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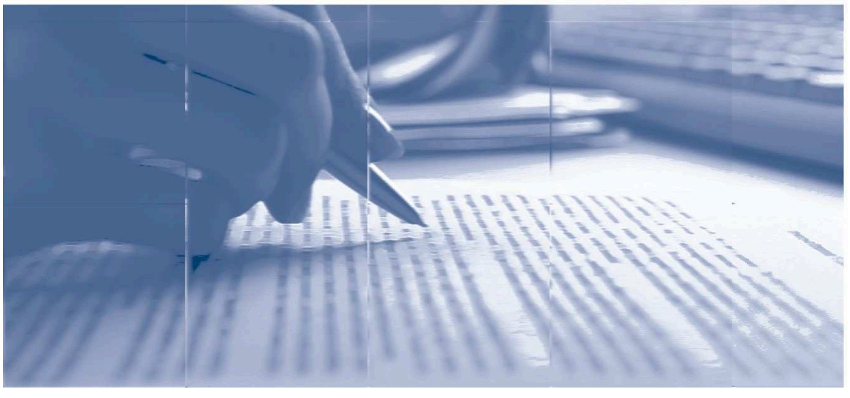

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Systemic Risk-Taking Channel of Domestic and Foreign Monetary Policy

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Abstract

The Working Papers should not be reported as representing the views of the Banco Central do Brasil. The views expressed in the papers are those of the author(s) and not necessarily reflect those of the Banco Central do Brasil.

The paper investigates the impact of domestic and foreign monetary policy on two systemic risk indicators in Brazil, namely, the Default Correlation and the DebtRank, which summarize, respectively, the joint default probability of financial institutions and the contagion through the interbank market given a default event. Results show that the domestic policy rate has a robust and statistically significant inverse relation with systemic risk, consistent with the risk-taking channel of monetary policy extended here for correlated risks and network externalities. Results are similar for the foreign policy rate, although not statistically significant in the most recent sample, consistent with a lesser role of banks in the transmission of foreign shocks. Results are also similar for reserve requirement rates, but not statistically significant, consistent with its operation on a narrower transmission channel.

Keywords: systemic risk, macroeconomic environment, monetary policy, banks.
JEL Classification: G21, E58.

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"Risk-taking channel (...) defined as the impact of changes in policy rates on either risk perceptions or risk-tolerance and hence on the degree of risk in the portfolios, on the pricing of assets, and on the price and non-price terms of the extension of funding" Borio and Zhu (2008)

1 Introduction

According to the risk-taking channel hypothesis, monetary policy easing leads financial intermediaries to increase leverage and to take on more risk, or the opposite in case of tighter monetary conditions (e.g. Borio and Zhu (2008), Adrian and Shin (2009), Dell'Ariccia et al. (2010)). To the extent that financial intermediaries take on correlated risks or ignore the contagion implications of their leverage decisions, this could be associated with simultaneous failures or even contagion processes causing multiple cascading failures. In other words, there would be a systemic risk-taking channel. Even though much of the interest in the risk-taking channel stems from its possible systemic risk implications, there is a large gap in the empirical literature, which has focused so far on local risks at financial institutions.

In this paper, we investigate the impact of monetary policy on systemic risk indicators of financial institutions in Brazil, measured as the contribution of each institution to overall systemic risk measures. The country is particularly relevant for the literature. First, it has a large and sophisticated financial market with rich and high quality datasets, including complete data for cross-exposures in the interbank market. Second, it presents large swings in the domestic policy rate implemented through open market operations, as well as important variation in reserve requirement rates affecting directly the narrow credit channel. Third, it maintains strong connections with the global financial market such that foreign monetary policy affects the domestic economy. Therefore, the country is an ideal setting to investigate the systemic risk-taking channel of monetary policy in both its domestic and cross-border dimensions. To our knowledge, this is the first empirical paper to investigate this research question.

The systemic risk indicators we consider are Default Correlation and DebtRank. These indicators capture two different types of systemic events, namely, the joint failure of banks or the stress related to the contagion process initiated by the failure of a bank. Default correlation is a novel concept proposed here. We start its computation using the Merton model to calculate marginal default probabilities. Next, we build joint pairwise distributions by minimizing the entropy conditional on these marginals (*cf* Segoviano (2006)) to compute joint default probabilities for pairs of banks. Finally, we compute the

Default Correlation as the average of the ten highest pairwise correlations of default events involving a particular financial institution and its peers. DebtRank is a standard concept, which captures the propagation of stress originating in a particular financial institution using the relevant set of cross exposures and capital buffers present in the interbank network Battiston et al. (2012)). Both indicators use high quality balance sheet and interbank exposures data.

The empirical strategy is to estimate standard dynamic panel models (Arellano and Bond (1991)) with monetary policy variables on the right hand side and the contribution of a bank to systemic risk (either Default Correlation or DebtRank) on the left hand side. We also include several macroeconomic and microeconomic control variables. Fixed effects and subsampling along different bank categories take care of heterogeneity and possible omitted variables. We explore results for a long sample from 2005 to 2014 (only for Default Correlation) and one comprising just the period following the global financial crisis.

The monetary policy indicators are the domestic policy rate, the effective domestic reserve requirement rate, and the foreign shadow policy rate. The cleanest measure is the domestic policy rate, which is set by the Central Bank in an inflation-targeting framework independently from financial stability considerations. On the other hand, effective reserve requirements depend on the rates set by the Central Bank and on the funding decisions by banks. The first component is set either as an instrument to affect the narrow credit channel independently of the policy rate or as a liquidity buffer for liquidity crisis.

The foreign monetary policy indicator comes from a shadow rate term structure model. It summarizes monetary policy even when the economy is operating very near the zero lower bound for interest rates, which is the case for the most recent period of our sample. We use the shadow policy rate for the United States from Wu and Xia (2015) because it has stable dynamic correlations with macro variables even when the policy rate is near the zero lower bound. We also use the corresponding indicator for the European Union in robustness exercises. These indicators seem better than other alternatives in the literature, such as the term spread. However, they do depend on the specific assumptions of the term structure model. Because of these measurement issues, the direct effects of reserve requirements and foreign shadow policy rate are interpreted with caution.

We also perform a robustness test to take into account macroprudential measures that have been used to mitigate systemic risk that might stem from the loosening of the domestic monetary policy and from speculative cross-border capital flows related to domestic and/or foreign monetary policy decisions. To do so, we build a macroprudential measures index that increases when tightening measures come into effect and decreases when there is loosening. These tests provide support for the results obtained for the Default Correlations risk indicator, but suggest that DebtRank-related results should be interpreted cautiously.

Our main contribution to the literature reviewed below are the estimated effects of domestic and foreign monetary policy on systemic risk-taking by Brazilian financial institutions. Second, the specification of dynamic panels with banks specific measures of their impact on systemic risk as dependent variable is novel and easy to reproduce and scale up once the systemic risk indicators are available. Third, the Default Correlation is a novel concept that has low information requirements and is, therefore, of wide applicability. Fourth, we extend the DebtRank systemic risk indicator to take into account the additional stress that arise from pledged collateral related to secured operations. This substitutes the usual approach, which is to consider that secured exposures are not stress sources.

Our results strongly favor the systemic risk-taking channel hypotheses. Monetary policy easing, as captured by the policy rate, increases systemic risk-taking, with higher default correlations and higher level of stress transmission through the interbank network - while the opposite holds true for monetary tightening. The effect is statistically significant in both the short run and the long run.

Foreign monetary policy easing, as captured by the shadow policy rate, affects systemic risk in the same direction as the domestic policy rate. However, in the case of the Default Correlation indicator, the effect is statistically significant only for the long sample. If the sample has only private banks, the effect is also significant for Debt Rank along the post-crisis period. The weaker effect in the post-crisis sample may signal that international banks and bank to bank credit has been weaker after the global financial crisis, an hypothesis we develop in more detail below. Reserve requirements also operate in the same direction, but the effects were not statistically significant, except for short run effects in private banks. This reflects both the lesser scope of the policy, which operate only on the narrow credit channel, and the use of the instrument to implement macroprudential objectives.

In Section 1.1, we review the literature, in Section 2, we present the context of the analyses and state the hypotheses we are investigating, in Section 3, we present the methodology employed in our analysis, specifically, the risk measures. In Section 4, we present data: banks risk data, bank-level controls and macro variables. In Section 5, we show results for each bank risk indicator. In Section 6, we perform and analyze robustness tests, and finally, in Section 7, we conclude.

