweden | NDA SS | SEK | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Skandinaviska Enskilda Banken AB | Sweden | SEBA SS | SEK | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Svenska Handelsbanken | Sweden | SHBA SS | SEK | ρ | From May 30, 2000 | ρ | ς | From May 30, 2000 | |
| Barclays PLC | United Kingdom | BARC LN | GBP | ρ | From May 17, 2000 | ρ | ς | From May 17, 2000 | |
| HSBC Holdings PLC | United Kingdom | HSBA LN | GBP | ρ | From May 17, 2000 | ρ | ς | From May 17, 2000 | |
| Royal Bank of Scotland Group PLC (The) | United Kingdom | RBS LN | GBP | ρ | From May 17, 2000 | ρ | ς | From May 17, 2000 | |
| HBOS PLC | United Kingdom | HBOS LN | GBP | From September 11, 2002 | From September 10, 2001 | ρ | ς | From September 11, 2002 | 2 |
| Lloyds TSB Group PLC | United Kingdom | LLOY LN | GBP | ρ | From May 17, 2000 | ρ | ς | From May 17, 2000 | |
| Standard Chartered PLC | United Kingdom | STAN LN | GBP | ρ | From May 17, 2000 | ρ | ς | From May 17, 2000 | |

Ω At least from May 2000.

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

Source: Bloomberg LP.

## 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) ΔDDs, 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 ΔDDs are derived as follows:

$$\Delta DD_{it} = \frac{DD_{it} - DD_{it-5}}{|\, DD_{it-5} \,|}\,. \tag{1}$$

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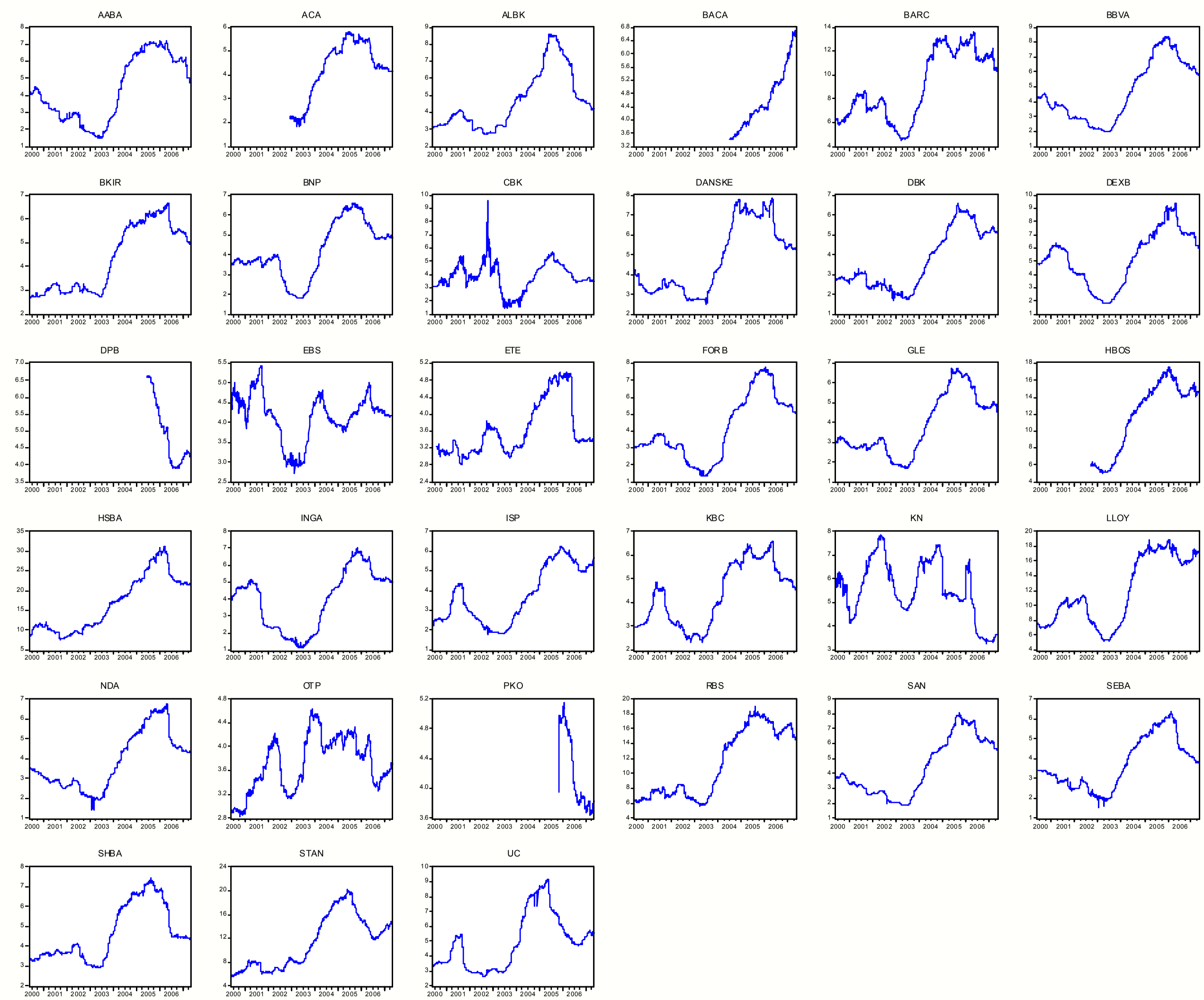
[9] See Čihák (2007) for a review of the literature.

