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Has Banks' Monitoring of other Banks strengthened Post-Crisis?

Evidence from the European Overnight Market*

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Abstract

Using the Eurosystem's proprietary interbank loan data from more than one thousand banks, practically all major banks in Europe for 2008-2016, we show that larger European banks have had a lower cost of overnight borrowing than smaller banks. The size premium remains significant after controlling for time, relationship lending, competitive environment of lenders, and bank risk characteristics but has decreased over time in countries that were stricken by the Sovereign Debt Crisis. Further, the ultra-short maturity of the overnight loans and the daily frequency at which we measure them provide for an ideal setting to use difference-in-differences analysis to study the potential effect of the Bank Recovery and Resolution Directive (BRRD) on the size premium in overnight rates and to avoid possible simultaneity problems. However, we find that changes in the size premium cannot be related to the implementation dates of the BRRD in different member countries.

JEL classification: G21, G22, G24, G28
Keywords: overnight rates, too big to fail, implicit government guarantee, interbank borrowing costs, Bank Recovery and Resolution Directive

*E. Jokivuolle (esa.jokivuolle@bof.fi), E. Tölö (eero.tolo@bof.fi) and M. Virén (matti.viren@bof.fi) are employed by the Bank of Finland and corresponding author E. Jokivuolle is a member/alternate of one of the user groups with access to TARGET2 data in accordance with Article 1(2) of Decision ECB/2010/9 of 29 July 2010 on access to and use of certain TARGET2 data. The Bank of Finland and the MIPC have checked the paper against the rules for guaranteeing the confidentiality of transaction-level data imposed by the MIPC pursuant to Article 1(4) of the above mentioned issue. The views expressed in the paper are solely those of the authors and do not necessarily represent the views of the Eurosystem or the Bank of Finland. We would like to thank Iftekhar Hasan, Jouko Vilmunen, and seminar participants at the Bank of Finland for valuable comments. All remaining errors are ours. Earlier version of this work has been circulated as "Are too-big-to-fail banks history in Europe? Evidence from overnight interbank loans", Bank of Finland Discussion Paper No 29/2015.

1. Introduction

We study pricing in the European interbank overnight loan market, with a particular focus on the potential effect of the Bank Recovery and Resolution Directive (BRRD), using the most extensive confidential dataset from Europe: the Eurosystem's proprietary transactions data from which the volumes and counterparties as well as interest rates on interbank loans can be filtered out. The daily data covers more than one thousand banks in 2008-2016. We focus on overnight loans which are by far the most liquid segment of the market.

We study three sets of factors that may drive the interbank loan pricing. First, as controls we include variables related to banks' risks as pioneered in interbank context by Furfine (2001). Second, our confidential data set allows us to directly observe the history of loan sizes as well as the number and identity of interbank counterparts of a bank. In addition to being potential explanatory variables of interbank loan rates as such, we also use these variables to construct measures of interbank lending relationships (see Cocco et al., 2009 and Tölö et al. 2017) as well as measures of bank connectedness and competitive position in interbank markets. Third, we use bank size (as well as a bank's interbank connections) as a simple measure of a bank's systemic risk and study changes in its role around the implementation of the BRRD in the various European Banking Union's member countries. In particular, we test whether the BRRD has reduced market expectations of the largest banks' alleged "too-big-to-fail" status. Our analysis can be seen as an extension of the analysis by Furfine (2001). Besides a substantially longer data period and a different continent, Europe, we consider a broader set of bank relationship variables and include a detailed analysis of the BRRD.[1]

A central aim of the BRRD is to facilitate bank restructurings without public bail-outs. Hence, if the BRRD framework and its implementation is considered credible by the markets, then we should expect a reduction in the role of bank size as a factor related to bank systemic risk in explaining interbank loan rates. The BRRD may also affect the role of other bank risk-related variables in explaining interbank loans, for which we also control. One obvious caveat is that the overnight interbank loans are not included in the first line of defense of bank liabilities in

[1] Furfine (2001), who refers to Rochet and Tirole (1996), was early to touch upon the too-big-to-fail issue in the context of overnight loan pricing: "if the largest banks were viewed as immune from failure, then these banks' creditors, including other banks, would have little incentive to monitor their exposures."

a bank's restructuring (ie, they are not immediately available for "bail-in").[2] However, as experience from the Global Financial Crisis shows, even the safest bank liabilities may become subject to "runs" and roll-over risk, when uncertainty is high and creditors want to avoid any delays in getting their money back (cf. Afonso et al 2011). Besides outright rationing the lenders may require collateral to reduce the cost of monitoring. However, there is evidence that even the repo market is subject to runs (Gorton and Metric, 2009), and that secured securities may become sensitive to borrower's credit risk (Dang et al, 2015). Hence, it is possible that the introduction of the BRRD indirectly affects all interbank liabilities, also perhaps partly due to imperfect information among market participants of the detailed institutional features of the resolution framework. We therefore test the effect of the BRRD on overnight loan pricing.

Importantly, because of their maturity of "one day", overnight loan rates should not reflect any market expectations of the effects of BRRD even just before the event date when the BRRD is implemented in each banking union member country. Therefore the daily overnight loan rates are exceptionally suited to a difference-in-differences analysis of the effect of BRRD on treated and non-treated banks in our sample around a tight event window and can therefore well avoid potential simultaneity problems. This may not be possible in similar studies using bank debt instruments of longer maturities.

To measure banks' borrowing costs, we use European banks' interbank overnight (uncollateralized) borrowing rates from June 2008 to September 2016, which includes both EU and non-EU banks and other financial institutions (henceforth "banks", for brevity, unless noted otherwise). There are more than 2,500 borrower banks in our original sample. We use the loan-level overnight borrowing rate, constructed from the transactions data, as our measure of a bank's funding cost.

We find that larger European banks have had a lower cost of overnight borrowing than smaller banks. The size premium remains significant after controlling for relationship lending, competitive environment of lenders, loan size, and bank risk characteristics. It has decreased over time in countries that adopted the Bank Recovery and Resolution Directive (BRRD) compared to countries that are not under the BRRD. The decrease in the size premium

[2] See European Banking Authority's Interactive Single Rulebook on Bank Recovery and Resolution Directive, Title IV, Chapter IV, Section 5, Subsection 1, Article 44: "liabilities to institutions, excluding entities that are part of the same group, with an original maturity of less than seven days" are excluded from the scope of bail-in.

is most pronounced for large banks in countries that were stricken by the Sovereign Debt Crisis. These results suggest that the BRRD may have helped to reduce the “too-big-to-fail” expectations concerning large banks. However, in the difference-in-differences analysis we find that the change cannot be timed to the implementation dates of the BRRD related bail-in provisions in different member countries.

The rest of the paper is organized as follows. Section 2 provides a brief review of the previous literature, focusing on the question of too-big-to-fail banks. Section 3 provides an overview of the Eurosystem’s interbank market. Section 4 introduces the data and section 5 presents the results. Section 6 concludes.

2 Literature review

The issue with TBTF institutions dates from long before the recent financial crisis and may apply not only to financial but also to non-financial firms. It has also been subject to intensive research, especially in the United States where bank failures have been much more common than in Europe where – even during the recent crisis – bankruptcies of financial institutions have been rare (cf. e.g. Brewer III and Jagtiani (2013), Hughes and Mester (2013), Noss and Sowerbutts (2012), Ueda and Weder di Mauro (2013), Wheelock and Wilson (2012), and Santos (2014)). Partly because of this regional asymmetry in empirical research, we focus in the current paper on European banks.

The previous literature has used several alternative measures to study the relationship between banks’ borrowing costs and bank size such as deposit rates, bond returns, CDS rates, or the weighted average of these various borrowing costs. Combinations of rating and rate-based measures as well as equity returns have also been used in studying the effect of bank size on its financing costs more generally. For example, Bassett (2014) examines differences in the cost of deposits of large and small banks, Demirguc-Kunt and Huizinga (2013) use CDS rates, and Santos (2014) uses bond spread differences between small and large banks. Kroszner (2013) provides a comparative review of results obtained with alternative measures.

Empirical evidence on the relationship between bank size and bank borrowing costs seems to depend on the time period and the measure of the borrowing cost. The CDS data which are perhaps most often used suggest that prior to the global financial crisis financial firms generally had lower spreads but that they were less sensitive to firm size than spreads for several other industries (see Ahmed et al 2015). This result in actuality appears consistent with the theory of Farhi and Tirole (2012) that many of the public sector's financial crisis fighting measures, including monetary policy operations, help the financial sector as a whole, not just the largest financial institutions. So, measuring the TBTF advantage of large banks from borrowing cost differentials of large and small banks may underestimate the full size of implicit government support to the financial sector.

As regards further industry comparisons, Kroszner (2013) provides some direct empirical evidence from the funding costs of the 3,000 largest US firms in terms of market capitalization with debt/equity ratios above the 10th percentile (in order to eliminate outliers).[3] Similar results were recently obtained by Goldman Sachs (2013). Their study finds that the funding cost advantage of large firms is almost three times larger in trade and leisure, and retail and technology, compared with banks. Only in industries such as basic materials and utilities, the within-industry bond spreads between large and small firms are lower than in the financial sector.

Large banks like large non-financial firms seem to have enjoyed a funding cost advantage especially prior to the Lehman Brothers bankruptcy (cf. Ahmed et al 2015). Similar results have been obtained with corporate bond returns (Ahmed et al 2015 and Goldman Sachs 2013). In contrast, the study with deposit rates of large and small banks (Bassett 2014) fails to show very strong evidence of the perceived TBTF subsidy (cf. also O'Hara and Shaw, 1990). The result applies not only to ordinary deposits but also to interest bearing liquid deposits. Overall, the differences in deposit rates between small and large banks appeared to be small. This may well be explained by deposit insurance. Acharya et al (2016) provide recent evidence that the largest banks' bond spreads are less risk-sensitive and those of smaller banks, which is consistent with the TBTF hypothesis. They do not find a similar relationship with non-financials.

One potential difficulty in measuring the TBTF advantage from borrowing cost differentials is that bank size and its borrowing costs may be related also for other reasons than TBTF

[3] The WACC differential in basis points between the top ten and other firms are: energy 84, consumer non-cyclicals 53, industrials 40, consumer cyclicals 39, banks 35, communications 30, non-bank financials 28, basic materials 28, technology 16, and utilities 53.

expectations. Most recent studies suggest that there are scale economies in banking even for the largest group of banks for various reasons (cf. e.g. Hughes and Mester (2013) and Araten and Turner (2013)). However, it is possible to control for the effect of efficiency via bank profitability measures such ROE (as we do in the current paper). Moreover, Davies and Tracey (2014) show that what may seem like cost efficiency may actually be a cost advantage arising from a TBTF status: after controlling for the TBTF factor, they find that the cost efficiency of the largest banks vanishes.[4]

Another potentially important factor that affects the overnight borrowing cost of a bank is the competitive environment in the interbank market. For instance, a bank may be relatively dependent on a few relationship lenders, or it can be a hub in a network of banks with a multitude of potential sources of interbank funds (cf. e.g. Cocco et al 2009 and Brauning and Fecht 2017). The advantage of our data is that it allows us to control for the number of interbank relationships. However, as already discussed above, the number of interbank relationships that we use could also proxy for a bank's systemic risk arising from its interconnectedness in the financial network. Interconnectedness can hence give rise to an additional source of market expectations of government support, not fully captured by bank size. Ringe & Patel (2019) point out the banks' interconnectedness can make almost the entire banking too risky to fail.