1.1 Literature Review

The literature on the risk-taking channel of monetary policy builds on Borio and Zhu (2008), who proposed the concept and corresponding causal mechanisms, such as risk tolerance increasing with wealth, sticky target rates of returns and the perception that the central bank reaction function is effective in cutting off large downside risks (implicit put of monetary policy to downside risks.) Adrian and Shin (2009) show leverage constraints are formally similar to risk appetite, so that easy money relaxes constraints and incentivizes leverage. Dell'Ariccia et al. (2010) formalize the argument that easy money incentivizes leverage through lower costs of debt, and high leverage reduces incentives for banks to monitor. Acharya (2009) argues that banks have incentives to undertake correlated investments due to limited liability, but does not establish the connection with the stance of monetary policy. Diamond and Rajan (2009) and Farhi and Tirole (2012) show that the banks have incentives to correlate their risk exposure if they have the expectation of a monetary policy bailout. De Groot (2014) argues that the volatility of monetary policy shocks and the shape of the monetary policy decision rule affect bank leverage decisions.

There is a growing empirical literature exploring the risk-taking channel of monetary policy from the point of view of individual financial institutions. Jiménez et al. (2014) use credit register data from Spain and show banks lend more to riskier firms during policy easing, particularly for banks with low capital ratios. Altunbas et al. (2012) show solvency problems during the crisis were more severe for banks in jurisdictions with low interest rates for a long time and for banks with less capital. Maddaloni and Peydró (2011) show lending standards deteriorate in response to lower short-term interest rates.

Lee et al. (2015) use syndicated loan data to show that, before the crisis, lenders invest in riskier loans in response to a decline in short-term US rates while, after it, to a decline in long-term US interest rates. Marques et al. (2013) show that government support measured with a proxy capturing the probability of bailout is associated with more risk taking by banks measured with the Z-score. Gong (2014) documents that banks protected by the public guarantee expect to be bailed out in systemic crisis and therefore are less concerned with aggregate risk. Compared to nonbank lenders in syndicated loans, they take more systematic risk than idiosyncratic risk, charging lower rates for aggregate risk.

Regarding reserve requirement policy, Camors and Peydró (2013) show that an increase of the requirements for short-term funding in Uruguay imply a reduction of credit supply, with increase in the exposure to riskier firms. Tovar Mora et al. (2012) document that reserve requirements affect credit growth, but have no implications for risk-taking.

Glocker and Towbin (2012) obtain a similar result for the case of Brazil. Montoro and Moreno (2011) survey the reserve requirements policy use in Latin America, including its use as a macroprudential tool in face of risky capital flows and liquidity shocks.

Bruno and Shin (2012) study the risk-taking channel of monetary policy in advanced economies and examine the relationship between low interests maintained by advanced economy central banks and credit booms in emerging economies. They find that the risk-taking channel stimulates cross-border banking sector capital flows, allowing that global banks branches in emerging economies increase their lending.

2 Background and Hypothesis Development

2.1 Background

The Central Bank of Brazil has both a price stability and a financial stability mandate, being responsible for monetary policy, financial regulation and financial supervision. Monetary policy follows an inflation-targeting regime since 1999. In principle, monetary policy and financial stability have different instruments: the policy rate is used for inflation targeting, whereas regulation and supervision are used for financial stability. In this context, the use of reserve requirements is less specific. Reserve requirements can be used both as a monetary policy instrument and as a regulatory measure to prevent systemic risk. Cordella et al. (2014) argue that there is evidence that developing countries have used reserve requirements for stabilizing capital flows and the credit cycle when there are severe limits on the policy interest rate's ability to smooth the level of credit and/or economic activity, case in which reserve requirements are used as a monetary policy instrument. In turn, Tovar Mora et al. (2012) highlight the reserve requirements' usage with macroprudential purposes, especially to foster financial stability, as follows. First, they can serve as a countercyclical tool to manage the credit cycle in a broad context, limiting the excessive leverage of borrowers in the upswing and operating as a liquidity buffer in the downswing. Second, they can help to contain systemic risks by improving the funding structure of the banking system. Third, in time of stress, reserve requirements can direct credit allocation to ease liquidity constraints in specific sectors of the economy that can pose systemic risk to the financial system. Fourth, reserve requirements can be a complementary tool for capital requirements. Finally, they can be employed as a bank capitalization tool. According to Cordella et al. (2014), the systemic risk-driven and business cycle-driven uses of reserve requirements cannot be separated one from the other. When reserve requirements are used to prevent systemic risk, they can contribute to macroeconomic stabilization, whereas when they are used to smooth the credit cycle, they promote financial stability

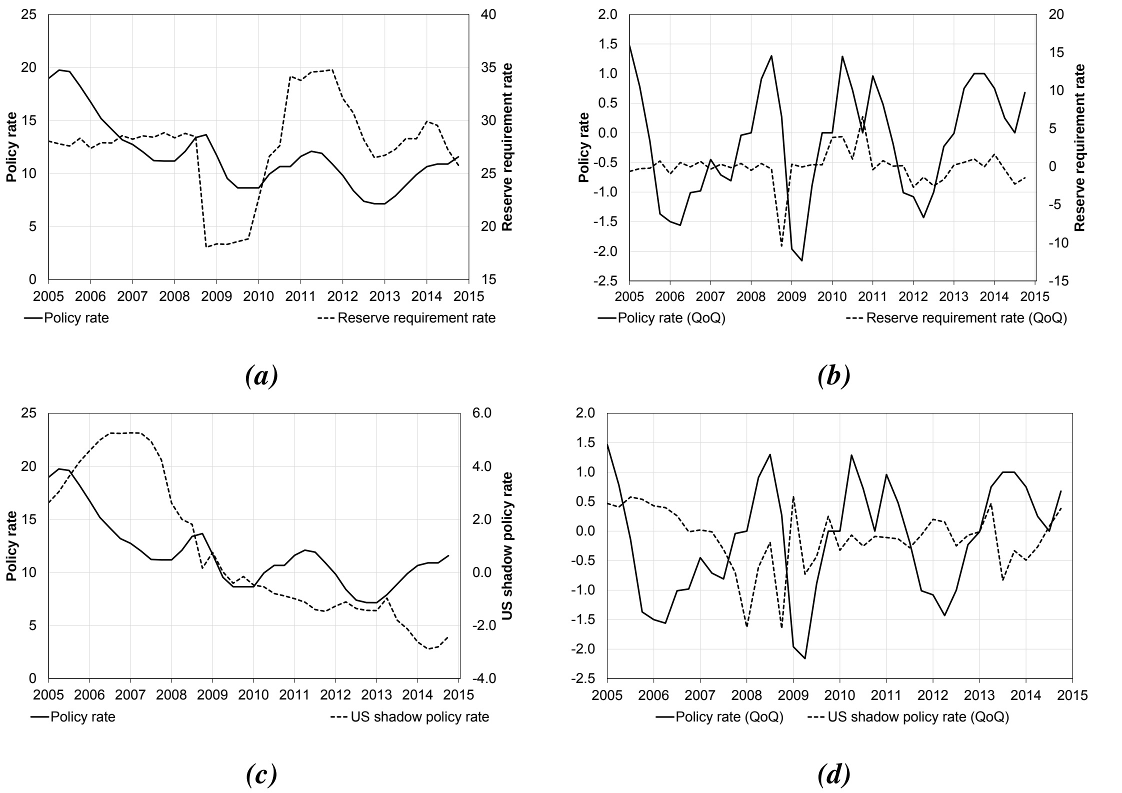


Figure 1: *Policy rate against the effective reserve requirement rate and the US shadow policy rate. Figures (a) and (c) compare levels, while (b) and (d) compare quarterly differences.*

by preventing excessive fluctuation in capital flows, which mitigates systemic risk.

In Brazil, reserve requirements rates are also used to incentivize banks to extend credit to specific economy sectors[1]. In this case, the rate setting operates directly in the narrow credit channel and is monetary policy in this sense. However, since it bypasses other transmission channels, it has been used in case they are obstructed, as in a liquidity crisis, or in case they would generate financial instability, as in a sudden flood of capital flows that could be exacerbated by higher policy rates.

Regarding the policy rate, according to Figure 1, there are three easing and three tightening cycles in the full sample that spans from the first quarter of 2005 to the last quarter of 2014. There is a very significant drop in the level of interest rates in the beginning of the sample usually attributed to the increasing credibility of the inflation-targeting framework. The period after the global financial crisis, from 2010 to 2014 is a period of relatively low interest rates, considering the historical standards of the country. Nonetheless, the last easing and tightening cycles carry large monetary policy surprises in the context of high and increasing inflation.