[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.

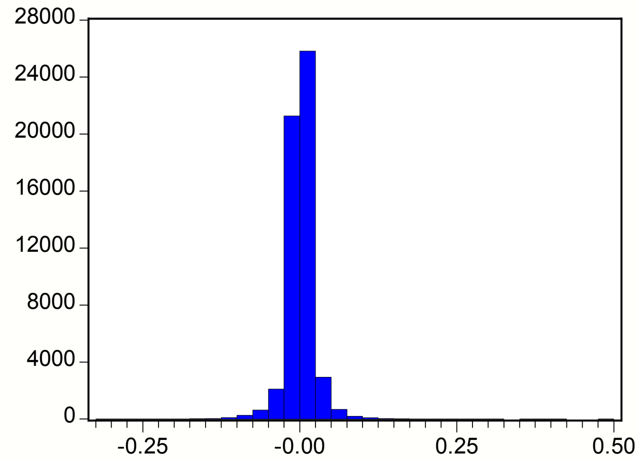
Figure 1. EU Banks: Changes in Distance-to-Default




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

We then rank all $\Delta DD_{it}$ 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 $10^{th}$ 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:

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

where $T_{10}$ is the $10^{th}$ 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,

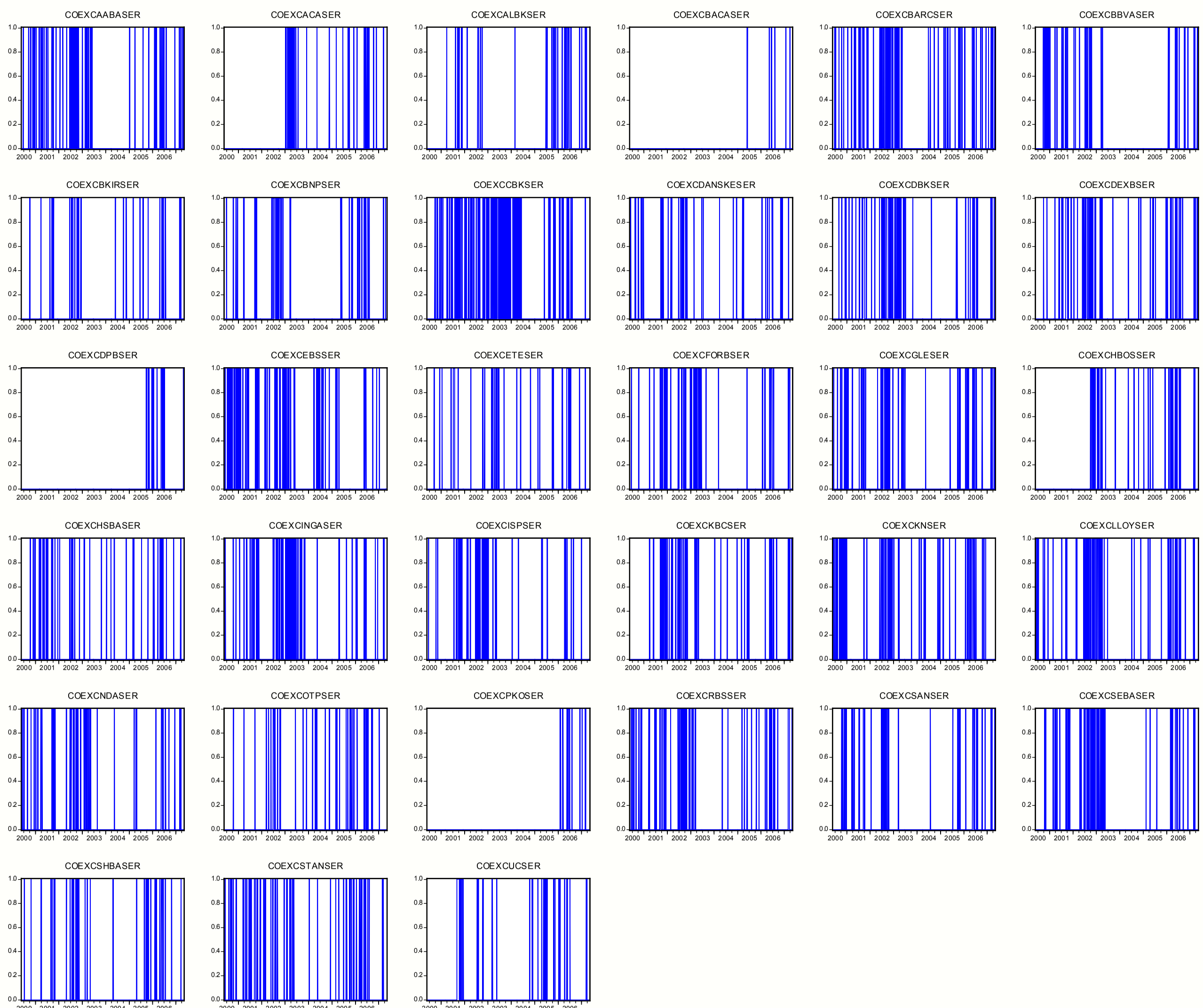
$$\Pr(y_{it} = 1 | x, \beta) = \frac{e^{\alpha_i F_{it} + \sum_{s=1}^{5} \rho_{si} C_{it-s} + \gamma_j \sum_{j=1}^{B} C_{jt-1}}}{1 + e^{\alpha_i F_{it} + \sum_{s=1}^{5} \rho_{si} C_{it-s} + \gamma_j \sum_{j=1}^{B} C_{jt-1}}}, \quad (3)$$

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 $\beta$ represents the slope coefficients $\alpha$, $\rho$, $\gamma$. The parameter $\alpha$ 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 ($F_{it}$); $\rho$ 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 $\gamma$ 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 $\Delta DD$s.

[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* ($\sigma_C$)

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,

$$X_t = c + \varepsilon_t, \text{ and} \tag{5}$$

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

where $X_t$ is the weekly local currency return in the country's stock price index and $\sigma_t^2$ is the GARCH volatility, both at time *t*.[14] The ARCH effect is captured by the lagged square residual, $\varepsilon_{t-1}^2$. 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 ( $\sigma_{t-1}^2$ ), and information about volatility observed in the last period ( $\varepsilon_{t-1}^2$ ). 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* ( $\Delta yc$ )

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).

$$\Delta yc_t = \frac{yc_t - yc_{t-5}}{| yc_{t-5} |}, \qquad (7)$$

where $yc_t$ is the term structure spread at time *t*.

