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Bank solvency risk and funding cost interactions in a small open economy: Evidence from Korea☆

Iñaki Aldasoro*, Kyounghoon Park†

Abstract

Using proprietary balance sheet data for Korean banks and a simultaneous equation model, we document that increased marginal funding costs lead to larger solvency risk (as measured by the Tier 1 regulatory capital ratio), which, in turn, leads to larger marginal funding costs. A 100 bp increase in marginal funding costs (solvency risk) is associated with a 155 (77) bp increase in solvency risk (marginal funding costs). The findings of an economically and statistically significant relationship are robust to considering different proxies for solvency risk, types of banks, interest rate regimes, and interest margin management strategies. They also hold irrespective of the funding profile considered. FX-related macroprudential policies can affect the negative feedback loop by muting the effect of marginal funding costs on solvency risk. Our findings can inform the calibration of macroprudential stress tests.

Keywords: Solvency risk, funding cost, simultaneous equation model, stress testing, macroprudential policy, bank business models

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1. Introduction

When banks are hit by a shock large enough to potentially compromise their solvency, they are perceived as riskier by others. This, in turn, will make it difficult for them to fund themselves at rates similar to those obtained pre-shock. In other words, solvency risk can increase funding costs (Acharya and Mora (2015), Hasan et al. (2016), Gambacorta and Shin (2016)). Similarly, if banks experience a persistent increase in funding costs, the business model and the ability of the bank to generate profits on a sustainable basis might be called into question. This may ultimately increase the solvency risk of the institution. To put it shortly, higher funding costs can increase solvency risk (Beau et al. (2014), Babihuga and Spaltro (2014)). Therefore, a negative feedback loop can emerge between the two sources of stress.

Solvency risk and funding costs are thus two forces that can interact with and feed upon each other. This interaction drives feedbacks that macroprudential stress tests should pay close attention to, as emphasized in recent calls for "making stress tests more macroprudential" (BCBS (2015)). In this paper, we study the interaction between solvency risk and funding costs using two proprietary data sets of the Bank of Korea that collect detailed balance sheet information and marginal funding costs at the quarterly frequency for Korean commercial banks.

The case of Korea is interesting for various reasons, each of which represents an angle along which our paper contributes to the literature. First, it is a small open economy. This allows us to distinguish between purely domestic and external variables. A second interesting aspect of our study is that the granularity of the data, in particular as it pertains to funding, allows us to distinguish between different bank funding models. We use the cross-sectional variation in the data to categorise funding models according to different quantiles in the distribution of FX funding shares. Importantly, we use unique data on marginal funding costs at the bank level, and argue that this is the right measure to look at when analysing solvency risk and funding cost interactions. Finally, Korea has applied so-called FX-related macroprudential policies in recent years.[1] While some papers have assessed the impact of such measures in the share of foreign currency borrowing (Kim and Lee (2017), Choi (2014)), we are the first to analyse the impact of macroprudential policy on the interaction between solvency risk and funding costs.

Figure 1 presents some unconditional evidence of the existence of a negative association be-

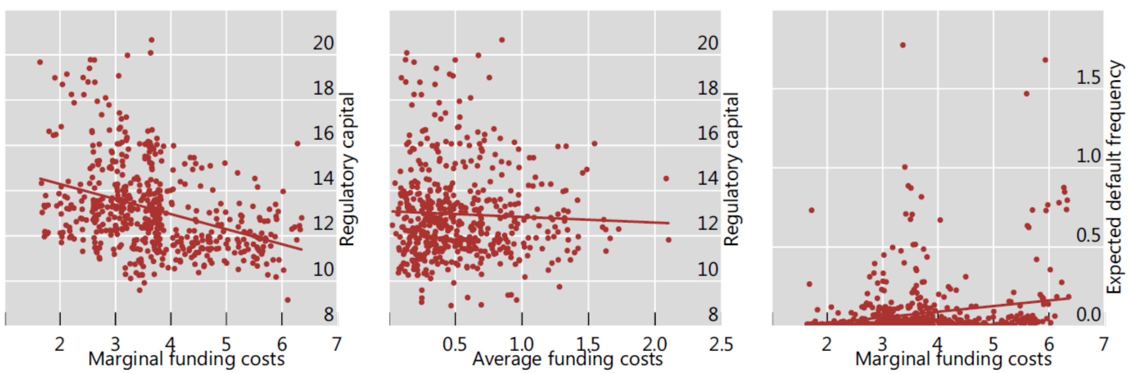
[1] The measures were introduced with the aim of mitigating the procyclicality of cross-border capital flows through banks, especially short-term non-core foreign exchange (FX) liabilities, which were identified as a source of vulnerability in the aftermath of the great financial crisis (Choi (2014)).

tween solvency risk and funding costs. For each bank-quarter, we plot the solvency position as captured by either the Tier 1 regulatory capital ratio or the expected default frequency (EDF),[2] versus funding costs as measured by marginal funding costs (left-hand panel) and average funding costs (centre panel, measured as interest expense over interest bearing liabilities).

When assessing how increased solvency risk may affect the price at which banks may fund themselves, marginal funding costs are the relevant measure. Indeed, marginal funding costs exhibit a negative correlation with solvency risk (positive when assessed versus EDF), whereas when using the more noisy average funding cost measure the correlation is negative but relatively small. To the best of our knowledge, we are the first to use marginal funding costs, capturing the weighted average interest paid for *new* (non-equity) funding, in an analysis of solvency risk and funding cost interactions.

Figure 1: Solvency risk and funding costs: some unconditional evidence

(see Table A.2 for variable definitions)



The joint determination and endogeneity of solvency risk and funding costs implies that a standard panel OLS estimation will not be fit for purpose.[3] Following Schmitz et al. (2017), to address endogeneity concerns we thus use a simultaneous equation approach to estimate the impact that solvency risk has on funding cost and vice versa, achieving identification via exclusion restrictions. We also look at the role of different funding models. This differentiation is important, since both with the crisis and with the implementation of FX-related macroprudential policies, the funding profile of Korean commercial banks changed significantly, both on average and in the cross-section (see the figures in Appendix B).

[2]In line with the literarure, we use the Tier 1 regulatory capital ratio as the benchmark measure of solvency risk. Below we discuss this choice in more detail.

[3]In particular, parameters estimated via OLS will be biased. The direction of this bias is, however, uncertain.

Our results can be summarised as follows. We show that a statistically significant and economically meaningful two-way negative interaction exists between solvency risk and marginal funding costs. A 100 bp increase in marginal funding costs is associated with a 155 bp reduction in the regulatory capital ratio, while a 100 bp increase in the regulatory capital ratio is associated with a 77 bp decrease in marginal funding costs.[4] OLS delivers biased estimates, with counterintuitive signs and no statistical significance. The findings are robust to considering: different bank types (general versus regional) separately,[5] different interest rate regimes, interest margin management of banks and alternative measures of solvency risk (EDF). We also show that using average funding costs, as normally done in the literature due to lack of data on marginal funding costs, can lead to the wrong conclusion regarding the link between solvency risk and funding costs.

In a first extension, we show that the main results also hold across the whole spectrum of funding profiles. However, the effect can be non-linear for some funding sub-categories, in particular wholesale funding. In a second extension, we present evidence that FX-related macroprudential measures (leverage cap, stability levy and interest income tax on foreign bond investors) were effective in breaking the negative feedback loop by muting the effect that marginal funding costs have on solvency risk (while keeping the market discipline effect of higher solvency risk leading to higher funding costs).[6] The macroprudential measures are aimed at curbing borrowing from abroad by incentivising banks to substitute foreign funding for domestic funding. As the latter is more costly than the former, funding costs will tend to rise for the same level of regulatory capital. This may, in turn, lead to less borrowing in the domestic market, potentially also forcing banks to raise capital in a context of rising funding costs. Ultimately, the aim of regulation is to put a ceiling on solvency risk, thereby breaking the loop between funding costs and solvency risk.

The remainder of the paper is organised as follows. Section 2 briefly overviews related literature and places our contribution. Section 3 illustrates our data and variables, and presents descriptive statistics. Section 4 introduces the empirical methodology and the identification strategy. Section 5 describes the main results, Section 6 robustness checks, and Section 7

[4]This is in line with Gambacorta and Shin (2016), who show, for a broader sample, that better capitalised banks face lower funding costs, allowing them to lend more. The finding is also reassuring as it highlights that market discipline works, at least to some extent.

[5]This also serves the purpose of establishing robustness to the type of risk-modelling approach used by banks.

[6]This is in line with expectations: regardless of whether prudential measures are in place, a riskier bank should face higher funding costs.

extensions. Section 8 concludes.

2. Related literature

Our study builds upon the growing stream of literature on the interaction between solvency risk and liquidity or funding costs, and aims to inform the design of stress tests. Distinguin et al. (2013) analyse funding volumes rather than funding costs and find that when banks face higher illiquidity they decrease their regulatory capital ratios. However, they also find that small banks tend to strengthen solvency standards when they are exposed to higher illiquidity.

Based on an analysis of determinants of CDS spreads, Annaert et al. (2013) show that a higher leverage increases funding costs of banks in the euro area during 2004-2008. Babihuga and Spaltro (2014) study an international panel of 52 banks in advanced economies from 2001 to 2012. They find higher quality of capital is related to lower bank funding costs. Hasan et al. (2016) show a similar result, where bank leverage raises funding costs during 2001-2011.

Our study is most closely linked to recent contributions by Aymanns et al. (2016), Schmitz et al. (2017) and Dent et al. (2017)[7]. Schmitz et al. (2017) adopt a simultaneous equations model (SEM) approach to address the joint determination of solvency risk and funding costs. They use a combination of market-based and balance sheet data, with one critical variable taken from each source, namely funding costs from market-data and solvency from balance sheet data. Aymanns et al. (2016), on the other hand, adopt balance sheet-based measures of both solvency and funding costs. However, they perform a panel analysis that does not allow for joint determination of funding costs and solvency. Our paper combines the approaches in these two papers, as we consider accounting-based and market-based data, and we base our conclusions on a simultaneous equation model.[8] The latter element we see as unavoidable given the discussion in the introduction. The relative focus on the use of balance sheet data is guided by both practical and theoretical considerations. At the practical level, the use of market-based data is restricted by the lack of such data for funding costs for our sample banks, many of which do not have CDS written on them nor are rated by rating agencies. Instead we adopt a unique proprietary data for marginal funding costs. At the same time, the use of balance sheet data allows us to inform directly the discussion and calibration of stress tests, which are based on

[7] See also BCBS (2015), which provided the original motivation to pursue this research.

[8] Imbierowicz and Rauch (2014) also use a simultaneous equation approach to study the interaction between credit risks and liquidity risks in a large panel of US banks.

such data (Aymanns et al. (2016)). Dent et al. (2017) is a recent contribution which places the focus directly on the interaction between solvency and *wholesale* funding costs for a sample of 4 large UK banks, using market data and without explicitly allowing for the joint determination of the variables of interest. These papers present evidence for the existence of non-linear effects in the interaction between solvency and funding costs, which we also corroborate to some extent.

Finally, our paper also speaks to the literature on the evaluation of macroprudential policies (IMF-FSB-BIS (2016)). This literature is vast and we do not aim to review it here. For a recent overview and assessment of macroprudential policies in Asia, see Bruno et al. (2017). Of particular interest to us is that part of the literature that studies the case of Korea. Bruno and Shin (2014) perform a cross-country panel analysis and conclude that macroprudential policies in Korea were effective in reducing capital flows. Using more granular data, Kim and Lee (2017) and Choi (2014) find that the FX-related macroprudential policies imposed in Korea since 2010 have been successful in curbing short term FX borrowing by banks. Our paper contributes to this literature by highlighting another positive effect of macroprudential policies, namely the moderation of the negative interaction between bank solvency risk and funding costs.