[1]One example for this is a regulation issued in 2012 by the Central Bank of Brazil on reserve requirements (BCB (2012)), which includes rules that state that the amounts related to motorcycle leasing operations and vehicles financing operations can be deducted from the reservable liabilities amount.

Figure 1 also shows the policy rate against the effective reserve requirement rate and the foreign shadow policy rate. There is a clear positive correlation between all monetary policy indicators in the post-crisis period. The beginning of the sample accommodates more heterogeneity between the different policies.

The effective rate of reserve requirements on deposits is large by international standards. For instance, it averaged 28% in the full sample, with a maximum of 35%. The rate was mostly flat before the global financial crisis, which signals it was not an important policy instrument. During the global financial crisis, the Central Bank released reserve requirements and the effective rate dropped to the historical low of 18%. This policy move came before the interest rate decisions. The post-crisis period (from 2010 onwards) begins with the tightening cycle designed to recompose the liquidity buffer released during the financial crisis and to respond to capital inflow pressures. The next easing cycles coincide in timing with the European sovereign debt crisis and with the tapering of quantitative easing measures by the Federal Reserve. We summarize these observations adding that from the crisis on, reserve requirements were used as a macroprudential policy instrument. Indeed, relative to other localized policies implemented during the same period, this was the macroprudential tool with broadest scope[2].

We use as foreign policy rate the US shadow policy rate as computed by Wu and Xia (2015). Before July 2009, the US shadow policy rate is the Fed Funds rate and, from that month onwards, it is a rate computed from a set of forward rates which dynamic correlations with macro variables is similar to those of the Fed Funds rate before the crisis. In Figure 1, in the pre-crisis period, the US shadow policy rate increases, reaching the maximum just before the beginning of the crisis. After the crisis has begun, in 2007, the US shadow policy rate decreases reaching the zero lower bound in July 2009. From then on, the rate has a decreasing trend, reaching a minimum in June 2014 and beginning a recovery thereafter.

There is a clear correlation between the policies and therefore it is relevant to assess if their systemic risk implications are in the same or in opposite directions. It is also clear that the strong second monetary policy cycle relative to stable or easing reserve requirements is an important source of identification.

[2]During the post-crisis environment of large global liquidity, the Central Bank of Brazil issued many localized regulation focusing financial stability, such as loan to value caps on housing loans and higher capital requirements on vehicle loans.

2.2 Hypotheses Development

The first hypothesis we investigate is related to the effect of monetary policy on systemic risk. Our starting point is the risk-taking channel hypothesis (e.g. Borio and Zhu (2008)), which says that monetary policy easing stimulates leverage and risk-taking, while tightening has the opposite effect.

We develop this hypothesis in the context of our systemic risk indicators. Our measure of default correlation is based on a distress barrier and a random walk for asset returns. Risk-taking implies higher volatility in the return process and leverage implies a tighter distress barrier. Correlated risk-taking would also translate into higher default correlations. All these effects points to higher default correlation. Considering our second systemic risk indicator, higher leverage reduces the capital buffer of financial institutions in relation to its liabilities, and therefore facilitates the transmission of stress over the interbank network. As a result, risk-taking would be associated with higher levels of stress. These arguments lead us to the first hypothesis.

Hypothesis 1. The policy rate has an inverse relation with the average systemic risk of financial institutions, including Default Correlation and DebtRank.

The second hypothesis considers the effect of reserve requirements on systemic risk taking. Reserve requirements operate directly in the narrow credit channel. Therefore, it should have similar implications for systemic risk as the other transmission channels. That is, in principle, it should not matter if the monetary authority occasionally uses reserve requirements to bypass other transmission channels as suggested above. A possible caveat here is that its use as a liquidity buffer may create expectations in market participants. For example, the renewal of the liquidity buffer after a shock might incentivize some agents to actually take on more risk - that is if they expect the monetary authority to use the buffer to minimize downside risks, as in (Diamond and Rajan (2009)). In summary, given that this policy instrument has less scope and a possible macroprudential role with possible ambiguous consequences for risk taking, we formulate a weaker hypothesis:

Hypothesis 2. The effective reserve requirement rate has an inverse relation with the average systemic risk of financial institutions, including Default Correlation and DebtRank, but this relation is weaker than the policy rate.

The third hypothesis considers the effect of the foreign monetary policy on systemic risk taking. The shadow policy rate conveys information on monetary conditions even at the zero lower bound. According to Bruno and Shin (2012), if short-term rates are low or if there are expectations that they will lower, the risk-taking channel mechanisms stimulate cross-border banking sector capital flows and increasing risk appetite. This channel implies foreign monetary policy may affect systemic risk indicators in the domestic financial system. As suggested by Bruno and Shin (2012), given the weak balance sheets of international banks, this channel may have a lesser role in the transmission of the shocks in the post-crisis period. However, to the extent that domestic banks absorb deposits that result from capital flow running through other channels, there might still be an effect, albeit lower, on systemic risk taking. That effect would be further attenuated by measures taken by the Central Bank of Brazil, who raised the reserve requirements to reduce the excess of liquidity along the post-crisis period. These arguments suggest the following hypothesis:

Hypothesis 3. The foreign monetary policy has an inverse relation with the average systemic risk of financial institutions, including Default Correlation and DebtRank, but this relation becomes weaker in the post-crisis period.

To be clear, we state both hypothesis with an implicit ceteris paribus clause that holds fixed the other policy instrument. Since there is a larger empirical literature investigating the risk-taking channel of monetary policy interest rates, including the papers that perform analyses for individual financial institutions, we also consider models excluding the reserve requirements. As a robustness exercise, we also estimate the same models restricted to the sample of private financial institutions. This is a relevant exercise given that public banks have acted in a marked countercyclical way since the financial crisis.

3 Methodology

We use dynamic panel models with bank fixed effects that include macroeconomic and microeconomic variables, taking a two-step GMM estimation as our baseline. We consider two dependent variables separately, namely, Default correlation and DebtRank, both are indicators of systemic risk. The main independent variables of interest are domestic policy rate and reserve requirement (as captured by the effective rate on deposits), and foreign policy rate. Additional macro controls are inflation, output gap, credit growth, exchange rate and country risk, and bank-level controls are size, equity ratio, liquidity and non-performing loans. This model is represented by the equation:

$$y_{it} = \alpha_i + \sum_{j=0}^{L} \beta_j' y_{it-j} + \sum_{j=0}^{N} \gamma_j' MP_{t-j} + \sum_{j=0}^{P} \delta_j' MV_{t-j} + \eta' B_{t-1} + u_{it} \quad (1)$$

In which y_{it} is the dependent variable Default correlation or DebtRank;

α_i is the bank i's fixed effect;
$\beta_j, \gamma_j, \delta_j, \zeta_j$and η are vectors of coefficients (for lag j);
$L, N$and P are numbers of lags;
MP_t are the monetary policy variables in time t: policy rates (domestic and foreign) and reserve requirement;
MV_t are macro environment controls in t (inflation, credit growth, output gap, exchange rate and country risk);
B_{it} are banks controls in t (size, liquidity ratio, return over assets and equity ratio).

We include these variables in the model as follows: for the dependent variables, we define the number of lags L to be included using the Arellano-Bond's test for serial correlations. We include three lags for Default correlations and one for DebtRank. For defining the number of lags of monetary policy variables and macro environment controls, we test models with only contemporaneous variables, with contemporaneous variables and one lag and with contemporaneous variables and two lags. The models with at most one lag of these variables present qualitatively similar results among themselves, that is, sign and statistical significance of their coefficients are roughly the same. Specifications with contemporaneous variables and two lags were deemed not appropriate because of collinearity problems. After dropping the variables related to those problems, we get results that differ significantly from those from specifications with a lower number of lags, therefore, we decide for using one lag for these variables, i.e., $N = 1$ and $P = 1$. The exceptions are inflation and credit growth variables, for which we use two lags in order to reduce seasonality problems. Finally, for bank-level controls, we take only lag 1 to avoid endogeneity. We adopt the above model specification and use it as our base model along the remainder of this work.

Next, we present the formal definitions of the systemic risk indicators.