*Regional Market Shocks* ($\sigma_E$)

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* ($\sigma_W$)

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: AUT | BLG | | | DMK | FRA | | | DEU | | HUN | IRL | | ITL | | NDL | | ESP | | SWE | | | GBR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 1 | 2 | 3 | 1 | 1 | 2 | 3 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 |
| | Initial shock to: | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Austria | Erste | | c | c5 | c5 | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Belgium | Fortis | c | | d1 | d1 | c | c1 | c1 | c | c1 | c5 | c | c | c | c | c | c1 | c1 | c | c | c | c | c | c | c | c | c | c |
| | KBC | c | d | | d5 | c | c | c | c | c | c | c5 | c | c | c5 | c | c | c | c | c | c | c | c | c5 | c | c | c | c |
| | Dexia (Luxembourg) | c | d | d1 | | c | c | c | c | c | c | c | c1 | c5 | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c |
| Denmark | Danske | c | c | c | c | | c | c | c1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| France | BNP Paribas | c | c | c | c | c | | d1 | d1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c |
| | Societe Generale | c | c | c | c | c | d | | d | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c1 | c | c | c | c | c |
| | Natixis | c1 | c | c | c | c | d | d5 | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c5 | c |
| Germany | Deutsche Bank | c | c | c | c1 | c | c | c | c | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Commerzbank | c | c | c | c | c | c | c | c | d1 | | c | c | c | c | c | c1 | c | c | c | c1 | c5 | c | c | c | c | c | c |
| Hungary | OTP | c | c | c | c | c | c | c | c | c | c | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Ireland | Bank of Ireland | c | c | c | c | c | c | c | c | c | c | c | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Allied Irish | c | c | c | c | c1 | c | c | c | c | c | c | d5 | | c | c | c | c | c5 | c | c | c | c5 | c | c | c | c | c |
| Italy | Unicredito | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | c5 | c | c | c | c | c | c | c | c | c | c | c |
| | Intesa Sanpaolo | c | c | c | c | c | c | c | c | c | c | c | c | c | d | | c | c | c | c | c | c | c | c | c | c | c | c |
| Netherlands | ING | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | | d5 | c | c | c | c | c | c | c | c | c | c |
| | ABN Amro | c | c | c | c | c | c5 | c1 | c | c | c | c | c | c | c | c | d | | c | c5 | c | c | c | c | c | c | c | c |
| Spain | Santander | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d5 | c | c | c | c | c | c | c | c |
| | Banco Bilbao Vizcaya | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | d1 | | c | c | c | c | c | c5 | c | c |
| Sweden | Nordea | c5 | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | d5 | c | c | c | c | c |
| | SEB | c | c | c | c5 | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c5 | c | d | | d | c | c | c | c | c |
| | Swedbank | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c1 | c | c | d5 | d | | c | c | c | c | c |
| United Kingdom | Barclays | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | d1 | d | d |
| | HSBC | c | c | c | c | c5 | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c1 | c5 | c5 | c | d | | d | d | d5 |
| | RBS | c | c | c1 | c | c | c | c | c | c | c | c5 | c5 | c | c | c | c | c | c | c | c | c | c | d | d | | d | d5 |
| | Lloyds | c | c1 | c | c | c | c | c | c | c | c | c | c | c5 | c | c5 | c | c | c | c | c | c | c | d5 | d | d | | d |
| | Standard Chartered | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | d | d | d5 | d | |
| Other factors | Constant | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: | ::: |
| | Change in term structure | | | 5 | | | ::: | | | | | | | | | | | | ::: | ::: | ::: | | | | | | | |
| | Local market volatility | | | | | | | | | | | | | | | | | | | | 5 | | | | | | | |
| | Regional market volatility | | | | | | | | | | | | | | | | | | | | | | | | | 5 | | |
| | Global market volatility | | | | ::: | | | | | | | | | | | | | | | | | | | | | 1 | | |
| McFadden's R-squared | | 0.36 | 0.55 | 0.48 | 0.54 | 0.57 | 0.59 | 0.51 | 0.53 | 0.45 | 0.39 | 0.51 | 0.54 | 0.60 | 0.57 | 0.47 | 0.44 | 0.45 | 0.58 | 0.51 | 0.55 | 0.40 | 0.50 | 0.41 | 0.42 | 0.47 | 0.47 | 0.39 |