3. Data

The main data source we use is the FAIRS data set (Financial Analysis Information Retrieval System) available at the Bank of Korea, which provides detailed balance sheet information at the bank level with a quarterly frequency. We complement this with another proprietary data set of marginal funding costs at the bank level, also available at the Bank of Korea. The use of marginal funding costs in our benchmark specification comes at the cost of restricting the sample size along the time dimension: data for marginal funding costs are available only starting in 2005.[9] However, this indicator is arguably the best used so far for such an analysis, as it overcomes the shortcomings of the alternatives used thus far (average funding costs or CDS spreads). Our sample ends in the second quarter of 2015. While data after that point are in principle available, we stop there to secure enough number of observations for each bank. As our sampling rule, we count banks by distinct bank identifiers. That is, when a bank identifier changes due to mergers and acquisitions (M&A), or bankruptcies, we consider the bank as a separate entity before and after such events, and do not track and link their identity. This is

[9] When using average interest expense (as a share of interest-bearing liabilities) as a measure of funding costs, our sample starts in 2000.

because the charter value of banks can change before and after M&A, and this might affect bank fundamentals and funding costs, hence potentially distorting our analysis.[10]

Capital regulation does not apply to foreign bank branches in Korea in the same manner as it does to domestic banks.[11] In particular, it is not possible for us to obtain a regulatory capital measure to capture solvency for the case of foreign branches. Instead, one can only compute a simple measure based on total assets and equity, as in Jeon et al. (2014). However, since the focus of our analysis is precisely on solvency risk, we keep foreign bank branches out of the sample. An issue which deserves mention is the way in which banks can calculate regulatory capital, namely whether they use the internal ratings-based (IRB) approach or the standardised approach (SA). In principle, this issue should be taken care of by the use of bank fixed effects. There are, however, a couple of banks which changed their approach within the sample. To assuage concerns that results may be driven by the type of approach used, in one of the robustness checks we partition the sample between general versus regional banks, where the latter all use the SA within our sample.

As in Jeon et al. (2014), we do not include special purpose banks in our sample. The business model of these banks is not comparable to that of general commercial banks. Special purpose banks are mostly or partly owned by government and conduct policy-oriented business such as syndicated loans for specific industrial development purposes or for promoting exports and imports of firms in certain industries, etc. These banks raise funding in a different manner, mainly by issuing bonds abroad (rather than, say, resort to retail funding as commercial banks do). At the end of the sample period, we have 13 commercial banks in total, among which seven are general banks and six are regional banks. The data set used for the benchmark model consists hence of an unbalanced panel over the period 2005:Q1-2015:Q2.[12]

Our analysis uses both accounting-based and market-based data for solvency risk, while we adopt marginal funding costs as reported by banks instead of CDS. Using balance sheet data

[10] Since there is no overlap between entities before and after M&A, this should not affect the result of the unbalanced panel analysis. For a paper using a similar approach to an unbalanced panel using the FAIRS data, see Jeon et al. (2014).

[11] The Basel Committee on Banking Supervision has introduced the D-SIB (domestic systemically important banks) requirement for foreign bank branches. At the moment, 5 countries/country groups adopted the D-SIB requirements (U.S., EU, Switzerland, China, Japan), with Korea yet to adopt it (see http://www.bis.org/bcbs/implementation/rcap_jurisdictional.htm).

[12] In the robustness checks where marginal funding costs are not included, the sample goes back to 2000:Q1. For descriptive statistics we also use the longer sample.

presents two advantages. First, we can cover larger cross-sections of banks and longer periods. Second, as stress tests are based on balance sheet data, by using such data we can directly inform the calibration of stress-testing exercises. For some variables, in particular funding costs, it can be reasonably argued that market data provides a good, even better,[13] alternative to balance sheet data. However, market data is not without its shortcomings for the type of analysis we tackle: they can easily be affected by monetary policy, market volatility and global risk aversion.[14] Therefore, the time dimension gained through market data can be more noisy than the cross-sectional dimension. Furthermore, market data such as CDS spreads are not available for most of the banks in our sample, and even when they would be available, it is not obvious they are the best proxy for funding costs. We strike a balance between this competing arguments by using a balance-sheet-based regulatory capital measure to capture solvency risk, and marginal funding costs (ie the cost of *new* funding) as a measure of funding costs in our benchmark model. We also show that our core results holds when using a market-based measure of solvency risk, and we also highlight that using average funding costs can lead to the wrong conclusion regarding the relationship between solvency risk and funding costs.

3.1. Main variable definitions

The description of the variables used in the regressions, as well as the respective sources, are summarised in Table A.2. Below we describe in more detail the choice of our main variables of interest, namely funding costs and solvency.

Funding costs. We adopt marginal funding costs (MFC) as reported by banks to the Bank of Korea. These data are proprietary to the Bank of Korea (hence not publicly available) and are not part of the balance sheet reporting template from the FAIRS data set. Marginal funding costs represent interest rates for *new* funding,[15] including retail, wholesale and bond issuance, per quarter. The measure is a weighted average of newly created funding, hence it can provide a

[13] A higher frequency is usually regarded as one of the main advantages of alternative market-based measures of funding costs, such as CDS spreads or bank bond prices.

[14] Furthermore, the supposed superiority of market-based measures is usually highlighted in comparison to the most commonly used measure of funding costs, namely average funding costs, which we argue is not in any case the best measure to capture funding costs.

[15] This can include new debt, as well as the rolling over of existing debt. We are not able to distinguish between the two from the data.

better picture of the evolution of funding costs in real time and how they may react to changes in solvency risk at the frequency of the data usually used for stress testing exercises. The extant literature has used thus far average funding costs based on accounting data (Aymanns et al. (2016)) or CDS spreads.[16] To the best of our knowledge, this is the first paper to use marginal funding costs when analysing the interaction between solvency risk and the cost of funding.

We also use a measure of average funding costs based on balance sheet data to show how results can differ relative to our benchmark.[17] In an extension, we also consider quantiles of each funding source and analyse whether business models in terms of funding structure play a role in driving the interaction between solvency and funding costs.

Solvency risk. The choice of a solvency risk measure is less controversial, though as discussed above, it can lead to a narrowing of the sample due to a lack of comparable solvency data for different types of banks (i.e. foreign versus domestic). As in Schmitz et al. (2017), our measure of solvency risk is the Tier 1 capital ratio, which is calculated as Tier 1 capital over risk-weighted assets. This variable is homogeneous across banks and underpins the regulatory capital calibration in international standards. It is arguably the best barometer against which to measure the risk of default of a bank, and indeed serves that purpose in stress testing exercises, an additional reason for us to consider it as benchmark.

To address robustness considerations, we also use a market-based measure for bank default probability, namely the Expected Default Frequency (EDF) provided by the Korean Risk Management Corporation. The construction method for the EDF of Korean banks is similar to that of Moody's Credit Edge, based on a Merton-type model. A market-based solvency measure may be more robust to changes in capital regulation and accounting rules.[18] Thus, its change can be more immune to balance sheet management by banks.

[16] Many banks in Korea are not publicly listed, thus CDS data are only available for a limited number of banks. Moreover, CDS spreads may contain information not only for marginal funding costs but also for bank solvency, potentially providing confusing signals on the interaction between solvency and funding. Against this background, we do not use CDS spreads as a proxy for funding costs in this paper. Regarding average funding costs, as used for instance in Aymanns et al. (2016), they come with the drawback that they lump together amounts corresponding to trades from different maturities contracted in different periods.

[17] The categories of total interest expenses are listed in Table A.1.

[18] Note, however, that our benchmark model includes year fixed effects, which should control for such potentially confounding factors.

3.2. Descriptive statistics

Table A.3 describes the funding structure of Korean banks in means, medians, and standard deviations. *Retail* funding covers two thirds of total liabilities, which implies most of the banks in our sample are retail-oriented commercial banks. There is, however, some cross sectional variation as shown in a large standard deviation (see also Figure B.4).

The second largest category is *borrowings*, which refers to borrowings in won, in foreign currency, call money (Call), and bonds sold under repurchase agreements (Repos). Borrowings in won consist of borrowings from the Bank of Korea, the government, other banking institutions, and non-banking financial institutions. Borrowings in foreign currency are mostly short-term borrowings such as credit lines from domestic foreign exchange banks or from foreign correspondence banks for transactions purposes, as well as mid- to long-term borrowings such as bank loans for operating expenses.

The third largest source of funding is *bonds payable*, which comprise 7.6 % of total liabilities on average, although the standard deviation shows some variance across banks. Among the bonds payable, finance debentures issued in won and in foreign currency dominate. The overseas finance debentures issued in foreign currency are used in the foreign branches of domestic banks to borrow from abroad.

Total foreign currency borrowings amount to around 4.7% of total liabilities on average. As shown in Figure B.6, there is some variability in the cross-section (also reflected in the corresponding funding cost measure), which we exploit for one of our extensions.

Table A.4 presents the summary statistics for the variables used in our main estimations. The regulatory capital ratio is on average 12.4%, and there is in relative terms not a great deal of cross-sectional variation, as evidenced both by the standard deviation and Figure B.2. As shown in Figure B.2, after dropping substantially in the immediate aftermath of the crisis, the average regulatory capital ratio jumped after 2009 (to the neighborhood of 14%), as banks engaged in substantial recapitalisation efforts. Among all funding cost measures considered, MFC presents the largest mean and median, though the standard deviation is smaller than average funding costs (other than retail). Average funding costs show the expected variability across sub-groups, with retail being substantially lower than the rest, and bond and wholesale on the other extreme.

4. Empirical strategy

As discussed earlier, a critical consideration when it comes to evaluating the interaction between solvency risk and funding costs, however measured, resides in the fact that these variables are arguably jointly determined and endogenous. On the one hand, when banks face higher solvency risk due to, say, low profitability (for instance during an economic downturn), they can find their funding costs rising as a consequence, since their counterparty risk is rising. On the other hand, higher funding costs reduce bank earnings, which can further deteriorate their solvency. How rising funding costs affect a bank will depend on the way in which the bank responds. One option for the bank is to try to compensate by charging higher lending rates. This, however, comes at the cost of losing market share and eroding the charter value of the institution. Furthemore, the bank may not be able to pass-through entirely the rise in cost to lending rates. Interest margins are thus likely to be curtailed, leading in turn to a reduced capacity for generating capital internally.

While part of the extant literature has disregarded such concerns, Schmitz et al. (2017) shows how simple panel OLS estimations can deliver biased estimates. The direction of the bias is in principle uncertain, and it will depend on the nature of the unobserved elements in the regression equation. In the case of Schmitz et al. (2017), the bias is substantial, with OLS estimates actually delivering opposite signs relative to a simultaneous equation approach.[19] Our benchmark model is therefore given by a simultaneous equation system, in which we explicitly account for the endogeneity of solvency and funding costs. We provide evidence that a system of equations approach that takes account of endogeneity (either through a two- or three-stage least squares procedure) is preferred to the OLS alternative.

4.1. Simultaneous Equations Model

A simultaneous equation model (henceforth SEM) approach is a standard way of accommodating the endogeneity of certain variables. Related literature has relied on this method to study the interaction between regulatory capital and liquidity (Distinguin et al. (2013)), credit risk and liquidity risk (Imbierowicz and Rauch (2014)), or closer to our paper, solvency and funding costs (BCBS (2015) and Schmitz et al. (2017)). In its structural form, the SEM can be

[19]In our sample this is also indeed the case: OLS estimates for our main variables of interest are statistically insignificant and present the opposite sign than expected. We omit OLS results due to space considerations, they are however available upon request from the authors.

written as follows

$$\mathbf{Y\Gamma} + \mathbf{XB} = \mathbf{E} \tag{1}$$

where $\mathbf{Y}$ represents a $T \times k$ matrix collecting all T observations for the k dependent (endogenous) variables (in our case $k = 2$: solvency risk and funding costs), $\mathbf{X}$ is a matrix collecting all observations of exogenous variables (bank specific characteristics, domestic and global macro variables), $\mathbf{E}$ stands for the structural disturbances, with variance-covariance matrix $E[(1/N)\mathbf{E}'\mathbf{E}|\mathbf{X}] = \mathbf{\Sigma}$. $\mathbf{\Gamma}$ and $\mathbf{B}$ are structural parameters' matrices. The reduced form version of Equation 1 can be written as:

$$\mathbf{Y} = -\mathbf{XB\Gamma}^{-1} + \mathbf{E\Gamma}^{-1} = \mathbf{X\Pi} + \mathbf{V} \tag{2}$$

where $\mathbf{\Pi} = -\mathbf{B\Gamma}^{-1}$ and the reduced form disturbances are given by $\mathbf{V} = \mathbf{E\Gamma}^{-1}$, with variance-covariance matrix $E[\mathbf{VV}'|\mathbf{X}] = \mathbf{\Omega}$. By estimating the reduced form Equation 2, we obtain estimates for $\mathbf{\Pi}$ and $\mathbf{\Omega} = (\mathbf{\Gamma}^{-1})'\mathbf{\Sigma\Gamma}^{-1}$. Then we can retrieve our items of interest in the structural equation, namely $\mathbf{B}$, $\mathbf{\Gamma}$, and $\mathbf{\Sigma}$, the variance-covariance matrix for $\mathbf{E}$. However, there is an identification problem, which we tackle by means of exclusion restrictions. To identify the two endogenous variables, we need to find at least two exogenous sources of variation in bank solvency and funding costs. These sources are to be specified in the structural equations below.