Various studies, including Furfine (2011) and Cocco et al (2009), report that large banks obtain interbank funding at a lower cost. Based on a dataset of around 100 banks that trade on the Italian based money market trading facility (E-MID), Angelini et al (2011) report that the overnight loans become sensitive to borrowers' creditworthiness and size following August of 2007 (also later after the failure of Lehman Brothers) and suggest that moral hazard risks related to TBTF have increased. Akram and Christophersen (2017) use Norwegian overnight loan data of 28 banks over the period 2006–2009 and find relatively lower funding costs for banks of systemic importance, but only in some periods. Relative to these studies, our contribution is a substantially more extensive dataset in terms of banks and time span and a detailed analysis of the BRRD implementation.

To summarize, in the current paper we focus only on banks (and other financial institutions). Although the previous literature shows that it is not clear-cut whether the TBTF effect is more

[4] Deposit insurance may constitute another problem (O'Hara and Shaw 1990), particularly in Europe where certain cross-country differences exist or have existed.

severe in the banking industry than other industries, our reading of the literature is that, on balance, the banking industry enjoys implicit support, perhaps in more subtle ways than generally thought. Expectations of this support may spur excessive risk-taking. If that is the case especially in the largest institutions, it can have severe implications for financial stability. Therefore it is of interest to further investigate the existence of TBTF expectations in the banking industry, and whether the recent legislative efforts to reduce the need for government support to troubled banks have actually worked in the sense that they have affected market expectations of such support.

3 The Eurosystem's interbank money market

In this section we give a brief overview of the functioning of the Eurosystem's interbank money market.[5] The Euro area monetary policy operations as well as the majority of transactions in the Euro area interbank market are settled in the TARGET2 system, which is the large value payment system of the Eurosystem.[6] Access to TARGET2 is granted primarily to EU central banks and their national communities of commercial banks (see Heijmans et al 2010). Money market transactions are a subset of bank-to-bank large value payments. The great majority of bilateral loans are negotiated over-the-counter and hence (in the absence of any transparency regulation for these loans) are known only to the two parties involved in each transaction. Payments are settled in central bank money with immediate finality (i.e., in real time). In 2012, TARGET2 had a 92% market share in value terms of all large value payments in euro.[7] TARGET2 and Fedwire Funds for the US dollar are the two largest real-time gross settlement systems in the world.[8]

The Euro money market has the following specific features with potential implications for the analysis of the overnight rates data. First, eligible counterparties have everyday access to the ECB's marginal lending facility and the deposit facility. The marginal lending facility offers relatively expensive overnight funding against eligible collateral, and the marginal lending facility rate set by the ECB governing council acts as an (not exactly strict) upper bound for

[5] The summary is adapted from Tölö et al (2017).
[6] The Eurosystem is formed by the national central banks of the European countries belonging to the European Monetary Union (having euro as their common currency) and the European Central Bank (ECB). In addition, a number of non-euro European countries, six in 2010, were also connected to TARGET2.
[7] See European Central Bank (2013). Another, privately owned euro payment system for banks operating in the European Union is EURO1.
[8] See TARGET2 Newsletter, I Issue, number 3, October 2010.

the uncollateralized overnight loan rates. The deposit facility offers a minimum return for overnight deposits, and the deposit facility rate set by the ECB acts as a (not exactly strict) lower bound for the overnight loan rates.[9] The third important rate is that of the ECB's weekly main refinancing operations which also may have an effect on the interbank overnight rates through general liquidity conditions. This rate is typically half-way between the deposit and marginal lending rate (the "corridor"), and until October 2008 the average overnight rate (Euro Over Night Index Average, i.e., EONIA) was very close to this rate (see Figure 1). Since 15 October 2008, the weekly main refinancing operations have been carried out through a fixed rate tender procedure with full allotment at the interest rate on the main refinancing operations. This and the ECB's subsequent Longer-Term Refinancing Operations (LTRO) (notably 3-year operations in December 2011, scant €500bn., and in February 2012, over €500bn.) as well as the asset purchase program since 2015 have significantly increased the amount of central bank liquidity in the TARGET2, and have moved EONIA closer to the deposit facility rate (see Figure 1). The fixed tender rate of weekly main refinancing operations acts as a soft upper bound on the interbank rates and a large proportion of overnight loans take place between deposit facility rate and the fixed rate tender rate. A bank would be willing to borrow at a rate above the fixed tender rate only if it has no access to the ECB facilities, it has no available collateral, or it is concerned of reputational costs that could arise from borrowing from the central bank.

In the course of three years following the 2008 financial crisis, the volume of unsecured overnight lending roughly halved and subsequently remained at a lower level (ECB, 2015). At the same secured overnight lending has remained at the 2007–2008 levels. Along with this development, bilateral repos increasingly take place through Central Counter Party (CCP) while the share of triparty repos has remained largely unchanged (ICMA, 2018).

4 Data

We use a rather novel dataset that comprises most of the global euro-denominated interbank overnight market for our sample period from June 2008 to September 2016. A central reason for focusing on the shortest (overnight) interbank loan maturity is the high liquidity of this

[9] These bounds are not strict because of two reasons. First, there may be banks without sufficient collateral who hence cannot access the ECB's liquidity facilities. Second, not all parties in the interbank market are eligible to access the central bank's facilities in the first place.

market segment[10]. The data are based on identification of transactions from the TARGET2 payment system, using improved version of the method described in Arciero et al (2016). The data quality is analyzed in detail in Arciero et al 2016, which also considers longer maturities. The quality is found to be very good for the overnight loans with false rates below 2 % for the overnight segment (cf. Armantier and Copeland 2012). In the improved version, the identification of the counterparties is further improved based on the originator and beneficiary fields of the transaction message. As a quality check for the more recent data, Table 1 shows the correlation between EONIA and the average overnight rate calculated from the identified transactions. It could still be that the data contains some bilateral non-CCP overnight repo transactions. To ensure robustness of our results in this regard, we have identified the subset of loans that are relatively more likely to be secured by collateral. The results are robust against excluding such transactions.[11]

Overall, the overnight loan data are extensive especially in terms of the number of banks, and it includes banks of all sizes. For example, the sample is much larger than in studies that use CDS data which are usually available only for large banks, or in studies based on banks with public credit ratings.[12] The time period includes the key episodes of the recent crises in Europe. This allows us to assess potentially different regimes of perceived public support to large banks.

Besides the borrowing rate and transaction size, the transaction data provides us with a number of other variables related to the bank's status in the overnight lending market. We use the number of lenders to proxy the bank's bargaining position. We adapt from Cocco et al 2009 the two relationship lending proxies Borrower Preference Index (BPI) and Lender Preference Index (LPI), which measure the strength of a borrower's relationship with certain lender and a lender's relationship towards certain borrower, respectively. As an alternative relationship lending proxy, we use the number of days within a given year that the lending relationship was active adapted from Furfine (2001). We also include a transaction based measure which probes the geographic reach of a given bank. This index is calculated based on a bank's country

[10] For longer maturities, there is much more heterogeneity e.g. in terms of collateral.

[11] Specifically, we obtain the Euro GC O/N Repo rate from Bloomberg. We define a proxy for bank's credit risk as $= -0.03 * \log(Z) - 0.04 * \mathrm{ROE} - 0.2 * \mathrm{Tier1\ Ratio}$. The subset of loans that are relatively more likely to be secured is defined as those borrowed by risky banks (those with CR above the 50th or 75th percentile) that have interest below "Euro GC O/N Repo rate + 5 bps". When these loans are excluded, the results are essentially unchanged.

[12] For comparison, the number of banking firms in e.g. the Ahmed et al (2015) study is less than 20 for each quarter.

distribution of incoming customer payments (payment type 1.1 in Target2).[13] We calculate the value share of customer payments originating from each country, and aggregate the shares into a Herfindahl index. It can be interpreted as the geographic diversification of the bank's incoming liquidity stream related to customers (often large corporations).

The transaction based data are combined with data from BankScope using the bank identifier codes (BICs). The BankScope data includes typical proxies for the bank's credit risk: ROE, ROA, leverage ratio (calculated here as equity divided by assets), Tier 1 ratio and NPL ratio. Additionally controls include the revenue share of non-interest income, the ratio of liquid assets to deposits and the loans-to-deposits ratio. We also identify G-SIFI banks and listed banks with dummy identifiers. We also obtain the iTraxx CDS index and sovereign CDS spreads from Bloomberg and Thomson Reuters, respectively. The final number of banks ranges from a few hundred up to 1,326 depending on which geographic regions and control variables are included.

Our yearly balance sheet data is of much lower frequency than the market based variables. Therefore we use the value reported for the previous year when matching it with the daily data. Moreover, we use robust standard errors clustered at the bank level to facilitate the analysis with mixed frequency data (we also experimented with taking yearly average of each bank's borrowing rate with no essential change in results). When the time period is short (a few weeks) as in the difference in differences analysis, we take time-series averages of the daily data to avoid overweighting any single bank. In addition, when the short window includes a new year, we use constant values for balance sheet data corresponding to that end of the year that is changing (for example from 20 December 2015 to 10 January 2016, we use end-of 2015 balance sheet data throughout). Table 2 a–b provide the data sources, definitions, and descriptive statistics.

5 Empirical results

5.1 Basic results

We study the effect of bank size and other determinants on the bank's borrowing cost in the overnight interbank market using the following baseline panel equation:

[13] A similar measure was calculated from the outgoing customer payments. The correlation between the two measures is 0.49. The measure based on incoming customer payments turned out to be more robust explanatory variable so we use it exclusively.

$$r_{ijt} = \alpha_t + \beta_1 \log Z_{it} + \sum_{k=2}^{K} \beta_k X_{ijt}^{(k)} + \varepsilon_{ijt} \quad (1)$$

The dependent variable r_{ijt} is the difference of the interest rate on an overnight loan, borrowed by bank i from bank j, and the EONIA rate on the same day, t.[14] The primary explanatory variable of interest is $\log Z_{it}$; the natural logarithm of the book value of total assets of bank i. $X_{ijt}^{(k)}$ are control variables, which may depend both on the borrower and the lender, and α_t captures fixed time effects.[15] Equation (1) is estimated in the standard fixed time effect panel setting using an unobserved cluster effect so the standard error estimates are adjusted according to the method pioneered by Huber (1967) and Rogers (1993). All reported regressions (i.e., Tables 3, 4, 5, 8, 9 and Figure 4) except for the difference–in–differences analysis are based on Equation (1).