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.2. May 30, 2000 to November 30, 2003 (First Sub-Period)

| Country | Bank | AUT 1 | BLG 1 | BLG 2 | BLG 3 | DMK 1 | FRA 1 | FRA 2 | FRA 3 | DEU 1 | DEU 2 | HUN 1 | IRL 1 | IRL 2 | ITL 1 | ITL 2 | NDL 1 | NDL 2 | ESP 1 | ESP 2 | SWE 1 | SWE 2 | SWE 3 | GBR 1 | GBR 2 | GBR 3 | GBR 4 | GBR 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial shock to: | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Austria | Erste | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Belgium | Fortis | c | | d | d1 | c | c1 | c | c | c | c | c | c | c | c | c | c1 | c1 | c | c | c | c | c | c | c | c | c | c |
| | KBC | c | d | | d | c | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Dexia (Luxembourg) | c | d | d1 | | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c5 | c | c | c | c | c1 | c | c | c | c |
| Denmark | Danske | c | c | c | c5 | | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c |
| France | BNP Paribas | c | c | c | c | c | | d1 | d1 | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c5 | c |
| | Societe Generale | c | c | c | c | c5 | d | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Natixis | c1 | c | c | c | c | d | d | | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c5 | c5 | c |
| Germany | Deutsche Bank | c | c | c | c1 | c | c | c | c | | d5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 |
| | Commerzbank | c | c | c | c | c | c | c | c | d5 | | c | c | c | c1 | c5 | c5 | c | c | c | c5 | c5 | c | c | c | c | c | c |
| Hungary | OTP | c | c | c | c | c | c | c | c | c | c | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Ireland | Bank of Ireland | c | c | c | c | c | c | c5 | c | c | c | c | | d | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c |
| | Allied Irish | c | c | c | c | c5 | c | c | c | c | c | c | d1 | | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Italy | Unicredito | c | c | c5 | c | c | c | c | c | c | c | c | c | c | | d | c | c | c | c | c | c | c | c5 | c5 | c | c | c |
| | Intesa Sanpaolo | c | c | c | c | c | c | c | c | c | c | c | c | c1 | d | | c | c | c | c | c | c | c | c | c | c | c | c |
| Netherlands | ING | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d5 | c | c | c | c | c | c | c | c5 | c | c |
| | ABN Amro | c | c | c | c | c | c | c5 | c | c | c | c | c | c1 | c | c | d | | c | c | c | c | c | c | c | c | c | c |
| Spain | Santander | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d5 | c | c | c | c5 | c5 | c | c | c |
| | Banco Bilbao Vizcaya | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | d1 | | c | c | c | c | c | c5 | c | c |
| Sweden | Nordea | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | d5 | c | c | c | c | c |
| | SEB | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c5 | c | d | | d | c | c | c | c | c |
| | Swedbank | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c1 | c | c | d | d | | c | c | c | c | c |
| United Kingdom | Barclays | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | d | d | d |
| | HSBC | c | c | c | c | c | c | c | c | c1 | c | c | c5 | c | c | c | c | c | c | c5 | c | c1 | c | d | | d | d | d1 |
| | RBS | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c5 | c | c | c | c | d | d | | d | d1 |
| | Lloyds | c | c1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | d | d | | d |
| | Standard Chartered | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | d | d5 | d | |
| Other factors | Constant | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Change in term structure | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Local market volatility | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Regional market volatility | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Global market volatility | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| McFadden's R-squared | | 0.34 | 0.50 | 0.49 | 0.56 | 0.57 | 0.63 | 0.51 | 0.53 | 0.39 | 0.37 | 0.59 | 0.67 | 0.69 | 0.71 | 0.45 | 0.40 | 0.44 | 0.61 | 0.50 | 0.51 | 0.34 | 0.56 | 0.43 | 0.43 | 0.45 | 0.49 | 0.40 |