In order to estimate our baseline SEM, we follow a 3-step estimation approach (Zellner and Theil (1962)). First, we regress each dependent variable on all exogenous variables in the system to obtain predicted values. Second, we regress the other dependent variables on the predicted values of the dependent variables and on the specific exogenous variables in the particular equation. In the third stage, we combine the two-stage least squares (2SLS) with seemingly unrelated regressions (SUR) to account for the correlation structure of errors in the structural equations (as in Schmitz et al. (2017) or Imbierowicz and Rauch (2014)). We provide tests to show that OLS is not preferred to 2SLS, that the instruments are not weak, that 2SLS is valid, and finally, to assess whether 3-stage least squares (ie 2SLS plus SUR) is preferred to 2SLS as an estimation procedure. We present results for either 2SLS or 3SLS, depending on what test results support.

We build two structural equations:[20] one for solvency risk and another for funding costs. For the exclusion restrictions we aim to use both bank-specific and global variables, to take into

[20] In both equations we also control for bank fixed effects and year fixed effects. Furthermore, we cluster standard errors at the bank level.

account the small open economy nature of the Korean economy. The equations defining our system are as follows:

Solvency

$$Solvency_{it} = \alpha + \beta_1 FundingCost_{it} + \beta_2 AMT_{it} + \beta_3 BroadDollar_t + \beta_4 NI_{it} + \beta_5 \Delta Regcap\_d_{it} + \beta_6 CreditGrowth_t + \alpha_i + year_t + \varepsilon_{it} \quad (3)$$

Funding Costs

$$FundingCost_{it} = \gamma + \delta_1 Solvency_{it} + \delta_2 VIX_t + \delta_3 SIRGAP_t + \delta_4 LiquidRisk_{it} + \delta_5 NI_{it} + \delta_6 \Delta Regcap\_d_{it} + \delta_7 CreditGrowth_t + \gamma_i + year_t + \nu_{it} \quad (4)$$

For the solvency equation, we take as exogenous variables: the amortisation ratio (AMT)[21], the broad dollar index ($BroadDollar$), the net income ratio (NI), real private domestic credit growth ($CreditGrowth$), and a dummy variable for excessive capital increase in each quarter to capture large swings in capital that may be explained by capital management in order to meet the regulatory requirements in the aftermath of the crisis ($\Delta Regcap\_d$).[22] The exclusion restrictions in the solvency equation operate through the amortisation ratio and the broad dollar index. A measure of asset quality has been used in order to identify solvency risk (Schmitz et al. (2017)), as such measure arguably directly affects the solvency position of a bank, with marginal funding costs being only indirectly affected through the impact on solvency risks. The broad dollar index has been identified as a global risk factor that reflects the shadow price of bank leverage (Shin (2016), Avdjiev et al. (2016), Avdjiev et al. (2018)). As such it can be expected to directly affect the solvency position of banks, while only affecting marginal funding costs indirectly.

The funding cost equation, in turn, includes the following exogenous variables: the VIX as a proxy for global risk aversion, a measure of the interest rate gap between the Korean and US economies ($SIRGAP$), a measure of liquidity risk ($LiquidRisk$), and as in the solvency equation, the net interest income (NI), domestic credit growth ($CreditGrowth$) and the dummy

[21] In order to have enough number of observations, we adopt the amortisation ratio as a proxy for asset quality instead of the loan loss provision ratio (LLP), since our data does not feature many of observations for the latter variable, which is usually used. Additionally, the LLP ratio is not without its shortcomings as a measure of asset quality (see BCBS (2015)).

[22] This may capture the deliberate management of capital for regulatory compliance, such as new issuance of share, asset sales, etc. Not controlling for such changes could potentially bias our results. This dummy indicator is equal to 1 if the change in regulatory capital in a given quarter is larger than 10%.

for capturing large changes in capital in any given quarter ($\Delta Regcap\_d$). Net income directly affects the solvency position of banks by allowing for recapitalisation to take place. However, it may also affect the need to raise external funding, which in equilbrium could also directly affect funding costs. For this reason, we include NI in both equations. Similarly, credit growth is included as a macroeconomic control to capture the effect of credit demand. In principle, one could expect this variable to directly affect solvency risk but only indirectly funding costs via its effect on the solvency position. However, if the supply of funding is not perfectly elastic, credit growth may also affect the funding cost. We thereby also include this variable in both equations. Finally, we also include the dummy $\Delta Regcap\_d$ in both equations as large increases in capital as captured by the variable directly affect the solvency position, but may also influence marginal funding costs by sending a positive signal to the market.

The exclusion restrictions in the funding cost equation work through the $SIRGAP$, VIX and $LiquidRisk$ variables. When the rate gap between domestic and foreign interest rates widens, banks may gravitate towards the lower funding cost alternative, which may translate into substitution between domestic and foreign currency borrowings. For this reason, we adopt the short-term interest rate gap ($SIRGAP$) between the call rate and the shadow rate of the U.S.[23] We adopt the most well-established of such shadow rate measures, namely that proposed by Wu and Xia (2016). When nominal interest rates hit the zero lower bound, the shadow rate can sink deeper into negative territory. This does not reflect of course an interest rate at which a bank can fund itself, but it rather intends to reflect the accommodative stance of monetary policy when policy rates lose their informational value after hitting the zero lower bound. On this account, decreases in foreign (shadow) rates will widen the gap, with an a priori uncertain effect on funding costs. Our working assumption is that the interest rate gap affects directly and contemporaneously marginal funding costs, and only indirectly affect bank solvency. As discussed earlier, we also include a measure of global risk aversion, captured by the VIX index.[24] Higher volatility (i.e. a higher VIX) could in principle be also interpreted as a signal of a downturn in economic activity or a general increase in the risk of borrowers, which

[23]We take the interest rate gap instead of the policy rate of the central bank, since for a small open economy such as Korea, global developments are more likely to have a larger influence.

[24]For the Korean economy the $VKOSPI$ (implied volatility of the $KOSPI$ 200 index) is available since the third quarter of 2005. However, we adopt the VIX (the CBOE implied volatility index) as a global risk aversion indicator as the correlation between $VKOSPI$ and VIX is 0.76 for the overlapping sample. Considering a global market index is also better aligned with our approach of emphasising the small and open nature of the Korean economy. In Table A.5 we present the pairwise correlations of the main variables used in the paper.

could affect the Tier 1 ratio via changes in the riskiness of the portfolio. We argue, however, that these represent rather indirect effects that materialise with time (and are reflected in the simulatenous equation framework via the marginal funding costs), whereas the effect of rising global risk aversion on the marginal cost of funding is more direct and immediate. Finally, we also control for liquidity risk by including a measure of non-core liabilities over core liabilities, following Hahm et al. (2013). Assuming that a significant share of non-core liabilities are of short term maturity (unfortunately we have limited information on the maturity structure of liabilities), higher readings of this indicator are associated with increased roll-over risks, as the short-term debt becomes large relative to the liquidity risk-bearing capacity of the bank. Controlling for liquidity risk is important because it can also be a confounding factor driving the interaction between funding and solvency.[25]

As the interaction between solvency and funding costs is expected to be more sensitive after the financial crisis, Schmitz et al. (2017) also run the analysis explicitly considering the great financial crisis period. During this period and its aftermath, global interest rates remained low for long and banks recapitalized in compliance with stronger prudential regulations, while at the same time having incentives to search for yield. Markets also required stronger solvency conditions for funding, relative to the pre-crisis period. In our benchmark model the effect of the crisis is arguably already captured by the variable VIX. As a robustness check we consider an indicator variable for the periods of interest rate increases ($\mathbb{1}_{\{\Delta callrate>0\}}$) and reductions ($\mathbb{1}_{\{\Delta callrate<0\}}$). $\mathbb{1}_{\{\Delta callrate>0\}}$ is equal to 1 if $\Delta callrate_t > 0$ and zero otherwise. Similarly $\mathbb{1}_{\{\Delta callrate<0\}}$ is 1 if $\Delta callrate_t < 0$ and zero otherwise.

In extensions, we also dig deeper into certain aspects of business models and non-linearities, as well as the effect of FX-related macroprudential policies on the strength of the link between solvency and funding costs. All these extensions build on the SEM model just described. While the exclusion restrictions we assume are naturally not beyond dispute, we provide tests results to back up our choices.

[25]While it can be argued that funding costs may affect in turn non-core liabilities, we posit that changes in the liquidity position of a bank as captured by our $LiquidRisk$ measure (a stock indicator) are more likely to affect the marginal cost of funding contemporaneously than the other way around, as changes in the marginal cost of funding will take some time to be reflected in changes in the non-core liabilities ratio. The results we present below are virtually identical if we use the lag of the liquidity risk variable, and are available upon request.

5. Benchmark results

Table C.7 reports the results of the 2SLS and 3SLS simultaneous equations model approach to estimating Equation 3 and Equation 4.[26] Results are presented both for accounting-based (benchmark with regulatory capital ratio) and market-based (robustness with EDF) solvency measures and marginal funding costs. The estimation approach consists of either two or three stages. The first stage is the regression for solvency and marginal funding costs with all exogenous variables in the system. The second stage regression adopts the predicted dependent variable from the first stage as explanatory variable. As a third stage, we run a SUR approach for both equations. The Breusch-Pagan test of independence shows whether the residuals from the two equations are independent. In our model, 2SLS is preferred for the case of accounting-based measure of solvency, while 3SLS is preferred when using the market-based measure. The table presents the results for the two models accordingly.

The first group of two columns (accounting-based model) shows a consistent negative association between solvency and marginal funding cost, as expected. A 100 bp increase in marginal funding costs is associated with a 155 bp reduction in the regulatory capital ratio, while a 100 bp increase in the regulatory capital ratio is associated with a 77 bp decrease in marginal funding costs. These numbers are not only statistically significant, but also relevant in economic terms. Furthermore, the effects are significantly larger than in the extant literature, which presents mostly a cross-country perspective.

For the market-based model, it is important to bear in mind that a positive coefficient is expected for our main variables of interest: larger marginal funding costs lead to higher EDF, which represents larger solvency risk, and a higher EDF translates into increased marginal funding costs. Note also that the coefficients are not directly comparable to the benchmark model. When we replace the accounting-based solvency measure with a market-based measure we therefore still observe that solvency and funding costs are negatively associated. For the most part, the sign of control variables is line with expectations and consistent between the models (ie the signs revert), though statistical significance varies.

To verify the choice of empirical model, we conducted several tests, reported in Table C.8.

[26] As mentioned earlier, an OLS panel fixed effects estimation of Equation 3 and Equation 4 delivers counter-intuitive results, as in Schmitz et al. (2017). As our tests indicate that OLS is not preferred to 2SLS/3SLS, we leave the former results out of the paper as they are uninteresting, given their bias and wrong sign. They are however available upon request from the authors.

First, we test whether the OLS estimation has endogeneity problems in the regressors by means of a Durbin-Wu-Hausman test. If either one of the equations shows OLS is not preferred to 2SLS, it is recommended to perform 2SLS for both equations. The test statistic rejects the null hypothesis that OLS is valid for the accounting-based as well as for the market-based model. Basing the assessment of the interaction between solvency and funding costs on OLS estimations is therefore misleading. Second, the tests of weakness of instruments show that instruments are relevant and not weak (with exception of the funding cost equation in the market-based model). Test results also support 2SLS as being a valid approach.[27] Finally the Breusch-Pagan test of independence does not reject the null hypothesis of independence of the two equations and thus the residuals of the two equations are not empirically correlated (i.e. 2SLS is preferred to 3SLS with SUR) in the accounting-based measure of solvency, while it is the opposite in the market-based measure of solvency. Taken together, the test results show that an OLS estimation is dominated by other estimation approaches that explicitly take into account the fact that solvency risk and funding costs are jointly determined and endogenous.