3.1 Risk measures

To assess the effects of macroeconomic conditions on systemic risk, we need to define how we measure it. Systemic risk, broadly speaking, is the probability that shocks affecting the financial system reduce significantly its financial intermediation activities. Materialization of systemic risk can be identified by observing the number of banks that default because of a given shock or by the amount of losses related to that shock. Vulnerability to such events could be detected by the stress of the banking system in a given situation. We choose measuring the banking system's stress along two dimensions. One of them is the loss-related stress caused by a shock in a bank, and the other is related to the default probabilities of each bank in the system, given their individual balance sheets.

We measure the correlation of default events based on the joint probability distribution of such events for pairs of banks, given the stylized fact that banks default probabilities tend to increase in economic downturns, becoming more correlated. These aspects are captured by the default correlations and the two DebtRank measures presented in the next sections.

3.1.1 Default Correlations

To compute correlations of default events, we need firstly to compute individual banks default probabilities in a given period (quarter). After, we compute conditional default probabilities for each pair of banks, and finally, we compute default correlations for these pairs. To compute banks default probabilities, we use the structural approach, which is one of the most important methods of modeling the credit risk of a loan portfolio. To use the structural approach to model banks default probabilities, one needs to assume that their assets follow a given stochastic process and that the bank will default if those assets' value falls below a predefined barrier. We implement that approach following Guerra et al. (2013), whom we refer for further details. We outline their methodology as follows. 1) Initially, obtain, for each bank of the system, empirical individual probabilities of default; 2) Consider that each pair of banks is a portfolio and, for each pair, estimate a bivariate density of banks returns using the Segoviano (2006)'s Consistent Information Multivariate Density Optimizing (CIMDO) methodology, and 3) Compute the conditional default probabilities for each pair of banks from the bivariate density. The main idea is to build, for each pair of banks in a given period, a multivariate distribution that is updated with the empirically observed barriers and individual default probabilities. Once the multivariate distribution is calculated, it is possible to compute conditional default probabilities.

Initially, we compute individual banks default probabilities using the contingent claims approach proposed by Merton (1974). This approach considers that the value of the bank's assets follows a stochastic process and that the bank defaults if the value of these assets falls below the value of its obligations in their maturity date. Merton (1974) models bank's assets as an European call option, with strike price equal to the bank's liabilities and time to maturity T. In case of default, shareholders receive nothing, otherwise they receive the difference between assets and liabilities values. Under this framework, the bank will default if its implied assets' value falls below a distress barrier (*DB*). Usually, *DB* is computed based on the KMV model (KMV (1999) and KMV (2001)), using accounting data, as:

$$DB = (\text{short-term debt}) + \alpha(\text{long-term debt}), \tag{2}$$

with the parameter α between 0 and 1. We apply the option pricing formula of Black and Scholes (1973) to the framework above to compute the shareholders' earnings as:

$$E = A\mathcal{N}(d_1) - DBe^{-rT}\mathcal{N}(d_2), \tag{3}$$

In Equation 3, r is the risk-free interest rate and $\mathcal{N}(.)$ is the cumulative normal standard distribution,

$$d_1 = \frac{\ln\left(\frac{A}{DB}\right) + \left(r + \frac{\sigma_A^2}{2}\right)T}{\sigma_A\sqrt{T}} \tag{4}$$

and

$$d_2 = \frac{\ln\left(\frac{A}{DB}\right) + \left(r - \frac{\sigma_A^2}{2}\right)T}{\sigma_A\sqrt{T}}. \tag{5}$$

We assume that the bank's asset values are log-normally distributed, which, according to Crouhy et al. (2000) is a quite robust assumption. Therefore, the default probability of a bank in a time horizon T is given by:

$$\begin{aligned} DP &= Prob(A_T \leqslant DB) \\ &= Prob(lnA_T \leqslant lnDB) \\ &= \mathcal{N}\left(-\frac{ln\frac{A_0}{DB} + \left(\mu_A - \frac{1}{2}\sigma_A^2\right)T}{\sigma_A\sqrt{T}}\right) \\ &= \mathcal{N}(-d_2). \end{aligned} \tag{6}$$

DP is the probability computed in $t = 0$ that a bank defaults at the time horizon T, i.e., that its assets value falls below the distress barrier at that time horizon. We follow the literature defining T as one year.

Having computed individual default probabilities, we now compute bivariate density functions of banks returns for each pair of banks using the CIMDO methodology. We will consider banking systems as portfolios of two banks i and j to estimate bivariate distribution functions of their returns. We start considering that banks i and j have logarithmic returns defined as the random variables x_i and x_j and assuming a prior parametric distribution $q(x_i, x_j) \in \mathbb{R}^2$ for the portfolio's stochastic process. The prior returns' distribution must be coherent with the two banks defaulting if their returns are low enough to lead their assets values to fall below their *DB*s. Using the CIMDO methodology, we estimate a bivariate posterior distribution $p(x_i, x_j) \in \mathbb{R}^2$ from the *prior* distribution through an optimization process in which the prior density is updated with the empirical information extracted from the *DP*s and *DB*s imposed by the restrictions of the optimization problem.

We solve the following optimization problem:

$$\widehat{p(x_i, x_j)} = \underset{p(x_i, x_j)}{\text{argmin}} \; C[p, q] = \int\int p(x_i, x_j) \ln[\frac{p(x_i, x_j)}{q(x_i, x_j)}] dx_i dx_j, \tag{7}$$

s.t.

$$\int\int p(x_i, x_j) \boldsymbol{I}_{(-\infty, \ln(DB_i/A_i))}(x_i) dx_i dx_j = DP_{i,t} \tag{8}$$

$$\int\int p(x_i, x_j) \boldsymbol{I}_{(-\infty, \ln(DB_j/A_j))}(x_j) dx_j dx_i = DP_{j,t} \tag{9}$$

$$\int\int p(x_i, x_j) dx_i dx_j = 1 \tag{10}$$

$$p(x_i, x_j) \geq 0. \tag{11}$$

In the optimization problem above, $\widehat{p(x_i, x_j)}$ is the estimate of the bivariate posterior distribution being computed, $DP_{i,t}$ and $DP_{j,t}$ are the banks i and j default probabilities in period t estimated initially, and $\boldsymbol{I}_{(-\infty, \ln(DB_i/A_i))}(x_i)$ and $\boldsymbol{I}_{(-\infty, \ln(DB_j/A_j))}(x_j)$ are indicator functions that the banks i and j assets fell below their distress barriers DB_i and DB_j. The restrictions (8) and (9) impose that the marginal densities of $p(x_i, x_j)$ incorporate the information obtained from *DP*s and *DB*s of each bank, and the restrictions (10) and (11) ensure that the solution of optimization problem, $\widehat{p(x_i, x_j)}$, is a valid density, i.e., that it adds to 1 over its support and that it satisfies the non-negativity condition.

We solve the problem using calculus of variations procedures, obtaining the following optimal posterior bivariate density:

$$\widehat{p(x_i, x_j)} = q(x_i, x_j) \exp\{-\left[1 + \hat{\mu} + \left(\hat{\lambda}_1 \boldsymbol{I}_{(-\infty, \ln(DB_i/A_i))}(x_i)\right) + \left(\hat{\lambda}_2 \boldsymbol{I}_{(-\infty, \ln(DB_j/A_j))}(x_j)\right)\right]\}. \tag{12}$$

In the equation above, $\hat{\lambda}_1$, $\hat{\lambda}_2$ and $\hat{\mu}$ are Lagrange multipliers. The posterior bivariate density that solves the problem, $\widehat{p(x_i, x_j)}$, complies with the empirically observed banks i and j *DP*s.

To compute conditional default probabilities for pairs of banks, specifically, the probability that bank j defaults given the default of bank i, we use their posterior bivariate density $\widehat{p(x_i,x_j)}$ and the bank i's default probability, $DP_{i,t}$, as follows:

$$DP_{j|i,t} = \frac{P(x_i < \ln(DB_{i,t}/A_i), x_j < \ln(DB_{j,t}/A_j))}{DP_{i,t}} \quad (13)$$
$$= \frac{\int_{-\infty}^{\ln(DB_{j,t}/A_j)} \int_{-\infty}^{\ln(DB_{i,t}/A_i)} \widehat{p(x_i,x_j)} dx_i dx_j}{DP_{i,t}}.$$

We compute the correlation of the default of a pair of banks i and j starting with banks i and j individual default probabilities and a conditional default probability, either of the default of bank i given the bank j's default or vice-versa. These figures are computed using the methodology presented above. We compute the correlation of default events $\rho_{DP(i,j,t)}$ in quarter t using Equation (14):

$$\rho_{DP(i,j,t)} = \frac{(DP_{j|i,t} - DP_{j,t})DP_{i,t}}{\sigma_{DP(i,t)}\sigma_{DP(j,t)}} \quad (14)$$

is the standard deviation of the bank i's default probability in time t, given by:

$$\sigma_{DP(i,t)} = \sqrt{DP_{i,t}(1 - DP_{i,t})} \quad (15)$$

Finally, we compute a measure of the default correlations for each bank in a quarter taking the average of the ten highest correlations between that bank and the others on the date. Thus, the default correlations panel will have entries for each date and bank with the average of the ten highest correlations between that bank and others from the system. The reason for taking the average of the ten highest correlations instead of that for the whole sample is that we intend to focus on groups of banks which default probabilities may increase faster in case of a crisis.