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 | AUT 1 | BLG 1 | BLG 2 | BLG 3 | DMK 1 | FRA 1 | FRA 2 | FRA 3 | DEU 1 | DEU 2 | HUN 1 | IRL 1 | IRL 2 | ITL 1 | ITL 2 | NDL 1 | NDL 2 | ESP 1 | ESP 2 | SWE 1 | SWE 2 | SWE 3 | GBR 1 | GBR 2 | GBR 3 | GBR 4 | GBR 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Initial shock to: | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Austria | Erste | | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c1 | c | c | c | c | c | c |
| Belgium | Fortis | c | | d | d | c | c | c1 | c | c | c1 | c | c | c | c | c | c | c | c | c | c1 | c | c1 | c | c | c | c | c |
| | KBC | c | d | | d1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Dexia (Luxembourg) | c | d | d | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c |
| Denmark | Danske | c | c | c | c | | c | c | c5 | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c1 | c | c | c | c |
| France | BNP Paribas | c | c | c | c | c | | d | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c5 | c |
| | Societe Generale | c | c | c | c | c | d | | d1 | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c |
| | Natixis | c | c1 | c | c5 | c | d | d | | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c1 | c | c | c |
| Germany | Deutsche Bank | c | c | c | c5 | c | c5 | c | c | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Commerzbank | c | c | c | c | c | c | c | c | d | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Hungary | OTP | c | c | c | c | c | c | c | c | c1 | c | | c | c | c | c | c | c | c5 | c | c | c | c1 | c1 | c | c | c | c |
| Ireland | Bank of Ireland | c | c | c | c | c | c | c | c | c | c | c | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | Allied Irish | c | c | c5 | c | c | c5 | c | c | c5 | c1 | c | d | | c | c5 | c | c | c5 | c | c | c | c | c | c1 | c | c | c |
| Italy | Unicredito | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | c5 | c | c | c | c | c | c | c | c | c | c | c |
| | Intesa Sanpaolo | c | c | c | c | c | c | c | c | c | c | c | c | c | d | | c | c | c | c | c | c | c | c | c | c | c | c |
| Netherlands | ING | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | c | c | c | c | c | c | c | c | c | c |
| | ABN Amro | c | c | c | c | c | c5 | c1 | c | c5 | c | c | c | c | c | c | d | | c | c | c1 | c | c | c | c | c | c | c |
| Spain | Santander | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | c | c | c1 | c | c | c | c | c |
| | Banco Bilbao Vizcaya | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | | c | c | c | c | c | c | c | c |
| Sweden | Nordea | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | d | c | c | c | c | c |
| | SEB | c | c | c1 | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | | d | c | c | c | c | c |
| | Swedbank | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | d5 | d | | c | c | c | c | c |
| United Kingdom | Barclays | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | | d1 | d | d | d5 |
| | HSBC | c | c1 | c | c | c | c1 | c | c | c | c | c | c | c | c | c5 | c | c | c | c5 | c1 | c | c | d | | d | d | d |
| | RBS | c1 | c | c5 | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c | c | d | d1 | | d1 | d |
| | Lloyds | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c1 | d | d | d | | d |
| | Standard Chartered | c | c | c | c | c1 | c | c | c1 | c | c | c1 | c | c | c | c | c | c | c | c | c | c | c | d | d | d1 | d1 | |
| Other factors | Constant | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ | ░ |
| | Change in term structure | | 1 | 5 | 1 | | | ░ | | | | | | | | | | | ░ | | ░ | ░ | | | | | | |
| | Local market volatility | | ░ | | | | | | | | 1 | | | | | | | | | | | | | | | | | |
| | Regional market volatility | | | | | 5 | | | | | ░ | | | | | | | | | | | | | | | 5 | | |
| | Global market volatility | | | | | | | | | | | | | | | | 1 | | | | | | | | | | | |
| McFadden's R-squared | | 0.34 | 0.50 | 0.49 | 0.56 | 0.57 | 0.63 | 0.51 | 0.53 | 0.39 | 0.37 | 0.59 | 0.67 | 0.69 | 0.71 | 0.45 | 0.40 | 0.44 | 0.61 | 0.50 | 0.51 | 0.34 | 0.56 | 0.43 | 0.43 | 0.45 | 0.49 | 0.40 |