Having established that funding costs (as captured by MFC) and solvency risk (as captured by both the Tier 1 regulatory capital ratio and the EDF) are jointly determined and negatively affect each other, we now turn to show the performance of the most commonly used balance-sheet-based measure of funding costs, namely average funding costs (Aymanns et al. (2016)). We compute average interest rates as interest expense over interest bearing liabilities. This is based on balance sheet data and comes with the advantage of allowing for a larger sample along the time dimension. Table C.9 replicates the structure of our benchmark results (Table C.7) but with average interest rates instead of marginal funding costs. The table also directly includes, in the lower part, the test results to decide between 2SLS and 3SLS, with the former being preferred for the model with regulatory capital, and the latter being preferred for the model with EDF as a measure of solvency. For our benchmark model with an accounting-based measure of solvency risk, the effect of solvency risk on average funding costs is negative as expected, but smaller in magnitude and not statistically significant. The effect of average funding cost on solvency is, in turn, not only not statistically significant but also bears the wrong sign: increased funding costs lead to a sounder solvency position. When using the EDF as a measure of solvency risk, the results remain robust to using average funding costs instead of marginal funing costs. All

[27] As with the Durbin-Wu-Hausman test, we only need avoid rejection of the null hypothesis in at least one of the two equations in the system. In any case, test results for our benchmark model strongly suggest 2SLS to be a valid approach.

in all, using average funding costs as a way to capture the interplay between solvency risk and funding costs is an inferior alternative to using marginal funding costs, which better capture the real time evolution of the cost of funding for different banks.

6. Robustness

6.1. General versus regional banks

We now turn to a series of robustness checks to assess our benchmark results, beyond the robustness to using a market-based measure of solvency already discussed above. We start by discussing whether the main result obtained above is driven by one specific type of bank in the sample. In particular, our sample features general banks and regional banks. The former are characterised by a more global and countrywide business model, whereas the latter have a smaller scale of business, with more of a local economy focus. In Table C.10 and Table C.11 we present, respectively, the regression results for models considering the two types separately, and the tests of validity for the empirical models.[28] As regional banks all use the standardised approach to credit risk throughout our entire sample, this robustness check also serves the purposes of assuaging any concern that our results may be driven by the way in which banks calculate regulatory capital.

For general banks we observe that net income is positive and significant, implying that increased profitability is associated with a sounder position in terms of solvency. For regional banks we also observe that the discretionary regulatory capital dummy is significant. Most importantly, the interaction between solvency and funding costs is negative and significant for both types of banks. While the size of the coefficients somewhat differs (being stronger for regulatory capital and weaker for marginal funding costs for regional banks), they are broadly in line with the numbers reported for the benchmark model in Table C.7. The model tests also confirm that OLS is not appropriate as the main variables of interest are endogenous, and that 2SLS is preferred to 3SLS for both types of banks.

6.2. Interest rate increase versus decrease

Next, we explore whether being in a period of increasing or decreasing interest rates (ie in a different monetary policy regime) might affect the interaction. This is motivated by the recent

[28] To assess the results from the samples of regional and general banks on an equal footing, we standardised the variables by each subgroup distribution of independent and dependent variables. We thank an anonymous referee for pointing us in this direction.

period in which either a binding zero lower bound or low-for-long interest rate environment may have imposed a similarly lower level of funding costs regardless of bank solvency. In such a context, banks with a stronger solvency position as well as relatively weaker banks may borrow at relatively low and similar costs, without large cross-sectional differences. At the same time, it is possible to argue that the core result presented in the previous section might be driven by the period in which interest rates were massively cut in response to the crisis (thereby reducing funding costs across the board), while regulatory capital was sharply increased in the wake of the post-crisis regulatory push. While such an argument disregards the effect of cross-sectional heterogeneity, it is nonetheless worth exploring.

To address this concern, we interact the indicator variable for the period of interest rate increases ($\mathbb{1}_{\{\Delta callrate>0\}}$) and decreases ($\mathbb{1}_{\{\Delta callrate<0\}}$). Table C.12 and Table C.13 respectively report the results for the models and the test results for the model with interaction terms for the indicator variables. We find that the interaction of bank solvency and funding costs is still negative and significant, without substantial changes in magnitude, for both periods of rising and declining interest rates. Furthermore, for both sub-samples OLS is still an inappropriate estimation strategy, and 2SLS is preferred to 3SLS. Table C.12 shows that the interaction presents asymmetric effects. During the period of interest rate increases, the effect of marginal funding costs on solvency is stronger than in the period of interest rate reductions. This could indicate that during contractionary monetary policy periods, banks cannot afford to adjust their funding to meet improved solvency conditions, while during an expansionary monetary policy period close to the zero lower bound, banks can have more leeway in terms solvency as there is not much variation in funding costs across banks with different solvency positions.

Taken together, the benchmark results are also robust to partitioning the sample according to the pattern of monetary policy rate changes.

6.3. Interest margin management

As a third robustness check, we consider another potential argument against our benchmark results: banks may try to increase interest margins by charging higher interest rates for new credit while paying lower funding costs. This is particularly plausible in a environment characterised by historically low interest rates. Through such behavior banks may improve their capital position. Thus, following this argument the interaction between bank solvency and funding costs we documented earlier might be spurious. To address this issue we adopt a measure of the interest margin (IM) defined as the gap between interest rates for *new* credit and marginal funding costs (recall that the latter are defined as the weighted average rate paid for *new* funding). We interact the solvency (funding cost) term with IM in the funding cost (solvency) equation Table C.14 reports the results. To assess the overall effect of the interaction between solvency and funding costs when considering interest margin management, we report the linear combination term in every third row in brackets. First we note that the robustness check is passed: the interaction between solvency and funding costs is still negative and statistically significant across specifications. Furthermore, interest margin management serves to moderate the effect of solvency (funding costs) in the funding costs (solvency) equation. This moderation effect is in fact quite strong for regulatory capital in the funding cost equation.

7. Extensions

7.1. Extension 1: Effect of bank business models in terms of funding structure

We extend our analysis to shed light on the main drivers of the negative relationship between solvency and funding costs. The implicit assumption in this section is that the interaction between solvency and funding costs can be affected by the different (funding) business models of banks. We categorize different types of business models in terms of funding structure: retail funding, borrowing, wholesale and foreign currency borrowing (see Table A.1).

Furthermore, the effect might be non-linear (Aymanns et al. (2016), Dent et al. (2017)). We extend the analysis to address this dimension from the funding structure perspective by splitting the sample into quantiles. We categorize the share of each funding source into 3 quantiles.

Table C.15 reports the results of the SEM for different quantiles in terms of 1-period lags of retail funding. $Retail\_large$ is a dummy variable equal to 1 if the average retail funding share of a bank is in the largest among three quantiles and zero otherwise. $Retail\_mid$ is a dummy variable equal to 1 if the average retail funding share of a bank is in the mid-quantile and zero otherwise. The non-interacted solvency and marginal funding cost variables represent the case of the smallest quantile of retail funding share ($Retail\_small$). To assess the overall effect of each funding quantile on the interaction between solvency and funding costs, we report the linear combination term in every fourth and fifth rows in brackets.

Heterogeneity in terms of retail funding does not affect the interaction between solvency and funding costs in that the coefficients remain negative (positive for the model using EDF as a proxy for solvency risk). A relatively large reliance on this funding source increases the absolute value of the interaction between solvency and funding cost; the coefficients are however insignificant (as captured by the interactions between $Regcap/MFC$ and $Retail\_large$). When comparing the overall effect across quantiles, we observe that the coefficients are always negative (positive for the market-based model) and significant in the solvency equation, although insignificant in the funding cost equation using an accounting-based measure of solvency. Furthermore, their magnitudes do not differ substantially, with the exception of low retail funding in the model based on an accounting measure of solvency: when reliance on retail funding is on the lower quantiles, the effect of marginal funding costs on solvency are large and significant, whereas that of solvency on marginal funding costs are also relatively large though not statistically significant.

Table C.16 reports the results for different quantiles in terms of wholesale funding. The overall coefficients of the regulatory capital ratio, EDF, or marginal funding costs are also significant and in line with the benchmark, with the exception that for banks with relatively low reliance on wholesale funding, the effect of solvency on funding costs seems to be muted, especially in the accounting-based model. As a counterpart to the results on retail funding, more heavy reliance on wholesale funding seems to be associated with a stronger effect of marginal funding costs on solvency risk. Thus, the negative relationship between solvency and funding costs still holds regardless of the wholesale funding share.

Table C.17 reports the results for borrowings, which includes wholesale funding and other borrowings. When considering the overall effect of each quantile, we observe as before that all are statistically significant and the coefficients do not vary much. The core results remain roughly unchanged and do not seem to be accounted for by any specific group of banks. Furthermore, we do not observe any non-linear effects.

Finally, Table C.18 describes the results of the SEM estimations for the three quantiles in terms of foreign currency borrowing share. In the funding cost equation the overall effect of regulatory capital (as well as the EDF) is considerably stronger in the small quantile. Furthermore, for banks in the mid and upper parts of the distribution in terms of foreign currency borrowing share, the negative (positive) effect of regulatory capital (EDF) on marginal funding costs is significantly moderated. When banks have more access to foreign currency borrowings, they seem to be better able to mitigate the intensity of solvency and funding cost interactions, mostly through the effect of solvency on funding costs.

7.2. Extension 2: Effect of FX-related macroprudential policy

In the analysis above, we find a negative association between solvency and funding costs. For the category of "foreign currency borrowings" in particular, there are relevant policy developments during our sample period which might affect the strength of the interaction. In particular, since 2010 the Korean government adopted several FX-related macroprudential measures to stabilize foreign currency funding. In Table A.6 we summarize the different measures, borrowing from Kim and Lee (2017).

Three main measures were implemented. The leverage cap, specified in percent of equity capital, is imposed on FX derivatives positions in order to limit banks' FX derivatives at or below a targeted level. The macroprudential stability levy revolves around putting an extra cost for holding non-core FX liabilities.[29] The third measure is an interest income tax on foreign bond investors.

Kim and Lee (2017) and Choi (2014) find that these measures where broadly successful in reducing short-term capital inflows, with a much smaller or nearly non-existent reduction in long term capital flows (see also Figure B.6, which shows how the FX borrowing share is reduced following the implementation of the measures). We want to address this issue in this extension, by including dummies for the respective dates in which the measures were binding.

Table C.19, Table C.20, and Table C.21 report the comparison of results with FX-related macroprudential policies by interacting the dummy variables for leverage cap, stability levy, and interest income tax, respectively.[30] Columns (1), (2), and (3) contain three different quantiles of the foreign currency borrowing share (large, mid, small).

We start by discussing the effect of the leverage cap, presented in Table C.19. In the first row, which features the non-interacted endogenous variables (thereby capturing the effect when the leverage cap does not bind), we observe that for both large and small shares of foreign currency borrowing, the effect of solvency on funding costs, and viceversa, is significant. As the interaction terms show, the leverage cap dummy seems to mitigate the interaction for those banks in the small quantile of foreign currency borrowing. For banks with a relatively large reliance on foreign currency borrowing, the overall effect of marginal funding cost on solvency loses statistical power after the introduction of the leverage cap; the economic significance as measured by the size of the coefficient, however, remains high (first column). For those banks that do not heavily rely on foreign currency borrowing in relative terms, the introduction of the leverage cap significantly mitigates the effect of solvency on funding costs, i.e. the interaction between *Regcap* and *Levcap* in the funding cost equation is positive and significant, and the overall effect computed in brackets is considerably smaller than the -0.435 reported for the

[29] For more discussion, we refer the reader to Choi (2014).

[30] As these measures are FX-related, the focus of the tables in terms of funding share is on foreign currency borrowing.

non-interacted variable (last column).

Table C.20 shows results for the stability levy. For banks that rely more strongly on foreign currency borrowing, this policy does not seem to be effective in cutting the link from solvency to funding costs, and if anything it makes it even stronger. That said, for the same group of banks, the policy does cut the effect of marginal funding costs on solvency, which becomes insignificant. This is actually a desirable outcome, as the two-way feedback loop between solvency risk and funding costs is muted, while preserving the effect of market discipline, ie banks with a more compromised situation in terms of solvency face higher marginal funding costs. For banks in the lower part of the distribution in terms of foreign currency borrwing share, the stability levy does seem to affect the channel going from solvency risk to marginal funding costs. This group is admittedly, however, not the main target of the policy.

Finally, Table C.21 reports the results for the interest income tax on foreign bond investors. Overall, this regulatory tool yields relatively strong mitigation effects across the different quantiles (especially the upper ones), in particular when it comes to the effect of marginal funding costs on solvency. The effect of solvency on marginal funding costs is only insignificantly affected for those banks with mid or a relatively small foreign currency borrowing share.