3.1.2 DebtRank

DebtRank is a measure of the stress that arises in a banks' exposures network subjected to a shock. This measure is computed for each bank that participates in the network and is strongly related to its leverage towards its network debtors. The intuition associated with that measure is as follows. Suppose that, in a network of mutually exposed banks, one of them defaults. That bank will not pay its liabilities towards its creditors. Those creditors will suffer losses that depend on the amount invested in the defaulting bank. Each of them, by its turn, having suffered a loss that puts it under stress will propagate that stress, reducing the payments of its liabilities by an amount proportional to that stress. That propagation continues until the banking system achieves equilibrium. Then, each bank's stress, from the banking system point-of-view, will be computed as its stress index (that is, the ratio between the amount of assets not received by it after the finish of the stress propagation process and its capital buffer) multiplied by the ratio of its total exposures to the network aggregated exposures.

The DebtRank methodology, proposed by Battiston et al. (2012), models the interbank market as a directed network, in which banks are nodes and the exposures between them are links. These links are represented by a weighted adjacency matrix, which elements A_{ij} are amounts lent by bank i to bank j. The total assets invested by i are given by $A_i = \sum_j A_{ij}$ and the relative economic value of a bank i is given by $v_i = A_i / \sum_i A_i$, which is the ratio of i's assets over the total assets in the interbank market. Each bank i has a capital buffer against shocks, E_i, which is the amount of its capital that exceeds a positive threshold γ. If a bank suffers a loss that depletes E_i, it defaults. If bank i defaults, all neighboring banks j suffer losses amounting to A_{ji}. These losses cause an impact on banks j given by $W_{ij} = \min(1, A_{ji}/E_j)$, which measures each bank j's distress inflicted by the default of bank i. Another interpretation for W_{ij} is that it is bank j's leverage related to its debtor, bank i.

The presence in the network of cycles inflates the computed impacts by counting the impact of a node onto another more than once. To avoid the distortion caused by this double-counting, Battiston et al. (2012) present an algorithm that allows a node to propagate impact only once as follows.

Let the state of bank i be composed of the following dynamical variables at time t:

- $h_i(t) \in [0,1]$, which accounts for the stress level of i. If $h_i(t) = 0$, i is undistressed; when $h_i(t) = 1$, i is on default.
- $s_i(t) \in \{U, D, I\}$, which is a discrete variable that assumes one of the following values: undistressed (U), distressed (D) and inactive (I).

The initial conditions for the simulation are set when $t = 1$. The banks with initial stress level $h_i(1) = 0$ are undistressed, i.e., $s_i(1) = U$; if $h_i(1) > 0$, the banks are distressed $s_i(1) = D$; and if $h_i(1) = 1$, they are initially on default. To ensure that a node i propagates impact only once, the algorithm deactivates node i (i.e., sets $s_i(t) = I$) in the step following that in which it has become distressed and propagated impact. After becoming inactive, a node does not propagate impact. The dynamics for each time step, starting from $t = 2$, is given by:

$$h_i(t) = \min\left\{1, h_i(t-1) + \sum_j W_{ji} f(h_j(t-1))\right\}, \text{ where } j \mid s_j(t-1) = D,$$

$$s_i(t) = \begin{cases} D & \text{if } h_i(t) > 0; s_i(t-1) \neq I, \\ I & \text{if } s_i(t-1) = D, \\ s_i(t-1) & \text{otherwise.} \end{cases} \tag{16}$$

Equation 16 above presents a more general DebtRank definition, taken from Battiston et al. (2015), in which bank i's stress in time t depends on the sum of the products of functions $f(\cdot)$ of the stress of its debtors in $t-1$ by its leverages towards them. In the standard DebtRank definition, $f(h(\cdot)) = h(\cdot)$. After a finite number of steps T, the dynamics described by Equation 16 stops and the DebtRank (*DR*) is given by the difference between the final and the initial systemic stresses:

$$DR = \sum_j h_j(T)\nu_j - \sum_j h_j(1)\nu_j. \tag{17}$$

DebtRank is a measure of the systemic stress that arises from a given configuration of banks and individual levels of stress. In this paper, we compute a bank's DebtRank as the stress given by Equation 17 that arises as a consequence of that bank being initially in default and the other banks undistressed.

3.1.3 Collateral-sensitive DebtRank

In this section, we propose an extension of the DebtRank measure that takes into account the differences between risk propagation characteristics of secured and unsecured assets. This differentiation is important when there is a significant share of collateralized exposures among the total exposures. When there are secured and unsecured exposures, a first approach is to consider only the unsecured ones for analysis, however, in fact, collateralized exposures are sources of stress for the borrowers that also should be taken into account.

The stress propagation process can be detailed as follows. Suppose that a bank i, which has secured and unsecured liabilities, suffers a loss related to one of its unsecured assets (exposures) within the network. It will become stressed proportionally to the ratio of that loss to its capital buffer and will propagate losses to its network creditors according to that loss ratio. However, bank i does not propagate losses related to its secured liabilities to the corresponding creditors. Instead, it covers these losses with pledged collateral. Thus, besides the loss suffered from its unsecured exposures, bank i suffers an additional loss that corresponds to the amount of pledged collateral loss. The stress that results from this sum of losses is then propagated to bank i's unsecured operations' creditors.

We compute the collateral-sensitive DebtRank measure as follows. We start defining the banking system's exposures matrix as in the standard DebtRank model, which elements A_{ij} are amounts lent by bank i to bank j. These amounts can be decomposed as $A_{ij} = A^S_{ij} + A^U_{ij}$, corresponding to the amounts of secured and unsecured exposures from bank i to bank j. We define the standard impact matrix related to unsecured exposures as $W^U_{ij} = \min(1, A^U_{ji}/E_j)$ and use this definition to compute the unsecured exposures amplified impact matrix, given by:

$$W^A_{ij} = \min\left(1, W^U_{ij}\left(1 + \frac{\sum_k A^S_{kj}}{E_j}\right)\right) \tag{18}$$

Substituting W^A_{ji} for W_{ji} in Equation 16 and rearranging, we describe the stress propagation dynamics along the banking system by:

$$\begin{aligned}
&h_i(t) = \min\left\{1, h_i(t-1) + \sum_j W^U_{ji} f_i(h_j(t-1))\right\}, \text{ in which } j \mid s_j(t-1) = D,\\
&f_i(h_j(t-1)) = \min\left(\frac{1}{W^U_{ji}}, 1 + \frac{\sum_k A^S_{ki}}{E_i}\right) h_j(t-1),\\
&s_i(t) = \begin{cases} D & \text{if } h_i(t) > 0; s_i(t-1) \neq I,\\ I & \text{if } s_i(t-1) = D,\\ s_i(t-1) & \text{otherwise.}\end{cases}
\end{aligned} \tag{19}$$

After the dynamics stops, we obtain the DebtRank measure from Equation 17.