Table 3 provides the basic results, considering seven different model specifications with the control variables. The number of banks (and hence observations) varies somewhat between specifications depending on the availability of data on the control variables. The main result in Table 3 is that bank size (the log of total assets) is negatively related to a bank's overnight borrowing cost. The coefficient is significant and stable across all model specifications. With one exception, the control variables obtain expected signs and are stable across the different model specifications (and consequently, sample sizes).[16]

Measures related to bank profitability; return on equity (ROE) and return on assets (ROA) are negatively related with the overnight funding cost. Bank solvency measures; leverage ratio (which is defined as equity divided by assets) and the Tier 1 ratio (Tier 1 equity divided by risk weighted assets) are also negatively related with the overnight funding cost, although only the Tier 1 ratio is significant (see model 7 in Table 3). The share of non-interest income of total revenue of a bank is negatively related to the funding cost, which suggests that more diversified revenue sources tend to reduce the bank's asset risks.

[14] Note that the number of loans can vary across banks and also across time for each bank.
[15] Because of time fixed effects, the only effect of subtracting EONIA from the loan rate is to downsize the R^2.
[16] The key results remain unchanged also if we take annual time-series averages of the daily data to match the true updating frequency of the lower-frequency data.The results are available from the authors upon request.

The sovereign CDS spread of a bank's home country is positively related to the overnight funding cost. In other words, a higher creditworthiness of the government (i.e., lower CDS spread) tends to lower the funding cost of banks domiciled in that country. The ratio of non-performing loans (NPL ratio), which is included as a measure of bank asset risk, the ratio of liquid assets to deposits, the ratio of loans to deposits, and a dummy for whether a bank is listed in the stock market are insignificant but obtain expected signs.

A dummy for global systemically important financial institutions (G-SIFI) obtains a positive coefficient, although it is insignificant in all specifications considered (see models 5-7 in Table 3). The positive coefficient is counter to the notion that the status of G-SIFI would imply enhanced government support in a crisis and hence lower funding costs. Our results suggest that if there are any such market expectations concerning G-SIFI banks in particular, they are already captured by the bank size variable.

Our data also allows us to include (the log of) transaction size as a control; see models 4-7 in Table 3. It obtains a significantly positive coefficient which is quite stable across the different models. The positive sign suggests that lender banks are able to charge a higher interest rate on bigger loans (recall that borrower bank size is our main explanatory variable of interest and hence controlled for). This possibly reflects expectations of increased credit risk or acute liquidity need of the borrower bank.

Table 3 also indicates (see model specifications 4-7) that the overnight funding cost of a bank is lower, the higher is the number of its counterparties in the overnight market. Interestingly, the coefficient on size declines (in absolute value) from -0.030 to -0.025 in specifications 4-7 suggesting that bank size is partly a proxy for the same factors potentially captured by the number of counterparties. These factors may include 1) the degree of competition in a bank's interbank lending relationships or 2) a bank's interconnectedness which increases its systemic importance in the financial network. As alternatives to the number of counterparties, we also consider two measures, the Borrow Preference Index (BPI) and Lender Preference Index (LPI) (see Cocco et al 2009 for details), in model 4 of Table 3 but find them both to be insignificant when all the other controls are included.

Given that both bank regulation and the overnight market have gone through significant changes during the sample period – e.g. the conversion of ECB's money market operations from partial allotment to fixed rate full allotment, the long-term refinancing operations and asset purchase programs – in Table 4 we also produce a set of results on determinants of overnight borrowing rates for each year in the sample. The set of control variables for this table is adopted from Furfine (2001) who uses a similar table (for one quarter in 1998) to demonstrate that in the overnight Fed funds market the lenders are sensitive to borrowers' risk characteristics.[17] Following Furfine (2001), the set of control variables are classified as borrower's credit risk variables, transaction characteristics, or relationship characteristics. Because the data is multi-country, we additionally introduce measures of geographic concentration, which is included in the relationship characteristics.

As seen in Table 4, running the regression for each year separately introduces significant variation in the coefficients. Overall, the results still follow similar pattern as those in Table 3. The coefficient of size is generally still the most consistent determinant of borrowing costs being of the anticipated sign and magnitude. Among the borrower's credit risk variables ROA, Tier 1 ratio, and relative transaction size are statistically significant in the full sample but often not significant when we look at the individual years. To some extent the magnitude of the size coefficient relative to log(Transaction size/equity) are inversely related, probably due to multicollinearity. Also the transaction size dummies are not very informative when the transaction size relative to bank equity is already accounted for. From 2010 onwards, relationship characteristics become relatively more important for borrowing costs starting with Euro area crisis as banks, especially small banks that rely on relationships or have more counterparties are able to get better borrowing terms.

Year 2008 differs markedly from rest of the sample. For that year the data spans the latter half of the year so e.g. the ROA (from previous year end) has unexpected positive sign. Moreover, the rapid repricing of risk starting from the sudden collapse of investment bank Lehman Brothers is likely behind the high importance of Tier 1 ratio and relative transaction size [log(transaction size/ equity)] risk variable for that year.[18]

At the bottom of Table 4a, we include joint significance tests for groups of credit risk and relationship variables. The tests show that borrower's credit risk and relationship

[17] We use this alternative set of controls here as it places more emphasis on the risk factors.

[18] Note that the numerator of log(Transaction size/Equity) is basically daily variable while the denominator dates back to previous year-end.

characteristics are relevant determinants of borrowing costs. The coefficients in the table tell that there is no single dominant credit risk variable just as there is no single dominant relationship variable. Figure 4 further illustrates the time dependence of interest rate determinants by showing the joint significance statistics on a daily level. The significance of different variable groups tends to offset each other. For example, from 2011 to 2013 the relationship variables are highly significant while credit risk variables are not. Then from 2013 to 2015 credit risk variables are highly significant while relationship characteristics are less important. The effect likely reflects the changing composition of borrowers and changes in country specific financial stress and business conditions. Moreover, the pricing practices are expected to vary to some extent depending on country.

We show the time-dependence of the joint-significance statistics using daily regressions in Figure 4. The figure shows the 10 day moving average of the p-value of the F-test. Figure 4a illustrates how the creditors become immensely sensitive to borrower banks' credit risk characteristics immediately following the Lehman Brothers' default (the clear pattern late 2008, which emerges exactly at the Lehman's default date). Similarly, Figure 4b illustrates how the relationship variables are highly significant determinants during the Euro Area sovereign debt crisis.

We deduce from the above considerations that fixed country effects could help the estimation of some interest rate determinants, and hence we repeat the results of Table 4a in Table 4b where we introduced country fixed effects and the setup is otherwise the same. The results for the size variable actually become less precise and the coefficient tends to decrease if fixed country effects are introduced. This is largely explained by the fixed effects coefficient absorbing the effect of size in countries where there is less size variation in among banks in the sample. If we scrutinize the estimated fixed effects, we find that they are typically smaller in countries where there is less variation in bank size (see Figure S1 in supplement). On the other hand, credit risk variables and especially geographic concentration gain in terms of statistical significance indicating more geographically diversified borrowers obtain cheaper loans. The joint-significance statistics also become generally stronger indicating that the credit risk and relationship characteristics gain in importance. Despite these improvements, we do not think that country fixed effects change the key messages. Hence, we exclude country fixed effects from the rest of the analysis which is primarily focused on the bank size and the issue of TBTF.

In Table 5 we provide further tests for whether the role of bank size indeed stems from the TBTF expectations. The idea is that if a bank is directly owned by a solid government, it would more likely receive government support in a crisis regardless of its size. For all other banks a large size would matter more as a "guarantee" of government support in a crisis. We test this in models 2 and 3 of Table 5. We form two dummy variables, the first of which ("State owned") is one if a bank is owned by any government in our sample, and the second of which ("Core state owned") is one if a bank is owned by a government with high credit worthiness.[19] We focus on the interaction of these dummies with bank size. In model 2 of Table 5, it turns out that the interaction with the first dummy is not statistically significant while in model 3 with the second dummy the interaction is statistically significant, Hence, bank size has a weaker effect on the overnight funding cost of banks which are owned by "core states". In model 3 of Table 5, the effective constant term is also affected by the second dummy, indicating that banks owned by the core states have lower average overnight funding costs. Overall, Table 5 provides support to the notion that bank size serves as a proxy for the strength of TBTF expectations.

5.2 Economic significance of the size premium

The coefficient of size can be turned into an interest rate differential by the following formula:

$$\Delta r = 100\, \beta_1 ln(Z_S/Z_L)\ , \qquad (2)$$

where Δr is a basis point interest rate differential, ln is the natural logarithm, Z_S and Z_L are the sizes of the two representative banks, and β_1 is the coefficient of size in Equation (2). The interpretation of the basis point differential depends on which control variables are included. When the synergies are controlled by ROE, the resulting interest rate differential can be viewed as a maximal value for the relative too-big-to-fail subsidy based on the sample at hand.

The magnitude of the large banks' cost advantage is economically significant. In Table 3 with controls, the coefficient of size is about –0.03. This suggests that a bank, ten times the size of its peer, holding other factors constant, has a funding advantage of 7 bps. Similarly a bank, fifty times the size of its peer, pays 12 bps less interest. For comparison, the coefficient of ROE

[19] Specifically, the dummy "Core state owned" refers to banks owned by a government belonging to the following group: Austria, Belgium, Finland, France, Germany, Luxembourg, Netherlands, and United Kingdom. The sample is restricted to EU countries.

(roughly 0.04 in Table 3) translates to a 4 bps change in interest for a 1 percentage point change in ROE. Overall the interest rate differentials are within the same scale of magnitude as in Furfine (2001).

5.3 The effect of the BRRD on the size premium

Next we study whether the effect of bank size on bank overnight funding costs has changed after the introduction of the new bank recovery and resolution framework (the BRRD) in the EU, the aim of which is to restrict government subsidies to banks. We consider the impact of BRRD in several alternative ways. First, we investigate changes in Bank Support Ratings published by Fitch Ratings (Fitch), which directly measure government support expectations.

Second, we perform a difference-in-difference (DD) analysis around country-specific BRRD implementation dates. Both of these analyses suggest that the impact of BRRD, if any, can't be dated to the known implementation dates.

As a further test, we assess the potential longer-term impact of the BRRD using dummy variables for relevant turning points in the process of introducing the BRRD.

Fitch's Support Ratings (SRs) reflect the agency's view on the likelihood that a bank will receive extraordinary support to prevent it defaulting on its senior obligations. The scale is 1–5 such that "1" corresponds to extremely high probability of external support while "5" corresponds to a possibility of external support, which cannot be relied upon. Figure 2 shows the evolution of average SR for European banks from 2005 to 2017. Until mid-2015 the average SR hovers around "2" (high probability of external support), there is a minor increase in support expectations before the global financial crisis and a minor decrease afterwards. In May 2015 the average SR jumps to around 3.5, which corresponds to moderate to limited probability of government support. This can be clearly attributed to the progress of implementing BRRD in the EU as documented by Fitch. In March 2014, Fitch published global rating path expectations concerning sovereign support for banks (Fitch 2014). The report said that EU banks would be most affected, and North America would also be affected, but there would be less urgency elsewhere. Fitch believed support for senior creditors would still be possible under BRRD but unlikely so that they expected a material weakening of sovereign support propensity for the majority of EU banks.[20] On 19 May 2015, Fitch downgraded the Support Ratings of 44 EU banks and their subsidiaries (Fitch 2015). Almost all EU and Swiss banks went to 'No Floor' category, reflecting Fitch's view that sovereign support can no longer be relied upon. Fitch's release date does not seem to correspond to any specific legislative action, but dates to the period of about one year when the bail-in provisions of the BRRD came into force in majority of EU member states (Table 6). Although only the view of a single ratings agency, the changes in Fitch Support Rating clearly support the notion that BRRD has reduced government support expectations. We next investigate whether the BRRD has also weakened the negative relationship between overnight borrowing rates and bank size.