The macroprudential measures are aimed at curbing borrowing from abroad by incentivising banks to substitute foreign funding for domestic funding. As the latter is more costly than the former, funding costs will tend to rise for the same level of regulatory capital. This may in turn lead to less borrowing in the domestic market, potentially also forcing banks to raise capital in a scenario of rising funding costs.

Taken together, the different FX-related macroprudential policies seem to be effective in mitigating the negative feedback loop between solvency risk and marginal funding costs. They do so by muting the effect that marginal funding costs have on solvency, in particular for those banks that rely more heavily, in relative terms, on foreign currency borrowing. These effects are stronger for the stability levy and the interest income tax. The effect of solvency on marginal funding costs remains strong and significant for those banks with a relatively large share of foreign currency borrowing. This is in principle desirable, as the different policies do not seem to undermine market discipline. However, by disincentivising such large shares, FX-related macroprudential policies can also be effective in mitigating that channel too.

8. Conclusion

With the rising prominence of stress tests in recent years, increased attention is being paid to the interaction between bank solvency risks and funding costs. Using confidential data for the Korean banking system, we have presented evidence that such interactions are present and important for a small and open economy such as Korea. Indeed, the effects are considerably stronger than in the extant literature, which focuses on aggregate cross-country studies and, most importantly, does not use a true measure of marginal funding costs. Increased solvency risk is associated with higher marginal funding costs (ie market discipline); rising funding costs, in turn, are linked to reduced regulatory capital ratios and thereby to increased solvency risk. In our benchmark regressions, a 100 bp increase in marginal funding costs (regulatory capital) is associated with a 155 bp (77bp) decrease in regulatory capital (marginal funding costs). Ignoring such feedback effects when designing shock scenarios for stress-testing purposes can lead to a substantial underestimation of risks and thereby to an overestimation of the resilience of specific institutions and maybe even the system at large. We document how system estimation techniques (either 2SLS or 3SLS) are preferred to OLS, and therefore underscore the need to explicitly take into account the endogenous nature of solvency risk and funding costs.

Our main findings survive the following robustness checks: considering "market-based" (as opposed to "balance-sheet-based") measures of solvency, distinguishing between different types of banks (general and regional), accounting for different interest rate regimes, and controlling for the interest margin management of banks. Furthermore, we show how using other commonly used measures for the changes in the cost of funding such as average funding costs can lead to erroneous conclusions regarding the interaction between solvency risk and funding costs.

Given the granularity of the data, we investigate the interaction for different subgroups in terms of their funding structure. This extension also serves as a robustness check of sorts, because we show in the process that our main results hold across the whole spectrum of the distribution.

As a second extension, we investigate the effect that different FX-related macroprudential policies implemented in Korea in recent years have had in terms of moderating the interaction between solvency risk and funding costs. The evidence suggests that these measures, especially the stability levy and the interest income tax on foreign bond holders, were effective in breaking the negative feedback loop by muting the effect that marginal funding costs have on solvency. By keeping the effect of solvency on funding costs largely unaffected, these policies are effective in mitigating the two-way feedback loop between solvency risk and funding costs while still preserving the desirable effects of market discipline.

Beyond feeding into the calibration of macroprudential stress tests, the findings in this paper can also be used for business-model-based monitoring of banks, as well as to assist regulatory authorities and policy makers in the evaluation of the effectiveness of FX-related macroprudential policies from an alternative angle that goes beyond the direct effect on cross-border banking flows.

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Appendix A. Descriptive tables

Table A.1: Interest expense by funding sources

Retail	interest on deposits in won
	interest on negotiable certificates of deposit
	interest on deposits in foreign currency
	interest on off-shore deposits in foreign currency
	interest on due to BOK in foreign currency
	interest on deposits in gold banking
Borrowings	interest on borrowings in won
	interest on borrowings in foreign currency
	interest on off-shore borrowings in foreign currency
	interest on borrowings in gold banking
(Wholesale)	interest on call money(Call)
	interest on bonds sold under resale agreements(Repo)
Bonds payable	discount fees on bills sold
	interest on finance debentures issued
	interest on off-shore finance debentures issued
Other	interest paid on foreign transactions
	interest paid on others in won
	interest on borrowings from trust accounts
	interest on credit card receivables sold to trust accounts
	interest paid on inter-office accounts in foreign currency
	interest paid on off-shore inter-office accounts in foreign currency
	interest paid on share capital repayable on demand

Table A.2: Variable definitions and sources

Variable	Definition	Source
Solvency		
Regcap	Tier 1 capital divided by risk weighted assets	FAIRS, The Bank of Korea
EDF	Expected default frequency	Korean Risk Management Corporation
Funding costs		
MFC	Weighted average of marginal funding costs for new funding sources, per quarter	The Bank of Korea
Avg_ir	Interest expense for interest bearing liabilities divided by interest bearing liabilities	FAIRS, The Bank of Korea
Avg_ir_retail	Interest expense on depository liabilities divided by depository liabilities	FAIRS, The Bank of Korea
Avg_ir_wholesale	Interest expense on call money and RP divided by call money and RP	FAIRS, The Bank of Korea
Avg_ir_borrowings	Interest expense on borrowings divided by borrowings	FAIRS, The Bank of Korea
Avg_ir_fcbrw	Interest expense on foreign currency borrowings divided by foreign currency borrowings	FAIRS, The Bank of Korea
Avg_ir_bonds	Interest expense on bonds divided by bonds	FAIRS, The Bank of Korea
Bank characteristics		
AMT	Amortization of credit losses	FAIRS, The Bank of Korea
NI	Net income divided by total assets	FAIRS, The Bank of Korea
Δ*Regcap_d*	Dummy variable equal to 1 if the quarterly change in the Tier 1 regulatory capital ratio is larger than 10%	FAIRS, The Bank of Korea, Author's calculation
LiquidRisk	Non-core liabilities divided by core liabilities	The Bank of Korea, Author's calculation
IM	Interest margin between new credit interest rate over new funding costs	The Bank of Korea, Author's calculation
Domestic macro variables		
CreditGrowth	Quarterly growth (year on year) of credit to private non-financial sector from all sectors in Korea	BIS, Authors' calculation
Global variables		
VIX	Natural logarithm of quarterly VIX (implied volatility index)	The CBOE
SIRGAP	Short term interest rate gap between call rate and U.S. effective federal funds rate augmented by shadow rate developed by Wu and Xia (2016)	ECOS, The Bank of Korea, FRB
BroadDollar	Trade weighted US dollar index: Broad	FRED, St. Louis Fed

Table A.3: Bank funding structure

This table presents banks' average funding structure in the sample, which is available for the 2000Q1-2015Q2 period. All variables are in percentage and based on quarterly data. Source: FAIRS data from the Bank of Korea.

Funding source	**Subclass**	**Mean**	**Median**	**SD**
I. Retail		72.32	72.83	8.09
	I.a. Deposits in won	64.64	65.99	11.95
	I.b. Negotiable certificates of deposit	5.08	3.85	4.95
	I.c. Deposits in foreign currency	2.59	1.23	3.63
	I.d. Off-shore deposits in foreign currency	0.004	0.00	0.02
	I.e. Due to BOK in foreign currency	0.18	0.00	0.71
	I.f. Deposits in gold banking	0.01	0.00	0.04
II. Borrowings		10.98	10.35	4.89
	II.a. Borrowings in won	3.67	3.11	2.18
	(from BOK)	1.09	0.96	0.76
	(from Government)	0.45	0.42	0.34
	(from Banking Institutions)	0.18	0.04	0.35
	(from Non-Banking Financial Institutions)	0.10	0.00	0.22
	II.b. Borrowings in foreign currency	3.61	3.44	2.08
	II.c. Off-shore borrowings in foreign currency	0.12	0.03	0.22
	II.d. Call money (Call)	1.08	0.67	1.43
	II.e. Bonds sold under resale agreements (Repos)	2.08	1.25	2.32
III. Bonds payable		7.60	7.00	4.05
	III.a. Finance debentures	7.58	6.99	4.04
	(III.aa. issued in Won)	6.94	6.29	3.55
	(III.ab. issued in Foreign Currency)	0.95	0.76	0.98
	[Domestic]	0.001	0.00	0.01
	[Overseas]	0.95	0.76	0.98
	III.b. Bills sold	0.24	0.07	0.43
	III.c. Off-shore finance debentures issued	0.03	0.00	0.10
(Wholesale)	II.d+II.e	3.15	2.45	2.68
(Foreign currency borrowings)	II.b+II.c.+III.ab.	4.68	4.70	2.59
(Offshore borrowings)	II.c.+III.c.	0.15	0.004	0.26
Interest bearing liabilities		90.90	92.36	5.15
Total liabilities		100.00	100.00	

Table A.4: Summary Statistics

This table presents summary statistics, reporting variable names, means, medians, standard deviations, 5% and 95% percentiles, and the number of observations for which data is available for the sample period 2000Q1-2015Q2 period. All variables are based on quarterly data. Sources: see **??**.

Variable Group and Name	**Unit**	**Mean**	**Median**	**SD**	**5%**	**95%**	N
Solvency							
Regcap	%	12.36	12.09	1.96	9.63	16.05	776
EDF		0.07	0.02	0.15	0.00	0.34	799
Funding Costs							
MFC	%	3.68	3.58	1.02	2.17	5.66	604
Avg_ir	%	0.53	0.44	0.35	0.12	1.27	492
Avg_ir_retail	%	0.04	0.01	0.08	0.00	0.22	502
Avg_ir_wholesale	%	3.48	2.45	4.73	0.55	8.40	747
Avg_ir_borrowings	%	1.67	1.47	1.03	0.41	3.85	509
Avg_ir_fcbrw	%	1.67	1.22	1.49	0.18	4.74	726
Avg_ir_bonds	%	3.55	3.32	1.94	1.16	7.36	736
Bank Characteristics							
AMT	%	0.61	0.41	0.64	0.06	1.92	777
NI	%	0.38	0.34	0.39	-0.03	0.98	775
Δ*Regcap_d*	%	0.04	0.00	0.20	0.00	0.00	1,080
LiquidRisk	%	39.95	37.32	16.00	16.79	68.79	777
IM	%	2.11	2.06	0.53	1.31	3.06	604
Domestic Macro Variables							
CreditGrowth	%	7.93	7.06	4.07	2.23	15.16	1,081
Global Variables							
VIX	logarithm	2.97	2.97	0.33	2.50	3.50	1,081
$SIRGAP$	%	2.12	2.40	1.95	-0.92	4.65	1,081
BroadDollar		108.61	107.25	9.57	95.77	127.04	1,010

Table A.5: Pairwise correlations between variables

This table reports the results of the pairwise correlations between variables for the 2000Q1-2015Q2 period. $Regcap$ refers to the Tier 1 capital divided by risk weighted assets. EDF refers to the market-based expected default frequency. MFC refers to weighted average of marginal funding costs. AFC refers to average funding costs. AMT is the amortisation of credit losses ratio; NI is the net income ratio; $\Delta Regcap\_d$ is a dummy variable equal to 1 if a quarterly change in regulatory capital is larger than 10% and zero otherwise; $LiquidRisk$ is non-core liabilities divided by core liabilities; IM is interest margin between interest rates of new credits and new marginal funding costs; $CreditGrowth$ is domestic private credit growth; VIX is the logarithm of the implied volatility index; $SIRGAP$ is the short-term interest rate gap between overnight call rate and the U.S. shadow rate for effective federal funds rate; $BroadDollar$ is broad trade-weighted US dollar index. Significance level is indicated by $^{*}p < 0.01$.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
(1) $Regcap$	1												
(2) EDF	−0.07	1											
(3) MFC	−0.35*	0.17*	1										
(4) AFC	−0.07	0.20*	0.50*	1									
(5) AMT	−0.30*	0.11*	−0.14*	0.32*	1								
(6) NI	0.33*	−0.11*	0.27*	0.54*	−0.40*	1							
(7) $\Delta Regcap\_d$	0.04	0.17*	0.12*	0.05	0.17*	−0.03	1						
(8) $LiquidRisk$	0.16*	0.09	0.42*	0.46*	−0.02	0.09	0.06	1					
(9) IM	0.24*	0.08	−0.351*	−0.25*	0.25*	−0.18*	0.04	−0.27*	1				
(10) $CreditGrowth$	−0.03	0.21*	0.81*	0.36*	−0.10*	0.15*	0.11*	0.23*	−0.27*	1			
(11) VIX	−0.04	0.35*	0.26*	0.22*	0.20*	−0.13*	0.16*	0.19*	0.21*	0.39*	1		
(12) $SIRGAP$	0.35*	0.03	−0.49*	−0.28*	−0.12*	0.05	−0.08*	−0.26*	0.16*	−0.09*	0.07	1	
(13) $BroadDollar$	−0.48*	0.12*	−0.20*	−0.04	0.39*	−0.18*	0.10*	−0.08	−0.07	0.09*	0.15*	−0.33*	1

Table A.6: FX-related Macroprudential Policies

This table lists the FX-related macroprudential policies adopted in Korea after the GFC. It is reproduced from the work of Kim and Lee (2017) and used for the extension of our analysis. Sources are the Ministry of Strategy and Finance, the Bank of Korea, and the Financial Services Commission.