Equation 19 shows that the propagation dynamics is equivalent to a particular case of the general DebtRank definition in Equation 16 computed for a network of unsecured exposures. In Equation 19, the term $\min\left(\frac{1}{W^U_{ji}}, 1 + \frac{\sum_k A^S_{ki}}{E_i}\right)$ in the definition of $f(h_j(t-1))$ is the amplification factor, greater than one when bank i has secured (collateralized) liabilities. For comparison, we also present results for the standard DebtRank computed over the exposure network defined as the sum of secured and unsecured exposures. No-

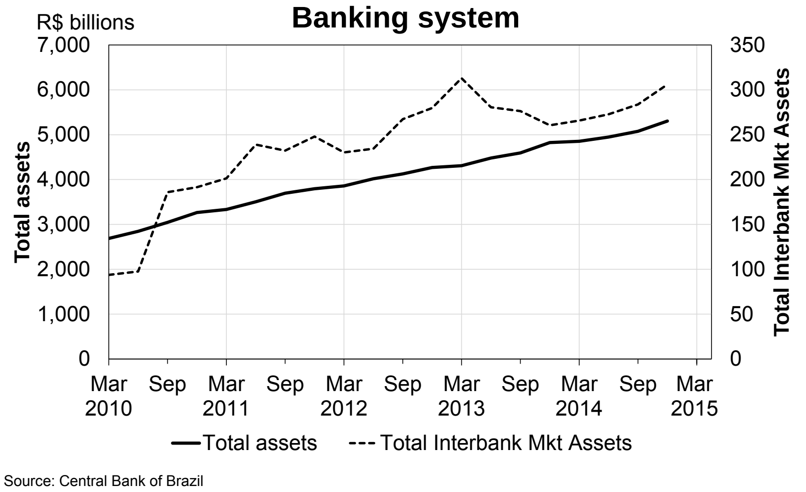


Figure 2: *Banking system's sums: individual banks total assets and interbank market assets.*

tice that this can also be represented as an amplification of the DebtRank computed over unsecured exposures[3].

We compute the DebtRank measure defined above and present the results in Figure 4.

4 Data

We analyze the Brazilian banking system, formed by financial conglomerates and individual banks that do not belong to a conglomerate in quarterly observations. For the DebtRank analyses, we take data from March 2010 to December 2014, while for the Default Correlation ones, data are from March 2005 to December 2014. We take two types of conglomerates: a Type-I conglomerate, which has at least one bank that can hold demand deposits, and a Type-II one, that does not have banks with a commercial portfolio but has at least one bank with an investment portfolio (that type of bank cannot take demand deposits). We also classify banks according to ownership: they are state-owned or private ones. The number of banks varies from 114 to 124 along the period, being 118 on average. Nine of these banks are state-owned. In Figure 2 we present the evolution of the sample banks' aggregated total assets, in nominal domestic currency units (Brazilian Real - R$).

We get data for the last business day of each quarter from three sources, depending on the following data types: a) accounting data; b) supervisory variables; and c) macroeconomic data. Accounting data come from the database of the Accounting Plan of the

[3]Just define $f_i(h_j(t-1)) = \min\left(\frac{1}{W^U_{ji}}, 1 + \frac{A_{ij}/E_i}{W^U_{ji}}\right) h_j(t-1)$.

National Financial System Institutions. This database has monthly records with standardized balance sheet information provided by banks to the Central Bank of Brazil. We get supervisory variables from the Supervisory Database, a unique database maintained by the Central Bank of Brazil Financial System Monitoring Department. This database has variables and indices collected and compiled during the surveillance process from the entities monitored by the Central Bank. These data comprise, among others, bank-level controls, network exposures among banks and variables used in the DebtRank computation. Both databases contain historical data, being the most recent ones from two months before the current date. We obtain macroeconomic data from three sources: the JP Morgan EMBI BR+ time series is taken from the Bloomberg, the US shadow policy rate, from the Federal Reserve Bank of Atlanta's website, and the remaining macroeconomic data, from the Economic Time Series Database that is compiled and maintained by the Economic Department of the Central Bank of Brazil. That database is built from data collected from several sources. The resulting time series have different periodicities. We use that database for compiling the panels' macro variables. Next, we explain data usage in more detail.

4.1 Bank Risk Variables

4.1.1 Default Correlations

We perform default correlation analyses employing data from March 2005 to December 2014. To obtain the banks default correlations in each period, we initially compute their individual default probabilities and their conditional default probabilities, given the default of another bank, for each pair of banks.

The individual *DP*s are estimated using the methodology described in Section 3.1.1. Due to the lack of market data (bonds, derivatives and Credit Default Swaps) for most of the Brazilian banks, we use monthly data from the Supervisory database to obtain the book value of both total assets and equities, and compute the total assets' volatility as in Souto et al. (2009). To compute the individual DP, we use Equation ((6)), substituting μ_A for the risk-free rate r, which we assume to be the interbank deposits' overnight interest rate *CDI*. To estimate the total assets' volatility, we follow the standard procedure in finance literature by taking the annualized standard deviation of the total assets' book value over the previous 12 months, as in the equation that follows:

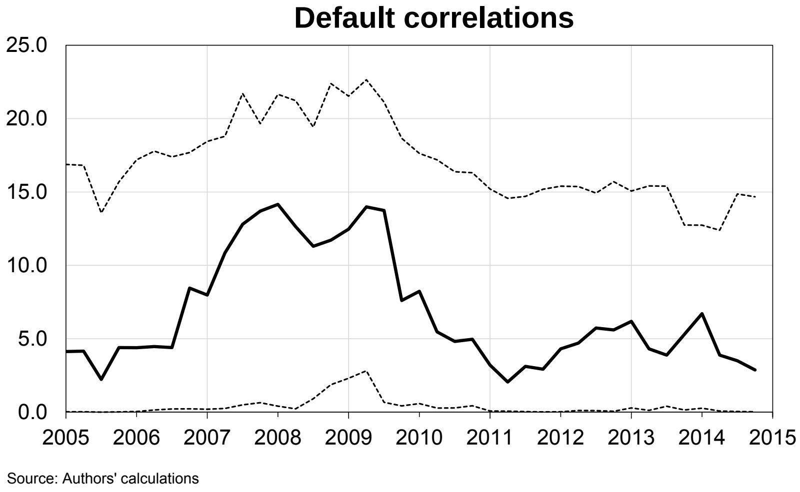


Figure 3: *Mean banking system's default correlations distributions along time: quantiles* 25, 50 *and* 75. *Correlations are multiplied by* 100.

$$\sigma_{A_t} = \sqrt{\frac{\sum_{i=0}^{11}(A_{t-i}-\overline{A})^2}{11}} \cdot \sqrt{12}, \tag{20}$$

In Equation (20), $\overline{A}$ is the average book value along the one-year period that finishes in t. Regarding banks distress barriers, we should compute them using Equation (2), however we do not have information on volumes of short- and long-term liabilities for all periods t. Thus, we assumed banks distress barriers as being 85% of their total liabilities amount, given that this percentage is the closest to that which would be computed from banks short-term obligations plus 50% of long-term obligations along the period with available liabilities data. Finally, to estimate the bivariate density distributions for each banks pair in a period t, we use Equation (12). We follow the literature considering the distribution density function prior $q(x_i, x_j)$ as a Student distribution with five degrees of freedom, approximating that distribution to a Normal, as, according to Guerra et al. (2013), results are quite similar.

Having estimated the bivariate distributions above, we compute conditional default probabilities for each pair of banks and period, and the default correlations measure that we use for each bank and date (it is the average of the ten highest correlations between that bank and the others at the date.) We show summary statistics for these correlations on Table (1). Figure (3) presents 25, 50 and 75% quantiles of the distribution of these correlations along for the period from March 2005 to December 2014. Along this paper, we use and present default correlations multiplied by 100.

Table 1: *Summary statistics - banks systemic risk indicators*

Variable	Mean	Std. Dev.	Min	Med	Max
Default corr	9.220	9.365	0	6.208	39.775
DebtRank	3.453	8.120	0	0.379	63.622
CS DebtRank	6.507	11.800	0	0.895	80.138

Source: Authors' calculations

4.1.2 DebtRank

Due to data availability issues, we perform DebtRank analyses for the period spanning from March 2010 to December 2014. To compute banks' DebtRank measures, we need, for each period t, two types of information: exposures data and capital buffer data. Both types of data are obtained from the Supervisory Database.

Interbank market exposures are taken from a dataset that contains monthly records of outstanding positions of a given conglomerate to its counterparties in the last day of the month for a given asset. These assets may be secured or unsecured, being mostly interfinancial deposits, bank deposit certificates, repos and reverse repos with federal securities, interbank onlending, credit and credit assignment operations, instruments eligible as capital, real state credit bills, financial letter and swap operations. These exposures are aggregated for each bank, regardless of their maturity date, and they are not netted out, as in case of a bank liquidation, the liquidated bank continues to receive its claims even if its payments are suspended, including those to a possible debtor. We present the interbank market exposures composition by asset type in Table 2 and a comparison between total interbank assets and the banking system's total assets along the period of analyses in Figure 2.