First, we perform a standard difference-in-differences analysis and investigate whether the adoption of BRRD's bail-in provisions had an immediate effect on overnight borrowing in the corresponding countries. The relevant dates are gathered by ISDA (2016) and documented in Table 6. In the basic specification, we consider a 20 day window around each event (10 day before + 10 day after). We take the treatment group to be the banks in countries that adopted the bail-in provisions at date t_I, and the untreated (control) group are the banks whose country either never adopted the bail-in provisions or adopted the bail-in provisions at different date (outside the 20 day window).[21] Letting S_i denote the treatment dummy for bank i (=1 for treated banks) and T denote the event dummy (=1 after implementation of the bail-in provisions), the DD can be implemented as the following regression:

$$r_i = \beta_0 + \beta_1 T + \beta_2 S + \beta_3 (T \cdot S_i) + \varepsilon_i \, , \tag{3}$$

where the treatment effect on borrowing rate level is given by $\hat{\beta}_3$. To avoid overrepresentation of the most active banks, we use the average rate spread for r_i for each over the periods (instead of daily averages of individual loans) and standard OLS standard errors. The estimated treatment effect on coefficient of size is given by $\hat{\beta}_6$ from the following regression:

$$r_i = \beta_0 + \beta_1 T + \beta_2 S_i + \beta_3 (T \cdot S_i) + [\beta_4 + \beta_5 T + \beta_6 S_i + \beta_7 (T \cdot S_i)] \log Z_i + \varepsilon_i \, , \tag{4}$$

[20] A small number of mostly public sector or wind-down banks were expected to be less affected.
[21] The "bank in countries that never adopted BRRD" in the untreated group, yet present in the overnight loan data, include large number of banks in many countries from Eastern-Europe, Africa, Asia, Australia and the Americas. However, the banks are quite heterogeneous compared to European banks.

where $\log Z_{it}$ is the log of total assets of bank i.

We calculate the DD estimates for the "2015-01-01" and "2016-01-01" implementation dates separately and an additional DD estimate that pools all the implementation dates into one regression.[22] The results are shown in Table 7. Considering first the rate level (coefficient of ST in columns 1–3) using regression in Equation (3), we see that none of the treatment effects is statistically significant, and only the 2016 treatment effect is positive. The coefficients of S and T are not statistically significant either. Next, we estimate the treatment effect for coefficient of size using Equation (4). In this case, the treatment effects (coefficients of ST) are not statistically significant and in the range –0.004–0.001 (see coefficient of ST*Size in columns 4–6 of Table 7). The treatment effects of the level term is not statistically significant either. The only statistically significant factor in these regressions is the coefficient of size, which is in the range 0.028–0.032 in absolute value.

Thus, we can conclude that adoption of the BRRD's bail-in provisions has not had a significant effect on banks' over-night interbank borrowing rate.

Even if the immediate impact is not clearly distinguishable, it is worth trying to see if we can find evidence in support of a more gradual long-term impact. We return to the basic specification (Equation 1) and multiply bank size by three alternative time dummy variables. The first of them equals one for the latter part of our sample starting from 1 July 2012, which indicates the European Commission's proposal for new recovery and resolution tools for banks in crisis. Similarly, the second dummy equals one starting from 16 March 2013 (until the end of sample period), when the multilateral agreement was reached of a partial bail-in of bank debtors as part of the rescue package for Cyprus. Brunnermeier et al (2016) argue that the resolution procedure applied in the case of Cyprus may already have fundamentally affected expectations regarding future crisis resolution policies in Europe. So, the first two dummies capture the various stages when concrete market expectations regarding future bank resolution legislation may have started to take shape. The third time dummy equals one starting from 1 January 2016 (until the end of sample) when the BRRD came into force.

[22] In this case, we use robust standard errors adjusted for clustering. In the other cases, the robust standard errors estimates are actually smaller than the OLS estimates.

If the new legislation, or anticipation of it, has had an intended effect in reducing the implicit TBTF subsidies to banks, then our hypothesis is that the subsequent impact of bank size on bank overnight funding costs would have been weakened. Because the central aim of the BRRD is to weaken the bank-sovereign loop, we also apply the time dummies on the sovereign CDS spread. Moreover, since it is possible that the intended effects are largest in the crisis stricken GIIPS countries, we also add a dummy variable for them.

Table 8 shows the results, considering three model versions. In regression 1 of Table 8, we find no evidence that the negative effect of bank size on the bank's overnight borrowing cost has changed in the course of the planning and implementation of the BRRD. Similarly, the effect of sovereign CDS price on banks' overnight borrowing costs in the respective country has not changed after the BRRD. Regression 2 and especially regression 3 in Table 8 indicate that the BRRD has considerably weakened the effect of bank size on bank overnight borrowing cost for banks that are domiciled in the GIIPS countries.[23] In regression 3, we include only the dummy starting from 1 January 2016 when the BRRD came into effect, by interacting it with the dummy for GIIPS countries and the log of total assets. The effective coefficient on the log of total assets of banks in the GIIPS countries after the BRRD is reduced (in absolute terms) by two thirds compared to the base coefficient.[24] In contrast, we cannot reject the null that the BRRD has *not* changed the effect of sovereign CDS price on overnight borrowing cost of banks in the GIIPS countries either.

In regression 2 of Table 8, we have included a separate constant for banks in the GIIPS countries for the different phases of the run-up to the BRRD. The results suggest that the average cost of banks' overnight borrowing in the GIIPS countries have come down. In regression 3 of Table 8 where we include the GIIPS constant only for the period after 1 January 2016, the difference is statistically significant. These results might well reflect the impact of unconventional monetary policy programs of the ECB; the Outright Monetary Transactions

[23] We have also tested whether the interaction terms of different dummy variables with the size are jointly statistically significant. F-test indicates that in regression (1) the interaction terms D(T) x log(Total assets) are not jointly significant (p=0.1731), but in regression (2) the interaction terms D(T) x GIIPS x log(Total assets) are jointly significant (p=0.0008).

[24] The sum of coefficients of log of total assets in the GIIPS country group is -0.026 prior to January 1 2016 and -0.009 after that.

program announced in 2012 and the quantitative easing started in 2015, which may have indirectly affected banks' creditworthiness, especially in the GIIPS countries.

In sum, although banks' overnight borrowing costs have generally come down in the GIIPS countries over the sample period, the results are consistent with the notion that the BRRD has over time reduced the overnight borrowing cost advantage of larger banks in these countries.

5.4 Robustness checks

In Table 9, we further examine the relationship between bank size and borrowing cost by conditioning this relationship on market turbulence. Overnight rates can be quite sensitive to market turbulence as seen in Figure 3, which depicts the standard deviations of overnight borrowing rates and iTraxx CDS index. We include the product of bank size (the log of total assets) and the iTraxx Financials index for Europe, based on 5 year CDS spreads which are the most liquid CDS contracts. Models 3 and 5 of Table 9 show that the coefficient of the multiplicative term is negative and clearly significant. On balance, the coefficient of the log of total assets drops roughly by half (cf. model 1 in Table 9) but is still significant. The significant interaction term indicates that although overnight funding costs are expected to rise for all banks during market stress, they do less so for larger banks. This may be taken as further evidence that bank size indeed serves as a proxy for the TBTF expectations.

In models 4 and 5 of Table 9 we consider the possibility that the European Central Bank's liquidity provisioning benefits banks differently depending on their size and might hence explain part of the effect of bank size on the overnight funding cost. The coefficient on the product of bank size and Target 2 excess liquidity is statistically insignificant.[25] Hence, central bank liquidity measures seem not to have directly interfered with our measurement of the markets' TBTF expectations with bank size. However, to the extent that ECB's monetary policy has calmed the markets reflected as lower levels of iTraxx, they may impact our quantification of TBTF expectations.

[25] Note that the time fixed effects which we use in this regression should take care of any effect of ECB's liquidity measures on the general level of banks' overnight rates.

In Table 9 we also consider potential non-linearity in the bank size-funding cost relationship. It is possible that TBTF expectations primarily concern the very largest banks (cf. Acharya et al 2016). In model 2 of Table 9 an additional quadratic bank size term appears to be only marginally significant but this could be due to high multicollinearity.

6 Conclusions

Using a comprehensive data set of European banks' interbank borrowing rates, filtered from the Target 2 transactions data, we have investigated whether larger European banks have a cost advantage in unsecured overnight borrowing and whether the introduction of the Bank Recovery and Resolution Directive (BRRD) has reduced implicit public guarantees to larger banks in the light of this alleged bank size-borrowing cost relationship. We find that the overnight borrowing cost advantage of larger banks does exist and it is very robust in terms of both time periods, control variables and selection of countries and banks. We also find that the size premium has decreased over the sample period for banks domiciled in the GIIPS countries but not generally. However, this effect cannot be timed to the specific implementation dates of the BRRD in various member countries. This finding may be naturally explained by the fact that the overnight interbank loans are not immediately "bail-inable" in the BRRD framework. Therefore, it is still possible that the effect of BRRD could be observed in other debt instruments subject to lower seniority. Due to the longer maturity of such instruments, further analysis would need to rely on unexpected events (i.e. other than BRRD).

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Tables and figures

Table 1. Correlation between EONIA and the identified overnight transactions.