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 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 1 | 1 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 | 6 |
| | Initial shock to: | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Austria | 1 Erste | | d | c5 | c5 | c | c | c | c | c | c5 | c5 | c | c | c | c | c | c | c | c | c1 | c | c | c1 | c | c | c1 | c5 | c | c | c | c | c | c |
| | 2 Bank Austria Creditanstal | d | | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c1 | c |
| Belgium | 1 Fortis | c | c | | d | d | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | 2 KBC | c | c | d5 | | d5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c5 | c5 | c | c | c | c |
| | 3 Dexia (Luxembourg) | c | c | d | d | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Denmark | 1 Danske | c | c | c | c | c | | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c5 | c | c | c | c | c |
| France | 1 BNP Paribas | c | c | c | c | c | c | | d | d | d | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c1 | c |
| | 2 Credit Agricole | c | c | c | c | c | c | d | | d | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c1 | c1 | c | c |
| | 3 Societe Generale | c | c | c | c | c | c | d | d | | d1 | c | c | c1 | c | c | c | c | c | c | c | c | c | c1 | c1 | c | c | c | c | c | c | c | c5 | c |
| | 4 Natixis | c | c | c | c5 | c | c | d | d | d | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c1 | c1 | c |
| Germany | 1 Deutsche Bank | c | c | c | c | c5 | c | c5 | c5 | c | c | | d | d | c5 | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c |
| | 2 Commerzbank | c | c | c | c | c | c | c | c | c | c | d | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | 3 Deutsche Postbank | c | c | c | c | c | c | c5 | c | c | c | d5 | d | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 |
| Greece | 1 National Bank of Greece | c | c | c5 | c5 | c | c | c | c | c1 | c | c | c | c5 | | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c1 | c |
| Hungary | 1 OTP | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c5 | | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c |
| Ireland | 1 Bank of Ireland | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | 2 Allied Irish | c | c | c | c5 | c | c | c5 | c | c | c1 | c5 | c1 | c | c | c | d | | c | c1 | c | c | c | c | c5 | c | c1 | c | c | c5 | c | c | c | c |
| Italy | 1 Unicredito | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | c1 | c | c | c | c | c | c | c | c | c | c | c | c | c |
| | 2 Intesa Sanpaolo | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | d | | c | c | c | c | c | c | c | c | c | c | c | c | c | c |
| Netherlands | 1 ING | c | c | c | c | c | c | c5 | c | c | c | c5 | c | c | c | c | c | c | c | c | | d | c | c | c | c | c | c | c | c5 | c | c | c | c |
| | 2 ABN Amro | c | c | c | c | c | c | c5 | c | c1 | c | c | c | c | c5 | c | c | c | c | c | d5 | | c | c | c5 | c | c | c | c | c | c | c | c | c |
| Poland | 1 PKO | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | c | c5 | c | c | c | c | c | c | c | c | c |
| Spain | 1 Santander | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d5 | c | c5 | c | c | c | c | c | c | c |
| | 2 Banco Bilbao Vizcaya | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | | c | c | c | c | c | c | c | c | c |
| Sweden | 1 Nordea | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | | d | d | c | c | c | c | c | c |
| | 2 SEB | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c5 | c | c | d | | d | c5 | c | c | c5 | c | c |
| | 3 Swedbank | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | d | | c | c | c | c | c | c |
| United Kingdom | 1 Barclays | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c5 | c | c | c | c | c | c | | d5 | d1 | d | d5 | d5 |
| | 2 HSBC | c | c | c | c | c | c | c | c | c | c1 | c | c | c | c | c | c | c | c | c | c | c | c | c | c1 | c | c5 | c | d | | d | d | d | d |
| | 3 RBS | c | c | c | c5 | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | d | d | | d1 | d1 | d |
| | 4 HBOS | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | d | d | d | | d | d5 |
| | 5 Lloyds | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c5 | c | c | c5 | d | d | d | d | | d |
| | 6 Standard Chartered | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c | c | c | c | c | c | c | c5 | c | c | c | c | c5 | c | d | d | d | d | d | |
| Other factors | Constant | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Change in term structure | | | | 1 | 5 | | | | | | | | | | | | | | 5 | | | | | | | | | | | | | | |
| | Local market volatility | | | | | | | | | | | | | | 5 | | | | | | | | | | | | | | | | | | 5 | |
| | Regional market volatility | | | | | | | 5 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Global market volatility | | | | | | | | | | | 5 | | | 5 | | | | | | 1 | | | | | | | | 5 | | | 5 | 1 | 1 |
| 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 | 0.76 | 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
(dotted) 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:

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

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

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:

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

[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 $\sigma_A$ 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:

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

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

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

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

$$d_2 = d_1 - \sigma_A\sqrt{T}\ . \tag{A.7}$$

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, $\sigma_E$, 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).

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