Date	Policy Content	Category
2010:06	Introducing New Macropudential Measures	Announcement
2010:07	Regulations on Foreign Currency Loan Use	Effective
2010:10	New Ceilings on FX Forward Positions	Effective
2010:11	Interest Income Taxes for Foreign Bond Investors	Announcement
2010:12	Macroprudential Stability Levy	Announcement
2011:01	Interest Income Taxes for Foreign Bond Investors	Effective
2011:04	Macroprudential Stability Levy	Announcement
2011:05	Tightening Caps on FX Forward Position	Announcement
2011:07	Tightening Caps on FX Forward Position	Effective
2011:08	Macroprudential Stability Levy	Effective
2012:11	Tightening Caps on FX Forward Position	Announcement
2013:01	Tightening Caps on FX Forward Position	Effective

Appendix B. Figures

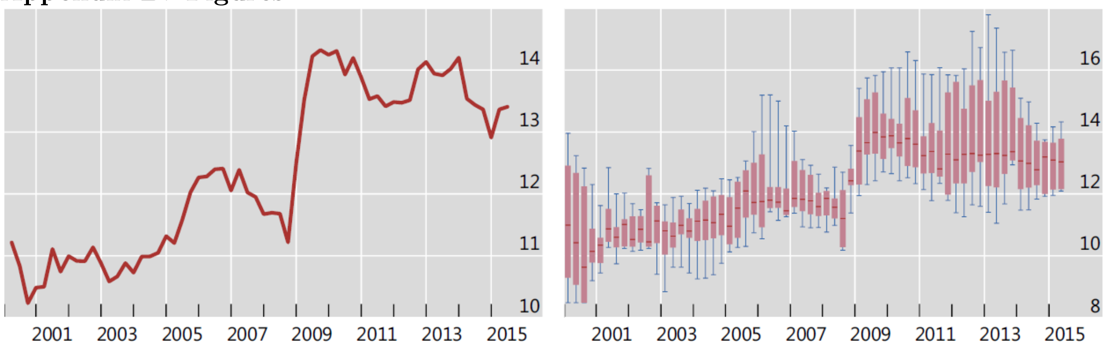

Figure B.2: Regulatory capital ratio (left: average; right: cross-sectional)

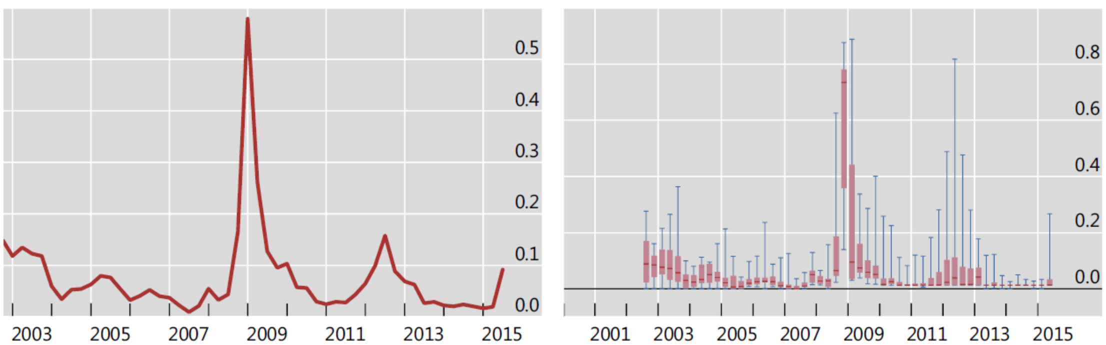

Figure B.3: Expected default frequency (left: average; right: cross-sectional)

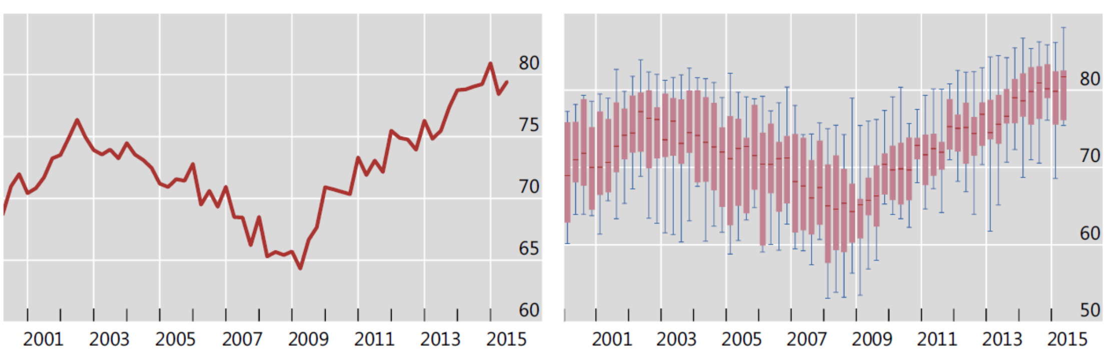

Figure B.4: Retail funding share (left: average; right: cross-sectional)

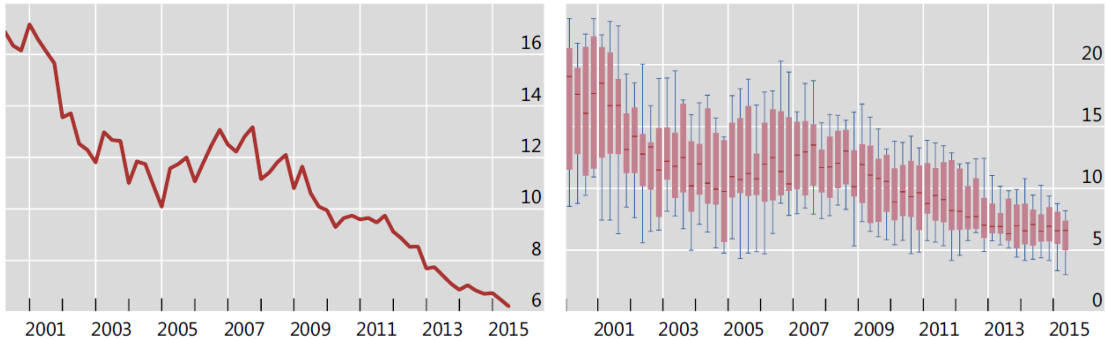

Figure B.5: Borrowings share (left: average; right: cross-sectional)

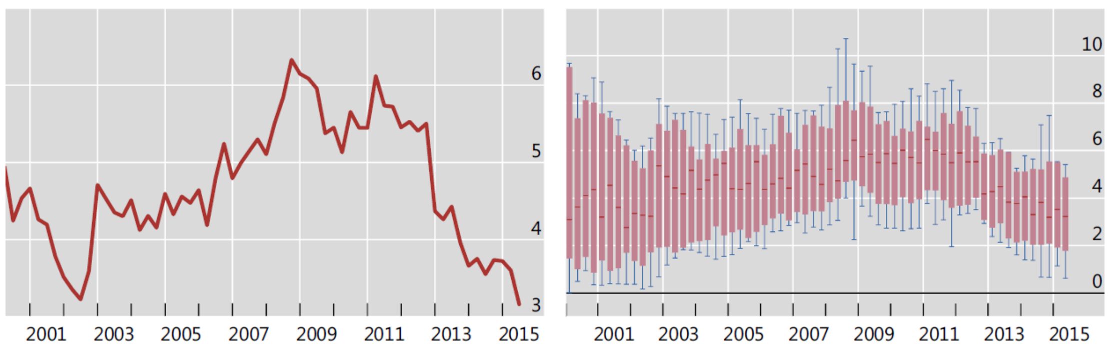

Figure B.6: Foreign currency borrowings share (left: average; right: cross-sectional)

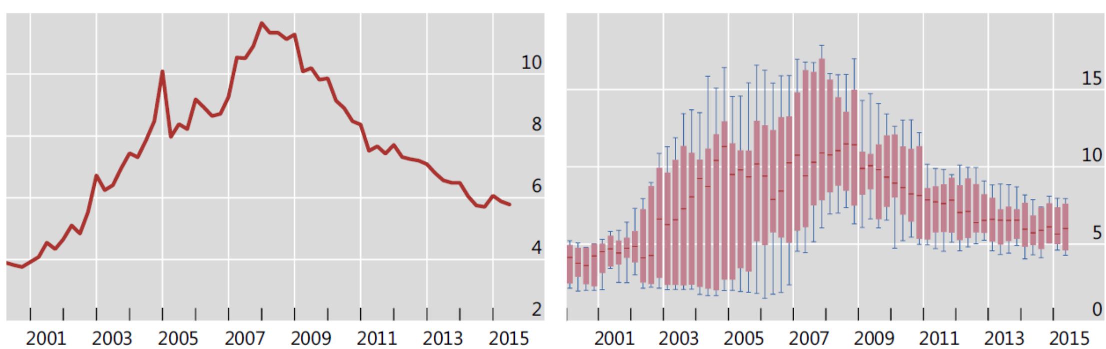

Figure B.7: Bond share (left: average; right: cross-sectional)

Appendix C. Regression tables

Table C.7: SEM results of bank solvency and marginal funding costs

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to Tier 1 regulatory capital divided by risk weighted assets. *EDF* refers to the market-based expected default frequency. *MFC* refers to the weighted average of marginal funding costs. *AMT* is the amortisation of credit losses ratio; *NI* is the net income ratio; $\Delta Regcap\_d$ is a dummy variable equal to 1 if the quarterly change in regulatory capital is larger than 10% and zero otherwise; *LiquidRisk* is non-core liabilities divided by core liabilities; *CreditGrowth* is domestic private credit growth; *VIX* is the logarithm of the implied volatility index; *SIRGAP* is the short-term interest rate gap between overnight call rate and the U.S. shadow rate; *BroadDollar* is the broad trade-weighted US dollar index (broad). Standerd errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	Accounting-based		**Market-based**	
	Regcap	*MFC*	*EDF*	*MFC*
Endogenous variables				
Regcap		-0.773^{***}		
		(0.204)		
EDF				0.387^{***}
				(0.085)
MFC	-1.550^{***}		0.205^{***}	
	(0.399)		(0.021)	
Exogenous variables				
Bank specific				
AMT	-0.207		0.082^{***}	
	(0.353)		(0.021)	
NI	1.126^{***}	0.848^{**}	-0.015	-0.001
	(0.378)	(0.345)	(0.021)	(0.041)
$\Delta Regcap\_d$	0.995^{***}	0.729^{***}	-0.008	0.015
	(0.166)	(0.204)	(0.023)	(0.044)
LiquidRisk		0.020^{*}		0.001
		(0.011)		(0.001)
Domestic				
CreditGrowth	0.004	-0.019	-0.014^{***}	0.060^{***}
	(0.038)	(0.035)	(0.005)	(0.010)
Global				
VIX		-0.166		0.078
		(0.209)		(0.062)
SIRGAP		0.002		0.177^{***}
		(0.108)		(0.029)
BroadDollar	-0.011		0.023^{***}	
	(0.025)		(0.003)	
Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
No. Obs.	524	524	518	518
No. Banks	15	15	14	14

Table C.8: Test Results for SEM

This table reports the test results for SEM. The Durbin-Wu-Hausman test is the regression based test of exogeneity of regressors. The weak instrument test is based on a Wald F statistic. The exogeneity of instrument test refers to the Hansen J statistic of overidentification test of instruments. If the null hypothesis is not rejected for at least one equation in the system, it supports the 2SLS as a system of IV estimation. The Breusch-Pagan test of independence reports whether the residuals of both equations are correlated. In case of rejecting the null of independence, it is recommended to adopt the 3SLS estimation.