2008	2009	2010	2011	2012	2013	2014	2015	2016
0.994	0.996	0.977	0.987	0.956	0.785	0.99	0.934	0.942

Table 2. Variables used in this study

a) Sources and definitions

Variable	Definition	Source	Frequency
Total assets	Borrower's total assets	BankScope	Year
ROE	Net income divided by total equity	BankScope	Year
ROA	Net income divided by total assets	BankScope	Year
Tier 1 ratio	Total (tier 1) capital as a fraction of risk-weighted assets	BankScope	Year
Leverage ratio	Total equity divided by total assets	BankScope	Year
Non-interest income / Revenue	Non-interest income divided by gross revenue	BankScope	Year
NPL ratio	Impaired loans (i.e. non-performing loans) divided by gross loans	BankScope	Year
Liquid assets / Deposits	Liquid assets divided by deposits	BankScope	Year
Loans / Deposits	Loans divided by deposits	BankScope	Year
G-SIFI identifier	1, institution is G-SIFI (global systemically important financial institution) or G-SIFI subsidiary. 0, otherwise.	BankScope	Year
Exchange traded identifier	0, unlisted company. 1, listed company.	BankScope	Year
Country CDS	5 year, senior bonds	Thomson Reuters	Day
iTraxx Financials CDS index (iTraxx)	Equally weighted subindex for financials of the iTraxx Europe index.	Bloomberg	Day
Overnight rate spread	Bank specific borrowing rate minus EONIA rate.	ECB Target2	Day
Geographic concentration	Proxy for bank's geographic concentration calculated from the incoming customer payments (payment type 1.1 in Target2) by forming Herfindahl index from the shares of volume incoming from each country within a year.	ECB Target2	Year
Transaction size	Amount borrowed by bank B from bank L on day t	ECB Target2	Day
Transaction size / Equity	Size of the Target2 transaction in euro divided by the borrower's total equity	ECB Target2/BankScope	Day
No. of days pairs	Number or days on which funds were sold by the given lender to the given borrower during a year	ECB Target2	Year
No. of lenders	Number of lenders that sold funds to the given borrower during a year	ECB Target2	Year
Borrower preference index (BPI)	Total funds B has borrowed from L divided by total funds B has borrowed in the market. Based on past 60 days.	ECB Target2	Day
Lender preference index (LPI)	Total funds L has lent to B divided by total funds L has lent in the market. Based on past 60 days.	ECB Target2	Day
Excess reserves	System level excess reserves in Target 2. Calculated as Current account holdings + Overnight Deposits - Reserve requirement.	ECB	Day

b) Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Median	Units	Frequency
Total assets	5,439	188,489.8	317,377.5	48,544.0	Million euro	Year
ROE	5,303	3.2	23.5	5.5	%	Year
ROA	5,317	0.3	1.4	0.3	%	Year
Tier 1 ratio	3,592	11.2	4.7	10.4	%	Year
Leverage ratio	5,439	6.5	5.6	6.0	%	Year
Non-interest income / Revenue	5,381	34.9	60.2	33.2	%	Year
NPL ratio	3,880	5.6	5.7	4.1	%	Year
Liquid assets / Deposits	5,394	43.6	71.1	31.3	%	Year
Loans / Deposits	5,365	84.9	44.5	81.4	%	Year
G-SIFI identifier	6,080	0.25	0.47	0	0 or 1	Year
Exchange traded identifier	5,531	0.32	0.47	0	0 or 1	Year
Country CDS	787,454	135	519	79	bps	Day
iTraxx Financials CDS index	2,135	135	60	122	bps	Day
Overnight rate spread	1,016,238	-0.05	0.17	-0.06	%	Day
Geographic concentration	791,495	0.62	0.21	0.64	Fraction	Year
Transaction size	1,016,238	82.5	180.7	25.0	Million euro	Day
Transaction size / Equity	814,505	4.1	25.0	1.3	%	Day
No. of days pairs	1,016,238	62.4	58.0	44	Number	Day
No. of lenders	1,016,238	61.3	59.9	43	Number	Year
Borrower preference index (BPI)	953,730	0.17	0.27	0.04	Fraction	Day
Lender preference index (LPI)	953,730	0.26	0.31	0.12	Fraction	Day
Excess reserves	2,135	386	201	315	Billion euro	Day

Table 3. Determinants of banks' overnight funding costs

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Log(Total assets)	-0.030	-0.031	-0.030	-0.032	-0.032	-0.031	-0.032
	[10.80]	[11.27]	[10.53]	[9.32]	[8.73]	[8.73]	[9.53]
ROE		-0.057	-0.039	-0.033	-0.038		-0.048
		[5.18]	[3.08]	[2.94]	[2.91]		[4.05]
ROA						-0.769	
						[1.33]	
Leverage ratio		-0.072	-0.077	-0.067	-0.138	-0.085	
		[0.86]	[0.55]	[0.48]	[0.76]	[0.52]	
Tier 1 -ratio							-0.196
							[2.25]
Non-interest income/Revenue					-0.011	-0.010	-0.014
					[2.32]	[1.92]	[2.84]
NPL ratio					0.155	0.142	0.041
					[1.51]	[1.27]	[0.67]
Liquid assets/Deposits					-0.015	-0.015	-0.008
					[1.61]	[1.63]	[0.81]
Loans/Deposits					0.010	0.011	0.005
					[0.73]	[0.81]	[0.42]
D(G-SIFI)					0.008	0.007	0.004
					[0.45]	[0.38]	[0.22]
D(Listed)					-0.003	-0.003	0.002
					[0.19]	[0.16]	[0.14]
Country CDS			0.003	0.003	0.002	0.002	0.002
			[3.61]	[3.65]	[3.14]	[3.60]	[3.37]
Log(Number of lenders)				-0.016	-0.018	-0.018	-0.014
				[3.12]	[2.93]	[3.02]	[2.19]
Log(Transaction size)				0.016	0.018	0.018	0.017
				[6.61]	[9.54]	[9.30]	[9.66]
BPI				-0.017			
				[0.78]			
LPI				0.008			
				[0.52]			
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	814,506	804,194	753,681	714,845	635,403	636,418	595,094
Banks	1,326	1,295	1,074	1,056	721	721	609
R^2	0.2431	0.2489	0.2646	0.2915	0.3160	0.3153	0.3165

The dependent variable is interest rate spread defined for every pair of lender and borrower as the daily average of the difference between the interest rate on the loans between those two banks and the EONIA interest rate on the same day. Numbers inside the brackets are t-values adjusted for clustering at the bank level. The results are based on the full sample of banks. These clustered t-values are about one half of the ordinary t-values obtained with annual data. Estimated coefficients of variables expressed in % (such as ROE) are multiplied by 100.

Table 4. Parameter estimates for different years

a) Time fixed effects only

Variable	2008	2009	2010	2011	2012	2013	2014	2015	2016	2008-2016
Log(Total assets)	-0.014	-0.018	-0.022	-0.038	-0.029	-0.033	-0.005	-0.013	-0.013	-0.022
	[2.00]	[2.59]	[6.35]	[3.93]	[3.00]	[2.87]	[2.27]	[2.84]	[2.86]	[4.59]
Borrower's credit risk:										
NPL ratio	-0.002	-0.001	0.0002	0.003	-0.001	0.002	0.003	0.002	0.0004	0.001
	[0.64]	[0.82]	[0.36]	[1.01]	[0.61]	[0.82]	[2.74]	[2.78]	[0.47]	[0.70]
ROA	0.038	-0.004	-0.001	-0.009	-0.027	-0.054	0.007	-0.005	-0.003	-0.010
	[1.90]	[0.90]	[0.19]	[0.52]	[2.25]	[2.44]	[1.76]	[0.71]	[0.43]	[1.85]
Tier 1 ratio	-0.013	-0.004	-0.005	-0.003	-0.001	0.0001	0.001	0.003	-0.0004	-0.002
	[4.04]	[1.27]	[2.30]	[1.16]	[0.40]	[0.05]	[1.69]	[1.17]	[0.53]	[2.41]
Log(Transaction size/equity)	0.029	0.021	0.006	0.010	-0.007	-0.003	0.010	0.005	0.009	0.010
	[4.63]	[3.04]	[1.26]	[1.30]	[0.73]	[0.41]	[3.49]	[1.18]	[1.42]	[2.26]
Transaction characteristics:										
Transaction size<10	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
10<Transaction size<100	0.005	-0.001	0.014	0.010	0.012	0.021	-0.009	-0.013	-0.014	0.005
	[0.44]	[0.10]	[1.64]	[0.79]	[0.72]	[1.23]	[1.48]	[1.27]	[1.02]	[0.69]
Transaction size>100	-0.003	-0.001	0.024	0.049	0.052	0.056	-0.016	-0.028	-0.029	0.021
	[0.11]	[0.04]	[1.35]	[1.87]	[1.64]	[1.95]	[1.52]	[1.85]	[1.48]	[1.39]
Relationship characteristics										
Log(no. of days pair)	-0.00001	-0.003	-0.003	-0.009	0.006	0.014	-0.0003	0.002	0.004	0.000
	[0.002]	[0.93]	[0.88]	[2.84]	[1.04]	[2.48]	[0.11]	[0.85]	[1.18]	[0.18]
Log(no. of days pair)	0.052	-0.008	0.008	0.015	0.088	-0.107	-0.008	-0.062	-0.029	0.069
*(small borrower)	[1.92]	[0.38]	[0.95]	[0.78]	[6.91]	[2.12]	[1.62]	[1.69]	[2.21]	[3.09]
Log(no. of lenders)	0.001	0.006	-0.008	-0.012	-0.042	-0.019	-0.003	-0.012	-0.016	-0.013
	[0.05]	[0.54]	[0.70]	[1.04]	[2.63]	[1.50]	[0.87]	[2.04]	[1.58]	[1.79]
Geographic concentration	-0.020	-0.011	0.033	0.083	0.00001	-0.079	0.021	-0.013	-0.051	0.004
	[0.41]	[0.35]	[0.96]	[1.46]	[0.0002]	[1.51]	[1.62]	[0.54]	[1.16]	[0.15]
Fixed effects										
	Time	Time	Time	Time	Time	Time	Time	Time	Time	Time
Banks	169	174	200	205	193	177	195	165	139	341
Observations	72,929	97,003	94,804	88,550	45,731	36,543	46,889	30,867	20,187	533,503
R-squared	0.248	0.333	0.338	0.324	0.432	0.413	0.318	0.368	0.311	0.313
Joint-significance of four credit risk variables										
Wald statistics	7.14	3.01	2.60	2.22	2.22	2.85	3.20	3.37	0.93	6.99
p-value	0.000	0.020	0.037	0.068	0.068	0.025	0.014	0.011	0.447	0.000
Joint-significance of four relationship characteristics										
Wald statistics	1.49	0.32	2.05	2.95	31.84	2.49	1.45	2.03	1.77	3.98
p-value	0.207	0.866	0.088	0.021	0.000	0.045	0.218	0.092	0.139	0.004

The dependent variable is the overnight rate spread. Sample includes EU banks only. Except for the risk factors, the notation is the same as in Table 3.