In Table 2, repos with federal securities are secured and credit assignment operations are partially secured. The remaining operations are unsecured. Unsecured operations account for less than a half of the exposures in volume. Given that secured exposures are collateralized, banks exposed to them do not receive stress from this type of exposure, as they take possession of the collateral in case of default. On the other hand, borrowers suffer stress when they lose these collateral assets in case of default. These losses add to those they may have suffered from their non-secured debtors, therefore, collateral losses add to the stress from non-secured exposures. We take these stress sources into account by computing the DebtRank risk indicator in two alternative ways: 1) we compute a standard DebtRank considering both secured and unsecured exposures, and 2) we compute the collateral-sensitive DebtRank presented in Section 3.1.3 from the same exposures considered in the previous item. We present distributions of Banks' DebtRank measures along time computed according to both methodologies in Figure 4 and their statistical summaries in Table 1. DebtRank distributions are highly asymmetric. A significant number of banks have zero or low DebtRank measures[4], whereas there are few banks with DebtRank measures of the order of 0.5 or more. Another key point is that collateral-sensitive DebtRank measures are higher than standard DebtRank ones[5]. Both DebtRank measures are used in the hypotheses tests in Section 5.2. Along this paper, we use and present DebtRank measures multiplied by 100.

Table 2: *Interbank market exposures composition (%)*

Assets	Dec 2010	Dec 2011	Dec 2012	Dec 2013	Dec 2014
Repos	48.0	56.1	54.9	47.2	55.7
Credit assignment	23.9	18.0	12.7	13.4	8.9
Interfinancial Deposits	12.8	13.5	13.8	12.3	10.2
Credit operations	6.6	6.1	6.2	9.2	10.0
Financial letters	0.0	0.1	4.3	8.1	7.2
Swaps	1.9	0.8	1.1	1.6	0.9
Others	6.8	5.4	7.0	8.2	7.1

Source: Authors' calculations

We compute a bank's capital buffer as the amount of that bank's total capital (Tier 1 + Tier 2 capitals) that exceeds 8% of its risk-weighted assets (*RWA*). In Brazil, the capital requirement is 11% for banks. Most banks hold capital buffers (their regulatory capital exceeds that requirement). We set 8% *RWA* as a reference for the computation of capital buffers as we assume that if a bank holds less than what is recommended by the Basel Committee on Banking Supervision (BCBS), i.e., 8% of its *RWA*, it will take longer to raise its capital to an adequate level and will suffer an intervention.

4.2 Bank-Level Controls

We obtain the bank-level control variables from the Accounting Plan of the National Financial System Institutions, using the following definitions:

Size = log(*Total assets*),

Equity ratio = Net worth / Total assets,

Liquidity = Liquid assets / Total assets, and

[4]Either they are exposed but have no liabilities towards other banks or they are small-sized banks with low-impact liabilities.

[5]Both were computed from the same exposures matrix.

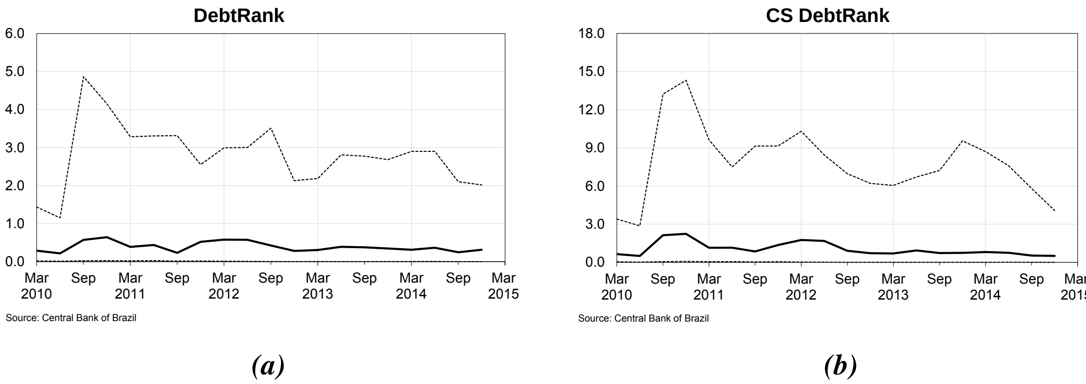


Figure 4: *Banking system's DebtRank distributions along time: quantiles* 25, 50 *and* 75. *DebtRank measures are multiplied by* 100. *Figure (a): standard DebtRank; Figure (b) collateral-sensitive DebtRank.*

NPL = Non-performing loans / Total loans.

We present the summary statistics for these variables in Table 3 for the period from March 2005 to December 2014.

Table 3: *Summary statistics - bank-level controls*

Variable	Mean	Std. Dev.	Min	Med	Max
Size	21.343	2.115	16.765	21.308	27.673
Equity ratio	0.228	0.178	0	0.174	0.984
Liquidity	0.299	0.211	0.000	0.242	0.990
NPL	0.015	0.030	0	0.008	1

Source: Authors' calculations

4.3 Monetary Policy and Macroeconomic Environment Variables

We compile macroeconomic environment variables, including the domestic monetary policy data, from the Central Bank of Brazil's Economic Time Series Database. The US shadow policy rate is taken from Wu and Xia (2015). These variables are as follows.

$\Delta Policy\ rate$ is the difference of the interbank interest rate at the end of the quarter to the rate at the end of the previous quarter. The target for that interest rate is the monetary policy interest rate set by the Monetary Policy Committee.

Δ*Reserve req* is a proxy for the effect of the reserve requirements fluctuations, given by the quarterly variation of the ratio of aggregate bank reserves to the sum of deposits (demand deposits + term deposits + savings deposits) in percentage points. The deposits sum is a proxy for the calculation base of reserve requirements.

$\Delta FgnPolicy\ rate$ is the difference between the US shadow policy rates computed for the end of consecutive quarters. The rates are computed according Wu and Xia (2015).

GDP gap: we compute that from a quarterly seasonally adjusted GDP time series, from March 2000 to December 2014. We take the log of each element of the series divided by 100 and filter the resulting series using an Hodrick-Prescott filter with $\lambda = 1600$. The cycle component from the filtering is multiplied by 100, resulting in the GDP gap time series.

Credit growth is a proxy for the economy's relative credit volume evolution. We start dividing the broad money supply by the monetary base volume, getting monthly ratios. Next, we average those ratios along a 3-month period ending in the month for which we are computing the variable. Then, we compute a similar average for a period ending 3 months before and subtract it from the first average.

Inflation is the quarterly change of the 3-month accrued inflation, in percentage points, given by the variation of the CPI index in a 3-month period.

Exchange rate is the quarterly change of the spot USD/BRL close selling rate taken at each quarter's last day.

JPM EMBI BR is the quarterly change of the country risk index JPM EMBI BR, in p.p., taken at each quarter's last day.

Table 4 presents their summary statistics, and Figures 5 and 6 present their evolution along the period from March 2005 to December 2014.

Table 4: *Summary statistics - monetary policy and macro variables*

Variable	Mean	Std. Dev.	Min	Med	Max
$\Delta Policy\ rate$	-0.148	0.961	-2.160	-0.005	1.470
$\Delta Reserve\ req$	-0.073	2.359	-10.415	0.029	6.553
$\Delta FgnPolicy\ rate$	-0.115	0.514	-1.650	-0.068	0.590
GDP gap	0.046	1.613	-4.925	0.280	3.431
Credit growth	0.590	0.727	-0.749	0.599	1.905
Inflation	-0.030	0.624	-1.290	-0.045	1.330
Exchange rate	0.000	0.078	-0.171	-0.014	0.200
JPM EMBI BR	-0.031	0.540	-1.410	-0.140	1.270