	Accounting-based		**Market-based**	
	Regcap	*MFC*	*EDF*	*MFC*
OLS vs. 2SLS				
Durbin-Wu-Hausman test				
(H0: Specific regressors are exogenous and OLS is preferred to 2SLS)				
F-Statistic	15.65	160.48	25.70	218.87
p-value	(0.001)	(0.000)	(0.000)	(0.000)
2SLS				
Weak instrument test				
(H0: Instruments are weak)				
F-Statistic	131.22	17.80	131.22	1.95
p-value	(0.000)	(0.000)	(0.000)	(0.181)
Exogeneity of instrument test				
(H0: 2SLS is valid)				
J-Statistic	3.932	0.014	5.601	0.562
p-value	(0.140)	(0.906)	(0.061)	(0.454)
2SLS vs. 3SLS				
Breusch-Pagan test of independence				
(H0: 2SLS is preferred to 3SLS)				
χ^2	0.093		10.197	
$P - value$	0.760		0.001	

Table C.9: SEM results with average funding costs

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. *EDF* refers to the market-based expected default frequency. *AFC* refers to average interest rates which is defined as the interest expense over interest bearing liabilities. *AMT* is amortisation of credit losses ratio; *NI* is the net income ratio; $\Delta Regcap\_d$ is dummy variable equal to 1 if a quarterly change in regulatory capital is larger than 10% and zero otherwise; *LiquidRisk* is non-core liabilities divided by core liabilities; *CreditGrowth* is domestic private credit growth; *VIX* is the logarithm of the implied volatility index; *SIRGAP* is the short-term interest rate gap between the overnight call rate and the U.S. shadow rate for effective federal funds rate; *BroadDollar* is the broad trade-weighted US dollar index. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	Accounting-based		**Market-based**	
	Regcap	*AFC*	*EDF*	*AFC*
Endogenous variables				
Regcap		−0.913		
		(0.584)		
EDF				1.358***
				(0.359)
AFC	1.074		0.526***	
	(0.748)		(0.073)	
Exogenous variables				
Bank specific				
AMT	−0.954**		−0.162***	
	(0.375)		(0.059)	
NI	0.310	1.325***	−0.297***	0.728***
	(0.586)	(0.334)	(0.048)	(0.067)
$\Delta Regcap\_d$	0.671***	0.713	0.015	−0.111**
	(0.167)	(0.443)	(0.037)	(0.052)
LiquidRisk		0.021*		0.001
		(0.012)		(0.002)
Domestic				
CreditGrowth	0.021	0.076	−0.008	−0.019
	(0.046)	(0.068)	(0.009)	(0.012)
Global				
VIX		−0.531		−0.092
		(0.518)		(0.102)
SIRGAP		0.413		0.053*
		(0.269)		(0.032)
BroadDollar	0.019		0.026***	
	(0.025)		(0.004)	
Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
No. Obs.	491	491	481	481
No. Banks	15	15	14	14
Breusch-Pagan test of independence				
χ_2	2.252		27.398	
$P - value$	0.134		0.000	

Table C.10: Robustenss test of SEM of bank solvency and marginal funding costs for general and regional banks with accounting-based solvency

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. MFC refers to weighted average of marginal funding costs. AMT is amortisation of credit losses ratio; NI is the net income ratio; $\Delta Regcap\_d$ is dummy variable equal to 1 if a quarterly change in regulatory capital is larger than 10% and zero otherwise; *LiquidRisk* is non-core liabilities divided by core liabilities; *CreditGrowth* is domestic private credit growth; VIX is the logarithm of the implied volatility index; $SIRGAP$ is the short-term interest rate gap between overnight call rate and the U.S. shadow rate for effective federal funds rate; *BroadDollar* is the broad trade-weighted US dollar index. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	General banks		**Regional banks**	
	Regcap	MFC	*Regcap*	MFC
Endogenous variables				
Regcap		-1.051^{**}		-1.613^{***}
		(0.512)		(0.270)
MFC	-0.995^{***}		-0.383^{*}	
	(0.226)		(0.196)	
Exogenous variables				
Bank specific				
AMT	0.063		0.030	
	(0.133)		(0.106)	
NI	0.207^{***}	0.238^{*}	0.074	0.063
	(0.074)	(0.142)	(0.095)	(0.111)
$\Delta Regcap\_d$	0.079^{***}	0.075	0.099^{***}	0.164^{***}
	(0.019)	(0.051)	(0.010)	(0.037)
LiquidRisk		−0.036		0.239^{**}
		(0.132)		(0.096)
Domestic				
CreditGrowth	0.008	−0.077	−0.023	0.134^{**}
	(0.116)	(0.247)	(0.098)	(0.062)
Global				
VIX		0.019		−0.012
		(0.067)		(0.058)
$SIRGAP$		−0.105		0.414^{***}
		(0.327)		(0.153)
BroadDollar	−0.119		−0.004	
	(0.180)		(0.093)	
Bank FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. Obs.	280	280	244	244
No. Banks	9	9	6	6

Table C.11: Robustness test results of SEM for general and regional banks with accounting-based solvency

The Durbin-Wu-Hausman test is the regression based test of exogeneity of regressors. The weak instrument test is based on a Wald F statistic. The exogeneity of instrument test refers to the Hansen J statistic of overidentification test of instruments. If the null hypothesis is not rejected for at least one equation in the system, it supports the 2SLS as a system of IV estimation. The Breusch-Pagan test of independence reports whether the residuals of both equations are correlated. In case of rejecting the null of independence, it is recommended to adopt the 3SLS estimation.

	General		**Regional**	
	Regcap	*MFC*	*Regcap*	*MFC*
OLS vs. 2SLS				
Durbin-Wu-Hausman test				
(H0: Specific regressors are exogenous				
and OLS is preferred to 2SLS)				
F-Statistic	22.51	126.61	4.52	9.18
p-value	(0.002)	(0.000)	(0.087)	(0.029)
2SLS				
Weak instrument test				
(H0: Instruments are weak)				
F-Statistic	70.11	6.03	268.35	18.36
p-value	(0.000)	(0.025)	(0.000)	(0.005)
Exogeneity of instrument test				
(H0: 2SLS is valid)				
J-Statistic	2.216	1.438	7.597	0.020
p-value	(0.330)	(0.231)	(0.022)	(0.888)
2SLS vs. 3SLS				
Breusch-Pagan test of independence				
(H0: 2SLS is preferred to 3SLS)				
χ^2	0.523		0.776	
$P - value$	0.470		0.378	

Table C.12: Robustenss of SEM of bank solvency and marginal funding costs with dummy for interest rate change

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. MFC refers to weighted average of marginal funding costs. $\mathbb{1}_{\{\Delta callrate>0\}}$ is indicator variable which is equal to 1 if $\Delta callrate > 0$ and zero otherwise. $\mathbb{1}_{\{\Delta callrate<0\}}$ is indicator variable which is equal to 1 if $\Delta callrate < 0$ and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	Specificiation (1)		**Specification (2)**	
	Regcap	MFC	*Regcap*	MFC
Endogenous variables				
Specification (1)				
Regcap		-0.860^{**}		
		(0.433)		
$Regcap \times \mathbb{1}_{\{\Delta callrate>0\}}$		0.392		
		(0.283)		
$(Regcap + Regcap \times \mathbb{1}_{\{\Delta callrate>0\}})$		-0.468^{**}		
		(0.224)		
MFC	-1.871^{***}			
	(0.442)			
$MFC \times \mathbb{1}_{\{\Delta callrate>0\}}$	0.330^{*}			
	(0.190)			
$(MFC + MFC \times \mathbb{1}_{\{\Delta callrate>0\}})$	-1.541^{***}			
	(0.367)			
Specification (2)				
Regcap				-0.617^{***}
				(0.218)
$Regcap \times \mathbb{1}_{\{\Delta callrate<0\}}$				0.302^{**}
				(0.146)
$(Regcap + Regcap \times \mathbb{1}_{\{\Delta callrate<0\}})$				-0.315^{***}
				(0.108)
MFC			-1.650^{***}	
			(0.435)	
$MFC \times \mathbb{1}_{\{\Delta callrate<0\}}$			0.603^{***}	
			(0.137)	
$(MFC + MFC \times \mathbb{1}_{\{\Delta callrate<0\}})$			-1.047^{***}	
			(0.321)	
Exogenous variables	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
No. Obs.	524	524	524	524
No. Banks	15	15	15	15

Table C.13: Robustness of test results for SEM for interest rate change with accounting-based solvency

The Durbin-Wu-Hausman test is the regression based test of exogeneity of regressors. The weak instrument test is based on a Wald F statistic. The exogeneity of instrument test refers to the Hansen J statistic of overidentification test of instruments. If the null hypothesis is not rejected for at least one equation in the system, it supports the 2SLS as a system of IV estimation. The Breusch-Pagan test of independence reports whether the residuals of both equations are correlated. In case of rejecting the null of independence, it is recommended to adopt the 3SLS estimation.

	Specification (1)		**Specification (2)**	
	Regcap	*MFC*	*Regcap*	*MFC*
OLS vs. 2SLS				
Durbin-Wu-Hausman test				
(H0: Specific regressors are exogenous and OLS is valid)				
F-Statistic	17.53	179.23	13.70	26.62
p-value	(0.001)	(0.000)	(0.002)	(0.000)
2SLS				
Weak instrument test				
(H0: Instruments are weak)				
F-Statistic	131.22	17.80	131.22	17.80
p-value	(0.000)	(0.000)	(0.000)	(0.000)
Exogeneity of instrument test				
(H0: 2SLS is valid)				
J-Statistic	3.800	0.350	4.318	1.353
p-value	(0.150)	(0.554)	(0.115)	(0.245)
2SLS vs. 3SLS				
Breusch-Pagan test of independence				
(H0: 2SLS is preferred to 3SLS)				
χ^2	0.146		0.174	
$P-value$	0.702		0.676	

Table C.14: Robustenss of SEM of bank solvency and marginal funding costs with interest margin management

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. MFC refers to weighted average of marginal funding costs. IM is interest margin between interest rates of new credits and new marginal funding costs. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	Regcap	MFC
Endogenous variables		
Regcap		-1.685^{***}
		(0.437)
$Regcap \times IM$		0.660^{***}
		(0.167)
$(Regcap + Regcap \times IM)$		-1.025^{***}
		(0.275)
MFC	-1.495^{**}	
	(0.709)	
$MFC \times IM$	0.365^{*}	
	(0.207)	
$(MFC + MFC \times IM)$	-1.129^{**}	
	(0.516)	
Exogenous variables	Yes	Yes
Bank FE	Yes	Yes
Year FE	Yes	Yes
No. Obs.	524	524
No. Banks	15	15
Breusch-Pagan test of independence		
χ_2	1.416	
$P - value$	0.234	

Table C.15: SEM with retail funding structure

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. *EDF* refers to the expected default frequency. *MFC* refers to weighted average of marginal funding costs. *L.Retail_large* is a dummy equal to 1 if the 1 quarter lag of average retail funding share is in the largest quantile among three quantiles and zero otherwise. *L.Retail_mid* is a dummy equal to 1 if the 1 quarter lag of average retail funding share is in the mid quantile among three quantiles and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01, ^{**} p < 0.05, ^{*} p < 0.1$.

	(1) Accounting-based		(2) Market-based	
	Regcap	*MFC*	*EDF*	*MFC*
Endogenous variables				
$Regcap(EDF)$		−0.812		0.307*
		(0.813)		(0.164)
$Regcap(EDF) \times L.Retail\_large$		0.668		0.035
		(0.684)		(0.192)
$Regcap(EDF) \times L.Retail\_mid$		0.694		0.163
		(0.697)		(0.189)
$(Regcap(EDF) + Regcap(EDF) \times L.Retail\_large)$		−0.144		0.342***
		(0.146)		(0.406)
$(Regcap(EDF) + Regcap(EDF) \times L.Retail\_mid)$		−0.118		0.469***
		(0.137)		(0.123)
MFC	−1.505***		0.200***	
	(0.553)		(0.022)	
$MFC \times L.Retail\_large$	0.330		0.009	
	(0.313)		(0.012)	
$MFC \times L.Retail\_mid$	0.297		0.010	
	(0.356)		(0.012)	
$(MFC + MFC \times L.Retail\_large)$	−1.175***		0.209***	
	(0.400)		(0.023)	
$(MFC + MFC \times L.Retail\_mid)$	−1.208***		0.210***	
	(0.428)		(0.022)	
Exogenous variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
No. Obs.	524	524	518	518
No. Banks	15	15	14	14
Breusch-Pagan test of independence				
χ_2	0.094		10.048	
$P - value$	0.759		0.002	

Table C.16: SEM with wholesale funding structure

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. *EDF* refers to the expected default frequency. *MFC* refers to weighted average of marginal funding costs. *L.Wholesale_large* is a dummy equal to 1 if the 1 quarter lag of average wholesale funding share is in the largest quantile among three quantiles and zero otherwise. *L.Wholesale_mid* is a dummy equal to 1 if the 1 quarter lag of average wholesale funding share is in the mid quantile among three quantiles and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$.