Variable	2008	2009	2010	2011	2012	2013	2014	2015	2016	2008-2016
Log(Total assets)	-0.023	-0.025	-0.029	-0.042	-0.025	-0.033	-0.023	-0.028	-0.022	-0.029
	[5.65]	[6.34]	[10.74]	[10.65]	[4.83]	[3.79]	[5.44]	[7.15]	[7.86]	[10.10]
Fixed effects	Time	Time	Time	Time	Time	Time	Time	Time	Time	Time
Banks	490	494	508	523	459	383	419	341	258	840
Observations	97,997	129,591	123,187	116,082	62,043	49,130	61,855	41,051	24,797	705,733
R-squared	0.161	0.242	0.245	0.228	0.188	0.176	0.264	0.345	0.269	0.243

Same as above but leaving out all other explanatory variables besides bank size.

b) Country and time fixed effects

Variable	2008	2009	2010	2011	2012	2013	2014	2015	2016	2008-2016
Log(Total assets)	-0.011	-0.006	-0.016	-0.018	-0.015	-0.020	-0.008	-0.012	-0.010	-0.010
	[0.97]	[0.73]	[2.56]	[2.04]	[1.88]	[2.34]	[2.14]	[2.48]	[2.85]	[1.99]
Borrower's credit risk:										
NPL ratio	-0.004	-0.003	0.000001	0.004	0.001	0.003	0.001	-0.0001	-0.001	0.000
	[1.21]	[1.66]	[0.00]	[1.80]	[0.43]	[1.55]	[1.63]	[0.15]	[1.33]	[0.65]
ROA	0.009	-0.008	0.004	0.009	-0.008	-0.025	0.001	-0.011	-0.009	-0.009
	[0.53]	[2.46]	[1.02]	[0.85]	[0.82]	[1.61]	[0.51]	[2.05]	[1.17]	[2.85]
Tier 1 ratio	-0.012	-0.005	-0.004	-0.002	-0.001	-0.0001	0.001	0.002	-0.0005	-0.002
	[3.60]	[1.46]	[1.62]	[1.17]	[0.26]	[0.06]	[1.57]	[1.25]	[0.73]	[2.84]
Log(Transaction size/equity)	0.025	0.024	0.009	0.020	0.006	0.009	0.010	0.003	0.005	0.015
	[4.87]	[5.88]	[2.25]	[4.50]	[0.86]	[2.01]	[5.44]	[1.60]	[1.61]	[5.57]
Transaction characteristics:										
Transaction size<10	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
10<Transaction size<100	-0.0002	-0.008	0.008	-0.003	0.009	0.021	-0.006	-0.007	-0.005	0.000
	[0.02]	[0.82]	[1.27]	[0.33]	[0.70]	[1.63]	[1.46]	[0.96]	[0.56]	[0.06]
Transaction size>100	-0.001	-0.009	0.015	0.009	0.017	0.029	-0.010	-0.014	-0.013	0.009
	[0.05]	[0.57]	[1.16]	[0.50]	[0.72]	[1.40]	[1.32]	[1.53]	[1.02]	[0.81]
Relationship characteristics										
Log(no. of days pair)	-0.005	-0.003	-0.002	-0.007	0.001	0.008	-0.002	-0.0002	0.002	-0.001
	[1.64]	[0.98]	[1.11]	[3.09]	[0.28]	[1.69]	[0.79]	[0.16]	[0.84]	[0.77]
Log(no. of days pair)	0.076	0.010	-0.001	0.027	0.078	-0.034	-0.011	-0.055	-0.058	0.067
*(small borrower)	[2.16]	[0.54]	[0.08]	[1.86]	[5.79]	[0.79]	[2.24]	[2.33]	[1.75]	[3.58]
Log(no. of lenders)	0.011	-0.0005	-0.008	0.005	-0.018	-0.010	0.005	-0.005	-0.022	-0.007
	[0.83]	[0.05]	[1.10]	[0.52]	[1.71]	[1.11]	[1.36]	[0.92]	[2.26]	[1.46]
Geographic concentration	0.041	0.079	0.043	0.151	0.077	-0.036	0.050	0.039	-0.045	0.054
	[0.75]	[1.64]	[1.72]	[3.87]	[2.58]	[0.84]	[3.90]	[1.91]	[0.94]	[2.70]
Fixed effects	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country
	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time
Banks	169	174	200	205	193	177	195	165	139	341
Observations	72,929	97,003	94,804	88,550	45,731	36,543	46,889	30,867	20,187	533,503
R-squared	0.301	0.418	0.379	0.437	0.622	0.577	0.400	0.536	0.461	0.388
Joint-significance of four credit risk variables										
Wald statistics	8.46	12.53	3.65	7.73	1.05	2.08	7.55	2.09	1.29	11.66
p-value	0.000	0.000	0.007	0.000	0.381	0.085	0.000	0.085	0.278	0.000
Joint-significance of four relationship characteristics										
Wald statistics	2.21	1.40	2.44	6.20	15.58	0.82	5.63	3.41	2.25	5.72
p-value	0.070	0.236	0.048	0.000	0.000	0.517	0.000	0.010	0.067	0.000

The dependent variable is the overnight rate spread. Sample includes EU banks only. Except for the risk factors, the notation is the same as in Table 3.

Variable	2008	2009	2010	2011	2012	2013	2014	2015	2016	2008-2016
Log(Total assets)	-0.021	-0.024	-0.026	-0.032	-0.026	-0.027	-0.020	-0.021	-0.020	-0.025
	[4.40]	[4.87]	[7.03]	[7.27]	[5.60]	[4.32]	[7.03]	[6.17]	[6.83]	[8.13]
Fixed effects	Country	Country	Country	Country	Country	Country	Country	Country	Country	Country
	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time	+ Time
Banks	490	494	508	523	459	383	419	341	258	840
Observations	97,997	129,591	123,187	116,082	62,043	49,130	61,855	41,051	24,797	705,733
R-squared	0.231	0.297	0.365	0.398	0.516	0.516	0.472	0.579	0.428	0.343

Same as above but leaving out all other explanatory variables besides bank size.

Table 5. Results for conditioning the size variable.

Variable	(1)	(2)	(3)
Log(Total assets)	-0.025	-0.025	-0.026
	[9.41]	[9.03]	[9.59]
D(State owned)*Log(Total assets)		-0.012	
		[0.95]	
D(Core state owned)*Log(Total assets)			0.021
			[2.88]
ROE	-0.037	-0.032	-0.032
	[2.48]	[2.10]	[2.78]
Leverage ratio	-0.185	-0.152	-0.139
	[1.61]	[1.37]	[1.19]
Country CDS	0.032	0.032	0.032
	[8.22]	[8.29]	[8.30]
D(State owned)		0.176	
		[1.15]	
D(Core state owned)			-0.183
			[2.27]
Time fixed effects	Yes	Yes	Yes
N	739,743	739,743	739,743
Banks	799	799	799
R-squared	0.3038	0.3107	0.3101

The notation and estimating equation is the same as Table 3. The sample is restricted to EU banks. The dummy of "Core state owned" refers to Austria, Belgium, Finland, France, Germany, Luxembourg, Netherlands, and United Kingdom. The dummy of "State owned" refers to state owned banks by any state in the sample.

Table 6. Country-specific BRRD implementation dates

Country	Date bail-in provisions come into force
Switzerland	2012-11-01
Hungary	2014-09-16
Austria	2015-01-01
Germany	2015-01-01
Gibraltar	2015-01-01
Slovakia	2015-01-01
Croatia	2015-02-26
Estonia	2015-03-29
Denmark	2015-06-01
Latvia	2015-07-16
Bulgaria	2015-08-14
Greece	2015-11-01
Netherlands	2015-11-26
Lithuania	2015-12-03
Czech Republic	2016-01-01
Belgium	2016-01-01
Finland	2016-01-01
France	2016-01-01
Ireland	2016-01-01
Italy	2016-01-01
Luxembourg	2016-01-01
Malta	2016-01-01
Portugal	2016-01-01
Romania	2016-01-01
Spain	2016-01-01
United Kingdom	2016-01-01
Sweden	2016-02-01
Cyprus	2016-03-18
Slovenia	2016-06-25
Poland	2016-10-09
Liechtenstein	2017-01-01
Iceland	Not yet implemented
Norway	Not yet implemented

Source: ISDA (2016).

Table 7. Short-term development of key variables around BRRD implementation events.

Variable	(1)	(2)	(3)	(4)	(5)	(6)
S	-0.01	0.011	-0.01	0.043	-0.098	-0.035
	[0.6]	[0.5]	[1.4]	[0.7]	[0.7]	[0.8]
T	0.022	-0.023	0.001	0.041	-0.008	-0.004
	[4.7]	[4.1]	[0.7]	[0.9]	[0.1]	[0.7]
S*T	-0.017	0.011	-0.003	-0.032	0.041	0.041
	[2.4]	[1.1]	[0.6]	[0.5]	[0.5]	[1.4]
Log(Total assets)				-0.028	-0.032	-0.028
				[5.8]	[3.7]	[7.8]
S*Log(Total assets)				-0.006	0.009	0.002
				[1.0]	[0.8]	[0.6]
T*Log(Total assets)				-0.001	-0.001	0.000
				[0.4]	[0.3]	[0.8]
S*T*Log(Total assets)				0.001	-0.002	-0.004
				[0.3]	[0.2]	[1.4]
Constant	-0.006	-0.002	0.003	0.281	0.336	0.293
	[0.6]	[0.1]	[0.5]	[5.3]	[3.4]	[7.3]
Event	2015-01	2016-1	All	2015-01	2016-1	All
N	276	194	3978	224	161	3171
Banks	138	97	398	114	81	297
R-squared	0.0157	0.0114	0.0006	0.3891	0.2655	0.237

Estimates are based on Equations (2) and (3). The LHS variable is the ON rate average within the 10 day pre-BRRD period or the 10-day post-BRRD period. Only banks that borrow both in the pre-BRRD and post-BRRD window are included. Numbers inside the brackets are t-values. For (3) - (5) these t-values are adjusted for clustering at the bank level.

Table 8. Impact of the EU resolution regime on the size-dependence of banks funding costs.

Variable	(1) ON rate	(2) ON rate	(3) ON rate
Log(Total assets)	-0.026	-0.023	-0.024
	[9.12]	[7.27]	[7.04]
GIIPS*Log(Total assets)		-0.003	-0.002
		[0.56]	[0.26]
D(2012-07-01)*Log(Total assets)	0.000		
	[0.07]		
D(2013-12-19)*Log(Total assets)	0.005		
	[1.04]		
D(2016-01-01)*Log(Total assets)	0.000		
	[0.06]		
D(2012-07-01)*GIIPS*Log(Total assets)		-0.001	
		[0.12]	
D(2013-12-19)*GIIPS*Log(Total assets)		0.008	
		[1.46]	
D(2016-01-01)*GIIPS* Log(Total assets)		0.011	0.017
		[1.82]	[3.67]
ROE	-0.038	-0.042	-0.040
	[2.52]	[2.87]	[2.74]
Leverage ratio	-0.191	-0.196	-0.186
	[1.67]	[1.86]	[1.65]
Country CDS	0.032	0.030	0.030
	[8.21]	[7.00]	[6.81]
D(2012-07-01)*Country CDS	0.005		
	[0.53]		
D(2013-12-19)*Country CDS	0.005		
	[0.53]		
D(2016-01-01)*Country CDS	-0.021		
	[1.33]		
D(2012-07-01)*GIIPS*Country CDS		0.039	
		[1.39]	
D(2013-12-19)*GIIPS*Country CDS		0.008	
		[0.19]	
D(2016-01-01)*GIIPS*Country CDS		0.035	0.081
		[0.94]	[1.23]
GIIPS		0.057	0.029
		[0.93]	[0.43]
D(2012-07-01)*GIIPS		-0.135	
		[1.59]	
D(2013-12-19)*GIIPS		-0.004	
		[0.07]	
D(2016-01-01)*GIIPS		-0.161	-0.282
		[1.78]	[3.04]
R-squared	0.3044	0.3103	0.3054
N	739743	739743	739743
Banks	799	799	799
F-test for all D(T)*Size = 0	F(3,798)=1.67	F(3,798)=5.62	F(1,798)=13.49
or for all D(T)*GIIPS*Size = 0	p=0.1731	p=0.0008	p=0.0003

The notation and the basic estimating equation is the same as in Table 3. The sample is restricted to EU banks. $D(T) = 1$ if $t \geq T$ and 0 otherwise. Size = log(Total assets).

Table 9. Testing for non-linearity in the size-dependence of banks funding costs.

Variable	(1)	(2)	(3)	(4)	(5)
Log(Total assets)	-0.030	-0.066	-0.014	-0.030	-0.015
	[10.53]	[2.31]	[4.21]	[10.95]	[4.32]
[Log(Total assets)]^2		0.002			
		[1.29]			
iTraxx*Log(Total assets)			-0.012		-0.013
			[4.86]		[5.36]
Excess reserves*Log(Total assets)				-0.002	0.010
				[0.35]	[1.79]
ROE	-0.039	-0.038	-0.039	-0.039	-0.040
	[3.08]	[2.99]	[2.88]	[3.08]	[2.92]
Leverage ratio	-0.077	-0.111	-0.086	-0.077	-0.084
	[0.55]	[0.79]	[0.61]	[0.55]	[0.59]
Country CDS	0.003	0.003	0.003	0.003	0.003
	[3.61]	[3.64]	[3.59]	[3.61]	[3.59]
Time fixed effects	Yes	Yes	Yes	Yes	Yes
N	753,681	753,681	753,681	753,599	753,599
Banks	1,074	1,074	1,074	1,074	1,074
R-squared	0.2646	0.2661	0.2715	0.2646	0.2721

The notation and estimating equation is the same as in Table 3. The results are based on the full sample of banks.

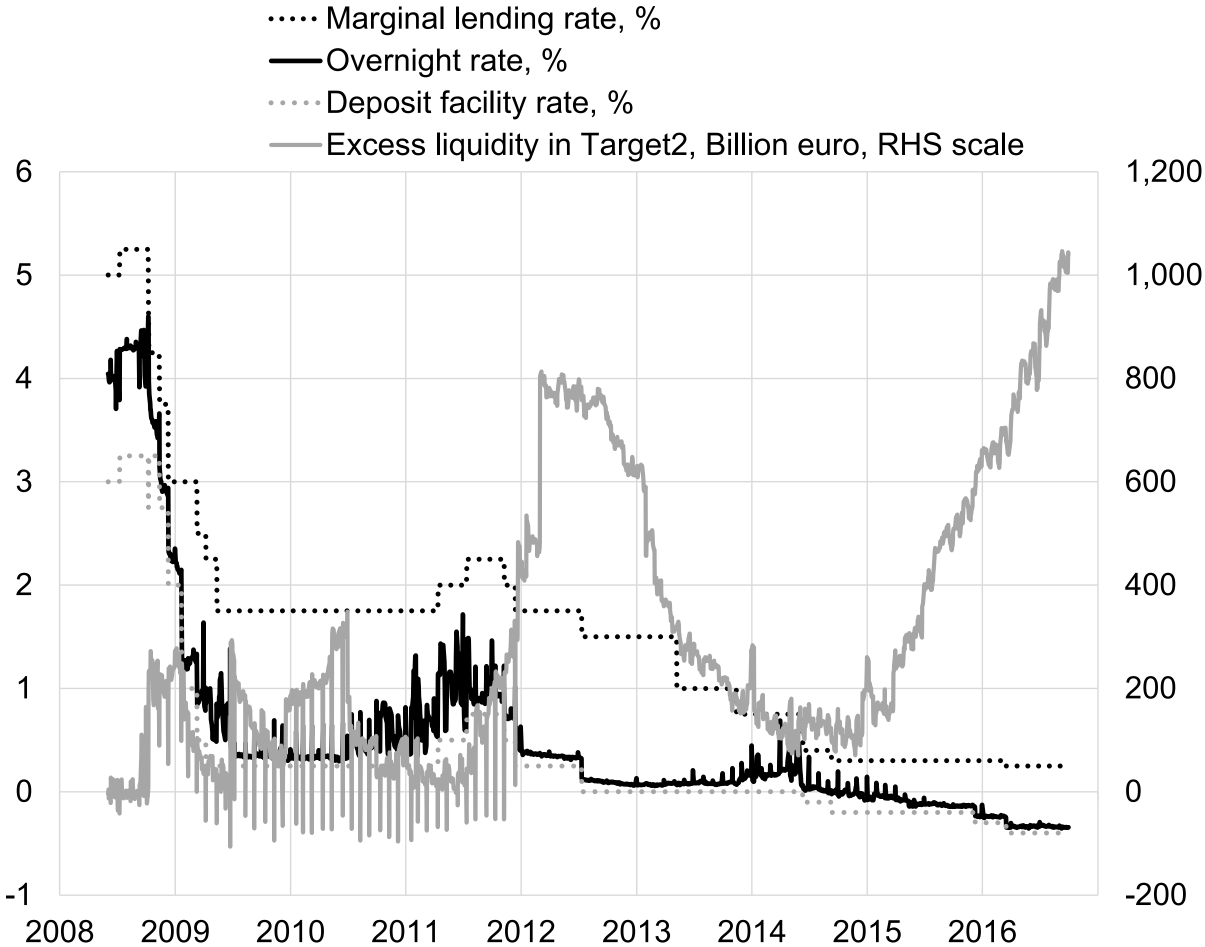


Figure 1. Euro overnight index average (EONIA), the corridor between marginal lending rate and deposit facility rate, and excess liquidity in Target 2.

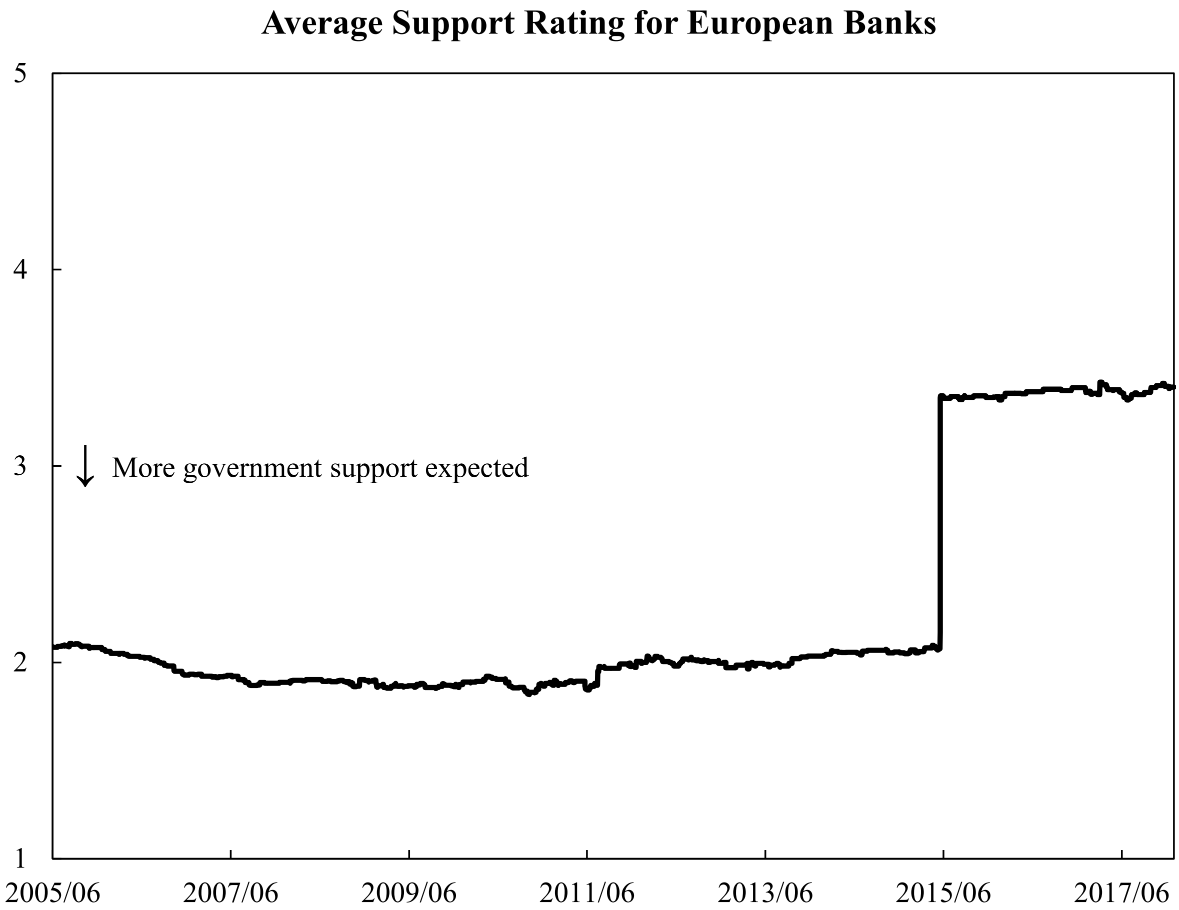


Figure 2. Historical development of Fitch Support Ratings for European Banks. The different rating categories are 1: A bank for which there is an extremely high probability of external support. 2: A bank for which there is a high probability of external support. 3: A bank for which there is a moderate probability of support because of uncertainties about the ability or propensity of the potential provider of support to do so. 4: A bank for which there is a limited probability of support because of significant uncertainties about the ability or propensity of any possible provider of support to do so. 5: A bank for which there is a possibility of external support, but it cannot be relied upon.