	(1) Accounting-based		**(2) Market-based**	
	Regcap	*MFC*	*EDF*	*MFC*
Endogenous variables				
Regcap(EDF)		-0.687		0.346^{**}
		(0.445)		(0.155)
Regcap(EDF) × *L.Wholesale_large*		0.589		0.019
		(0.430)		(0.178)
Regcap(EDF) × *L.Wholesale_mid*		0.587		0.091
		(0.430)		(0.191)
(*Regcap(EDF)* + *Regcap(EDF)* × *L.Wholesale_large*)		-0.099^{*}		0.365^{***}
		(0.059)		(0.116)
(*Regcap(EDF)* + *Regcap(EDF)* × *L.Wholesale_mid*)		-0.101^{**}		0.438^{***}
		(0.044)		(0.134)
MFC	-1.370^{***}		0.198^{***}	
	(0.430)		(0.021)	
MFC × *L.Wholesale_large*	-0.331		0.020^{*}	
	(0.218)		(0.012)	
MFC × *L.Wholesale_mid*	0.066		0.006	
	(0.251)		(0.011)	
(*MFC* + *MFC* × *L.Wholesale_large*)	-1.701^{***}		0.219^{***}	
	(0.492)		(0.023)	
(*MFC* + *MFC* × *L.Wholesale_mid*)	-1.304^{***}		0.205^{***}	
	(0.418)		(0.023)	
Exogenous variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
No. Obs.	524	524	518	518
No. Banks	15	15	14	14
Breusch-Pagan test of independence				
χ_2	0.109		10.129	
$P - value$	0.741		0.002	

Table C.17: SEM with borrowing structure

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. *EDF* refers to the expected default frequency. *MFC* refers to weighted average of marginal funding costs. *L.Borrowing_large* is a dummy equal to 1 if the 1 quarter lag of average borrowing share is in the largest quantile among three quantiles and zero otherwise. *L.Borrowing_mid* is a dummy equal to 1 if the 1 quarter lag of average borrowing share is in the mid quantile among three quantiles and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	(1) Accounting-based		**(2) Market-based**	
	Regcap	*MFC*	*EDF*	*MFC*
Endogenous variables				
Regcap(EDF)		-0.604^{*}		0.591^{***}
		(0.342)		(0.172)
Regcap(EDF) × *L.Borrowing_large*		0.529		−0.247
		(0.344)		(0.190)
Regcap(EDF) × *L.Borrowing_mid*		0.498		−0.292
		(0.348)		(0.206)
(*Regcap(EDF)* + *Regcap(EDF)* × *L.Borrowing_large*)		−0.075		0.344^{***}
		(0.056)		(0.103)
(*Regcap(EDF)* + *Regcap(EDF)* × *L.Borrowing_mid*)		-0.106^{**}		0.298^{**}
		(0.044)		(0.152)
MFC	-1.586^{***}		0.202^{***}	
	(0.418)		(0.022)	
MFC × *L.Borrowing_large*	−0.295		0.016	
	(0.238)		(0.012)	
MFC × *L.Borrowing_mid*	−0.118		−0.001	
	(0.238)		(0.011)	
(*MFC* + *MFC* × *L.Borrowing_large*)	-1.880^{***}		0.218^{***}	
	(0.492)		(0.024)	
(*MFC* + *MFC* × *L.Borrowing_mid*)	-1.703^{***}		0.201^{***}	
	(0.404)		(0.022)	
Exogenous variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
No. Obs.	524	524	518	518
No. Banks	15	15	14	14
Breusch-Pagan test of independence				
χ_2	0.160		9.095	
$P - value$	0.690		0.003	

Table C.18: SEM with foreign currency borrowing structure

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. *EDF* refers to the expected default frequency. *MFC* refers to weighted average of marginal funding costs. *L.FCBRW_large* is a dummy equal to 1 if the 1 quarter lag of average foreign currency borrowing share is in the largest quantile among three quantiles and zero otherwise. *L.FCBRW_mid* is a dummy equal to 1 if the 1 quarter lag of average borrowing share is in the mid quantile among three quantiles and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$.

	(1) Accounting-based		**(2) Market-based**	
	Regcap	*MFC*	*EDF*	*MFC*
Endogenous variables				
Regcap(EDF)		-0.574^{**}		0.566^{***}
		(0.287)		(0.134)
Regcap(EDF) × *L.FCBRW_large*		0.420^{*}		-0.446^{**}
		(0.241)		(0.226)
Regcap(EDF) × *L.FCBRW_mid*		0.399^{*}		-0.222
		(0.239)		(0.159)
(*Regcap(EDF)* + *Regcap(EDF)* × *L.FCBRW_large*)		-0.153^{**}		0.121
		(0.074)		(0.195)
(*Regcap(EDF)* + *Regcap(EDF)* × *L.FCBRW_mid*)		-0.174^{*}		0.344^{***}
		(0.094)		(0.106)
MFC	-2.074^{***}		0.202^{***}	
	(0.379)		(0.023)	
MFC × *L.FCBRW_large*	0.277		-0.012	
	(0.243)		(0.013)	
MFC × *L.FCBRW_mid*	0.404		0.011	
	(0.263)		(0.011)	
(*MFC* + *MFC* × *L.FCBRW_large*)	-1.797^{***}		0.190^{***}	
	(0.473)		(0.023)	
(*MFC* + *MFC* × *L.FCBRW_mid*)	-1.700^{***}		0.213^{***}	
	(0.441)		(0.022)	
Exogenous variables	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes
No. Obs.	524	524	518	518
No. Banks	15	15	14	14
Breusch-Pagan test of independence				
χ_2	0.077		10.382	
$P - value$	0.781		0.001	

Table C.19: SEM with foreign currency borrowing structure under the Leverage Cap

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period under the FX forward leverage cap. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. EDF refers to the expected default frequency. MFC refers to weighted average of marginal funding costs. $FCBRW\_large$ is a dummy equal to 1 if average foreign currency borrowing share is in the largest quantile among three quantiles and zero otherwise. $FCBRW\_mid$ is a dummy equal to 1 if average borrowing share is in the mid quantile among three quantiles and zero otherwise. $FCBRW\_small$ is a dummy equal to 1 if average foreign currency borrowing share is in the smallest quantile among three quantiles and zero otherwise. *Levcap* is a dummy equal to 1 if the period corresponds to the announcement and implementation of leverage cap and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	(1) FCBRW_large		**(2) FCBRW_mid**		**(3) FCBRW_small**	
	Regcap	MFC	*Regcap*	MFC	*Regcap*	MFC
Endogenous variables						
Regcap		-0.349^{***}		-0.018		-0.435^{*}
		(0.056)		(0.077)		(0.228)
Regcap × *Levcap*		-0.018		0.004		0.268^{*}
		(0.018)		(0.053)		(0.125)
(*Regcap* + *Regcap* × *Levcap*)		-0.367^{***}		-0.014		-0.167^{*}
		(0.064)		(0.027)		(0.091)
MFC	-1.722^{***}		-0.695		-1.401^{**}	
	(0.573)		(0.454)		(0.545)	
MFC × *Levcap*	-0.245		-0.827^{**}		-0.054	
	(0.515)		(0.362)		(0.303)	
(MFC + MFC × *Levcap*)	-1.968^{*}		-1.523^{**}		-1.456^{**}	
	(1.017)		(0.587)		(0.700)	
Exogenous variables	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
No. Obs.	121	121	198	198	205	205
No. Banks	4	4	6	6	5	5
Breusch-Pagan test of independence						
χ_2	0.477		0.936		0.027	
$P - value$	0.490		0.333		0.869	

Table C.20: SEM with foreign currency borrowing structure under the Stability Levy

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q2-2015Q2 period under the stability levy. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. *EDF* refers to the expected default frequency. *MFC* refers to the weighted average of marginal funding costs. *FCBRW_large* is a dummy equal to 1 if average foreign currency borrowing share is in the largest quantile among three quantiles and zero otherwise. *FCBRW_mid* is a dummy equal to 1 if average borrowing share is in the mid quantile among three quantiles and zero otherwise. *FCBRW_small* is a dummy equal to 1 if average foreign currency borrowing share is in the smallest quantile among three quantiles and zero otherwise. *Stablevy* is a dummy equal to 1 if the period corresponds to the announcement and implementation of the stability levy and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01, ^{**}p < 0.05, ^{*}p < 0.1$.

	(1) FCBRW_large		**(2) FCBRW_mid**		**(3) FCBRW_small**	
	Regcap	*MFC*	*Regcap*	*MFC*	*Regcap*	*MFC*
Endogenous variables						
Regcap		-0.191^{***}		-0.011		-0.392^{*}
		(0.037)		(0.061)		(0.212)
Regcap × *Stablevy*		-0.057^{***}		0.002		0.191^{*}
		(0.007)		(0.033)		(0.109)
(*Regcap* + *Regcap* × *Stablevy*)		-0.248^{***}		-0.009		-0.201
		(0.041)		(0.030)		(0.122)
MFC	-1.586^{***}		-0.724		-1.428^{**}	
	(0.520)		(0.483)		(0.561)	
MFC × *Stablevy*	1.135		0.417		-0.180	
	(0.985)		(0.537)		(0.765)	
(*MFC* + *MFC* × *Stablevy*)	-0.451		-0.307		-1.607^{*}	
	(1.264)		(0.537)		(0.952)	
Exogenous variables	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
No. Obs.	121	121	198	198	205	205
No. Banks	4	4	6	6	5	5
Breusch-Pagan test of independence						
χ_2	0.463		0.899		0.035	
$P - value$	0.496		0.343		0.851	

Table C.21: SEM with foreign currency borrowing structure under the Interest Income Tax

This table reports the results of the simultaneous equations model for Korean banks for the 2005Q1-2015Q2 period under the interest income tax. *Regcap* refers to the Tier 1 capital divided by risk weighted assets. EDF refers to the expected default frequency. MFC refers to the weighted average of marginal funding costs. $FCBRW\_large$ is a dummy equal to 1 if average foreign currency borrowing share is in the largest quantile among three quantiles and zero otherwise. $FCBRW\_mid$ is a dummy equal to 1 if average borrowing share is in the mid quantile among three quantiles and zero otherwise. $FCBRW\_small$ is a dummy equal to 1 if average foreign currency borrowing share is in the smallest quantile among three quantiles and zero otherwise. $Irtax$ is a dummy equal to 1 if the period corresponds to the announcement and implementation of interest income tax and zero otherwise. Standard errors clustered at the bank level are in parentheses. Significance levels are indicated by $^{***}p < 0.01,^{**} p < 0.05,^{*} p < 0.1$.

	(1) FCBRW_large		**(2) FCBRW_mid**		**(3) FCBRW_small**	
	Regcap	MFC	*Regcap*	MFC	*Regcap*	MFC
Endogenous variables						
Regcap		-0.193^{***}		-0.039		-0.358^{**}
		(0.048)		(0.059)		(0.167)
Regcap $\times$ $Irtax$		-0.059^{**}		0.031		0.136
		(0.026)		(0.031)		(0.085)
(*Regcap* + *Regcap* $\times$ $Irtax$)		-0.252^{***}		-0.008		-0.222^{**}
		(0.025)		(0.030)		(0.086)
MFC	-1.349^{***}		-0.856		-1.396^{***}	
	(0.407)		(0.523)		(0.482)	
$MFC \times Irtax$	4.517^{**}		1.958^{***}		0.570	
	(2.074)		(0.653)		(0.972)	
$(MFC + MFC \times Irtax)$	3.168^{*}		1.102		-0.826	
	(1.729)		(0.693)		(0.749)	
Exogenous variables	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes	Yes
No. Obs.	121	121	197	197	205	205
No. Banks	4	4	6	6	5	5
Breusch-Pagan test						
of independence						
χ_2	0.239		0.992		0.014	
$P - value$	0.625		0.319		0.905	

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