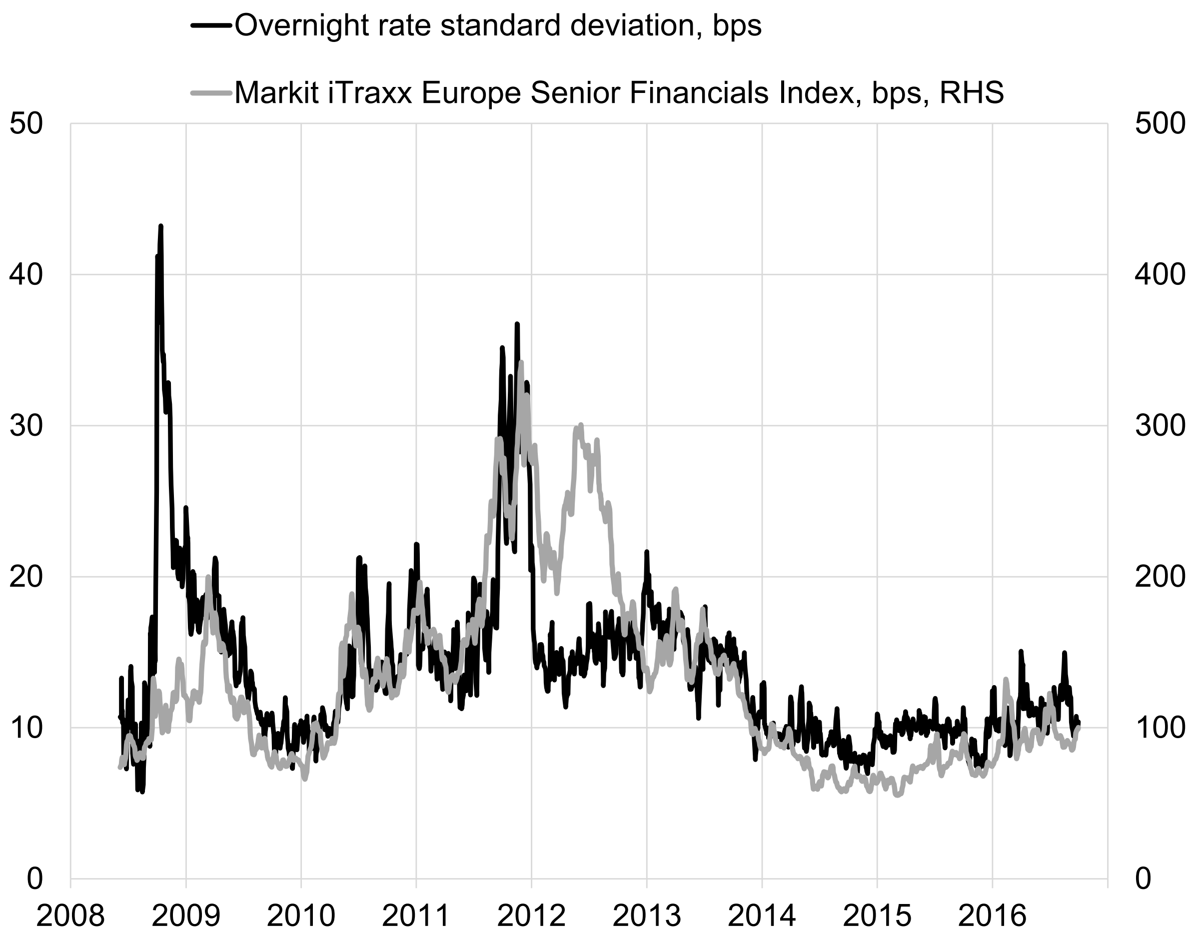
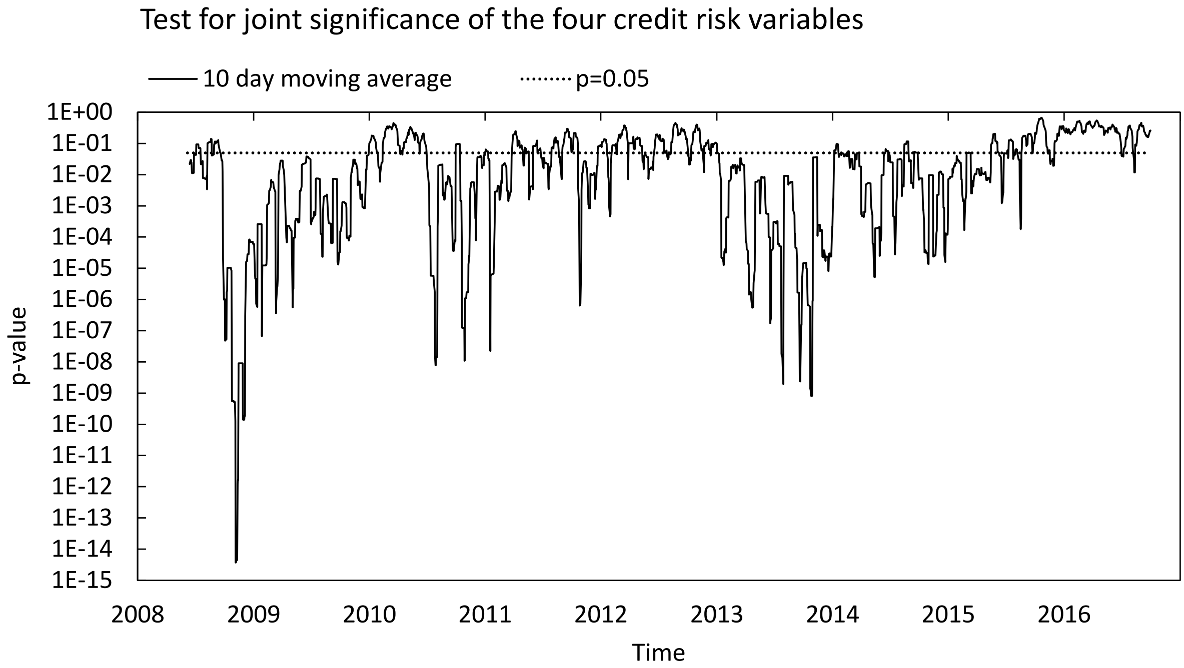


Figure 3. Standard deviation of overnight borrowing rates and iTraxx CDS index.

The lines are weekly moving averages. Full sample is used.

a) Test for joint significance of the four credit risk variables



b) Test for joint significance of the five relationship variables

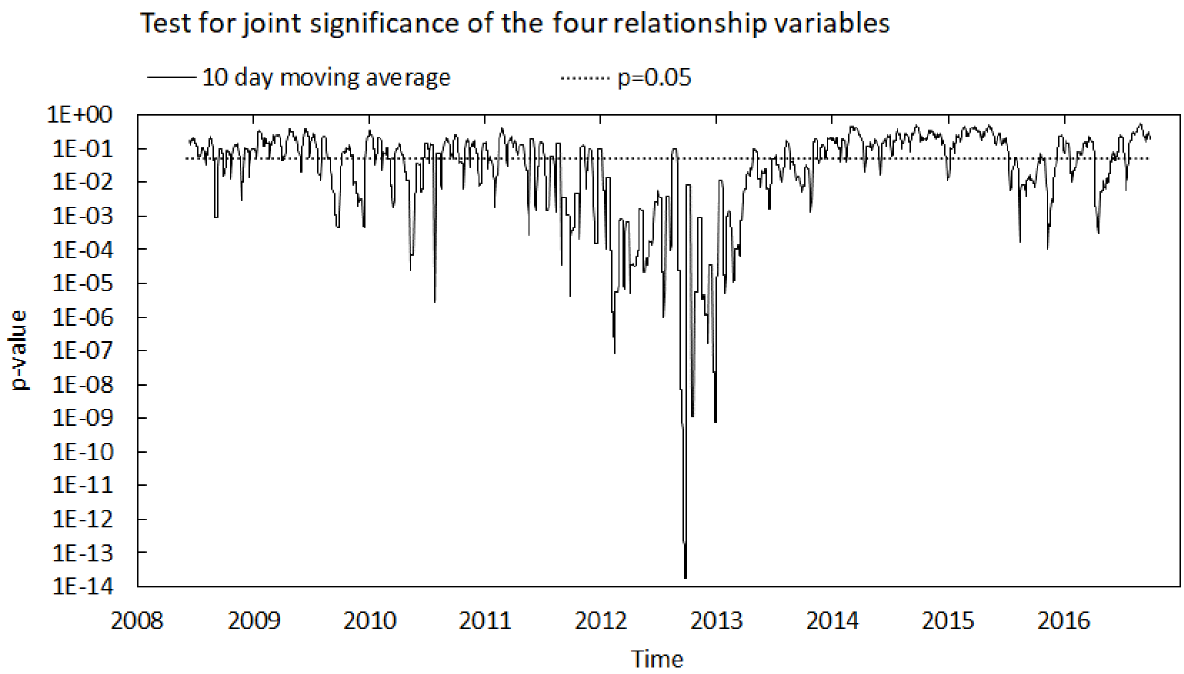


Figure 4. Dynamics of borrowing rate determinants
Graphs show the joint significance of credit risk or relationship variables calculated separately for each of the 2,136 business days in the sample. Values below the dotted line are statistically significant at the 95 % confidence level. The regression specification is same as in Table 4a.

Supplementary figures:

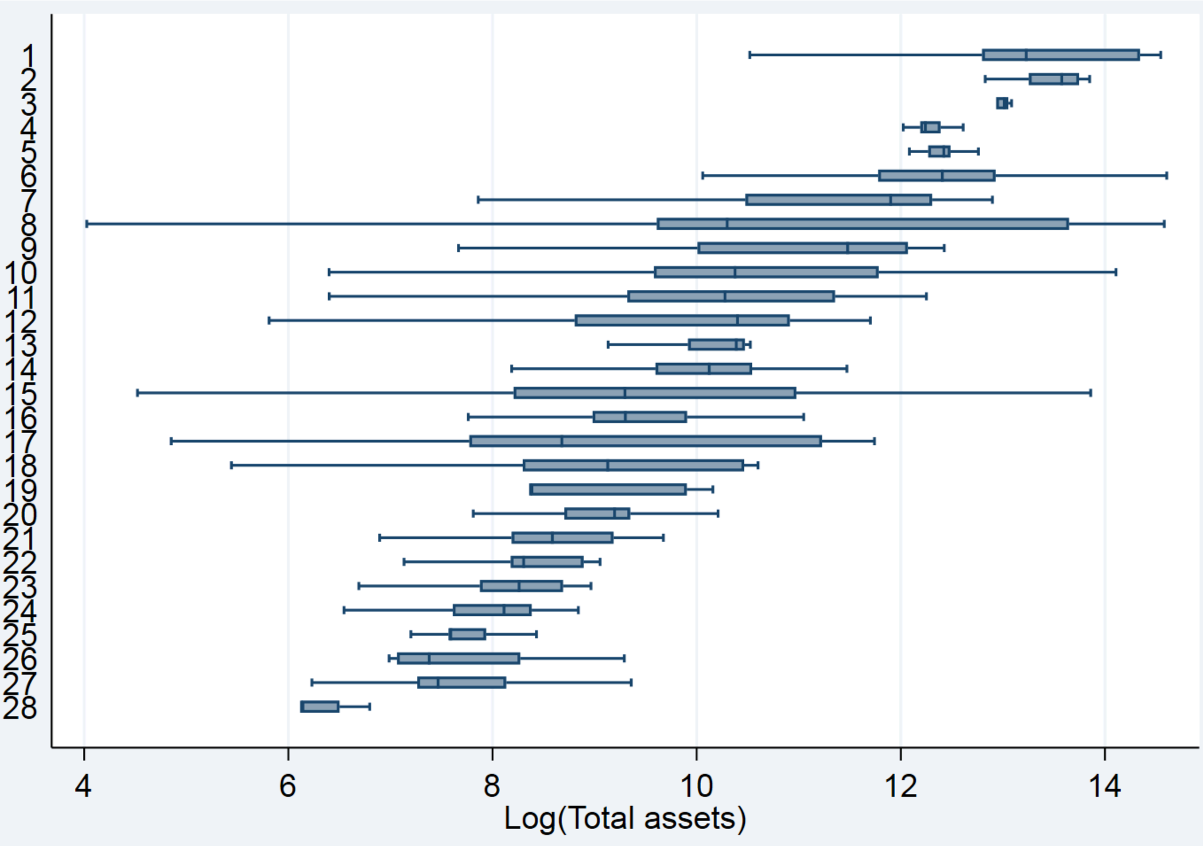


Figure S1. Size distribution of sample banks in different countries

The countries are anonymized and ordered by mean bank size.

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