Source: Authors' calculations

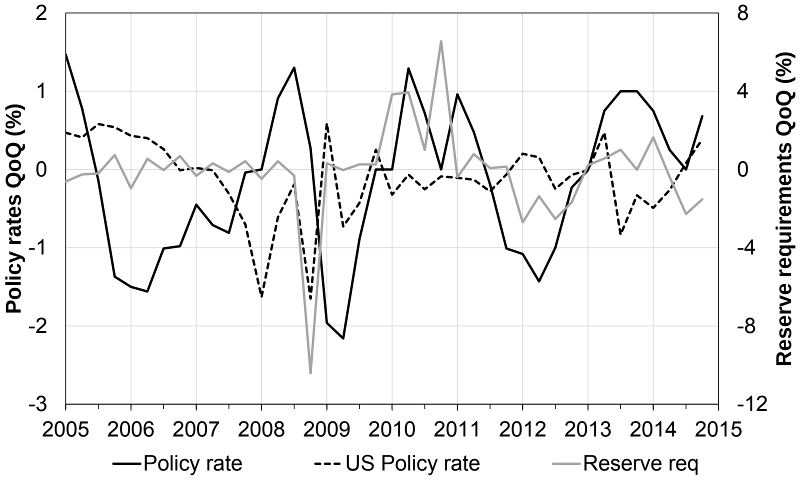
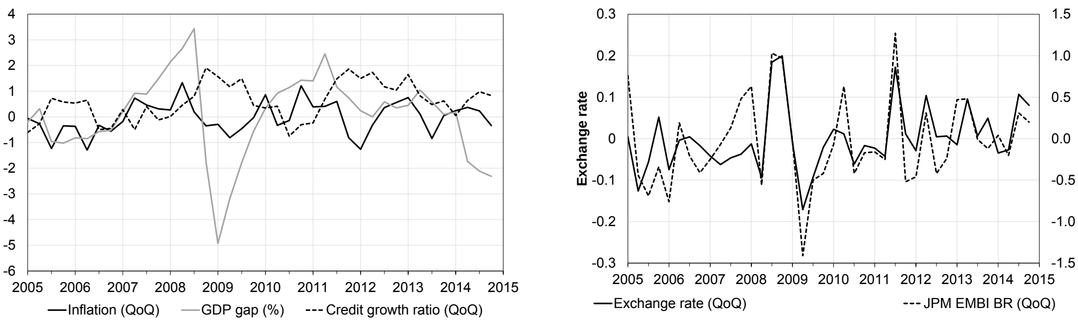


Figure 5: *Quarterly changes of monetary policy variables: domestic policy rate, foreign policy rate and reserve requirements.*



(a) ***(b)***

Figure 6: *Quarterly changes of macroeconomic environment variables. Figure (a) shows the evolution of Inflation, GDP gap and Credit growth, while Figure (b), the evolution of Exchange rate USD/BRL and JPM EMBI BR (p.p.).*

5 Results

We study the impact of domestic and foreign monetary policies on systemic risk, in special, testing the hypotheses regarding the systemic risk-taking channel. These hypotheses state that any monetary easing through domestic or foreign monetary policy decisions will lead to an increase of the contribution to systemic risk by individual banks. This contribution will rise if either the domestic or foreign policy interest rates decrease or if the reserve requirement decreases. The collective rise of systemic risk individual contributions by the banking system leads to an increase of the overall systemic risk.

For the analyses we perform in this section, we chose individual banks' systemic risk indicators that summarize two different dimensions of that risk. The Debtrank indicators used in this paper are computed for a network of banks in which links are ratios between a bank's exposure to a given counterparty and its regulatory capital. They require only contemporary data and are measures of the stress that a bank's failure induces on the banking system. Default correlation, on the other hand, is a measure derived from banks' default probabilities. These are related to a comparison between the volatility of banks' assets and their distance to default. This computation requires accounting data from the previous 12 months, thus, default probabilities react to shocks more slowly than the DebtRank indicators. The Default correlation indicator is built from the individual banks' overall default probabilities, while DebtRank indicators, as we compute here, can be seen as systemic-stress-given-default measures.

In our analyses, we compute the long-run effects of the explanatory variables on systemic risk, as in our models they are represented with their first lag. We also perform robustness tests, presenting their results in Section 6.

5.1 Default Correlations

We run a set of six regressions of Default correlations on monetary policy variables, controlling for macroeconomic environment and bank-level variables, as defined in Section 2.2. Regarding the explanatory variables, we run two specifications, one with reserve requirements variables and other without them. For these basic specifications, we run three tests: 1) for all banks, using only macro controls; 2) for all banks, using macro and bank-level controls, and 3) for private banks, using macro and bank-level controls. The purpose of these tests is: 1) to test if part of the effects we observe is due to the banks' heterogeneity. We perform this test comparing the results of the regressions with and without bank-level controls, and 2) to test a sample only with private banks, excluding state-owned banks, that had an anti-cyclical role regarding credit extension along the sample period.

In our regressions, we treat the endogeneity of the domestic monetary policy variables, i.e., Δ*Policy rate* and Δ*Reserve req*. Using the Arellano-Bond's test for serial correlations, m1 and m2, we include the three first lags of Default correlations into the model. The Sargan test does not reject any of the models presented in this Section.

We perform the tests described above for two samples: the entire sample, comprising the period from 2005:Q1 to 2014:Q4 and the post-crisis sample, that spans from 2010:Q1 to 2014:Q4. We present the results for models specified with and without reserve requirements variables in separated tables. In each of these tables, we present the test results for the entire sample and for the post-crisis sample side by side.

We also analyze the economic significance of the coefficients found to be statistically significant by computing the ratio:

$$R_E = \frac{\text{mean}(\text{abs}(Ivar))\ Coef_{Ivar}}{\text{mean}(\text{abs}(\Delta Depvar))} \tag{21}$$

In Equation 21, $Ivar$ is one of the interest variables $\Delta Policy\ rate$, $\Delta FgnPolicy\ rate$ or $\Delta Reserve\ req$, $Coef_{Ivar}$ is the variable's coefficient in the regression, and in the denominator, $\Delta Depvar$ is the quarterly variation of the dependent variable's average (here, the average of the individual banks' *Default corr* variables in a period). In turn, the interest variables are already quarterly variations. If $R_E < 5\%$, we can assume that the economic contribution of the variable is marginal, thus we classify it as economically not significant. In Table 5, we present the data required for the economic significance evaluation.

Table 5: *Data required for the computation of the interest variables' economic significance. The table presents means of the absolute values of quarterly variations of variables for the periods of analysis.*

Variable	2005-14	2010-14
Default corr	0.651	0.524
DebtRank		0.409
CS DebtRank		0.950
$\Delta Policy\ rate$	0.779	0.642
$\Delta Reserve\ req$	0.377	0.243
$\Delta FgnPolicy\ rate$	1.258	1.631

Source: Authors' calculations

We first analyze the two samples using models without reserve requirements. Table 6 presents the results of the corresponding regressions. For the entire sample, we find that domestic and foreign monetary policy rates have negative and highly (statistically) significant effects. For the domestic policy rate, the magnitude of the coefficient is nearly the same for all regressions, whereas for the foreign policy rate, the model without bank-level controls has the lowest-magnitude coefficients. All the statistically significant coefficients are also economically significant. The long-run analyses for this sample present negative and statistically significant coefficients, coherent with the existence of the systemic risk-taking channel related to variables of domestic and foreign policy rates.

Table 6: *Default correlations regressions - Model without reserve requirements*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	2005-14	2005-14	2005-14	2010-14	2010-14	2010-14
Default corr$_{t-1}$	0.77***	0.73***	0.72***	0.70***	0.70***	0.69***
	(0.043)	(0.049)	(0.049)	(0.035)	(0.059)	(0.063)
Default corr$_{t-2}$	-0.01	-0.02	-0.02	0.02	0.04	0.04
	(0.022)	(0.021)	(0.020)	(0.024)	(0.042)	(0.041)
Default corr$_{t-3}$	-0.13***	-0.16***	-0.17***	-0.16***	-0.12***	-0.12***
	(0.040)	(0.045)	(0.046)	(0.019)	(0.026)	(0.039)
Δ*Policy rate*$_t$	-0.56***	-0.58***	-0.64***	-1.09***	-0.89**	-1.05**
	(0.160)	(0.161)	(0.167)	(0.360)	(0.417)	(0.472)
Δ*Policy rate*$_{t-1}$	0.15	0.20	0.21	-0.08	-0.01	-0.05
	(0.128)	(0.124)	(0.137)	(0.301)	(0.354)	(0.428)
Δ*FgnPolicy rate*$_t$	-0.62***	-0.90***	-0.97***	-0.46	-0.34	-0.42
	(0.199)	(0.242)	(0.250)	(0.448)	(0.475)	(0.552)
Δ*FgnPolicy rate*$_{t-1}$	-0.17	-0.37*	-0.44**	-0.18	0.09	0.02
	(0.194)	(0.216)	(0.222)	(0.451)	(0.507)	(0.596)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	4,465	4,215	3,816	2,211	2,064	1,890
Number of Banks	160	150	137	137	126	117
N. Instruments	121	125	125	124	107	106
m1	-7.69***	-7.38***	-7.21***	-6.50***	-5.31***	-5.21***
m2	-0.37	-0.66	-0.67	-0.36	0.18	0.14
Sargan	112.57	108.00	102.54	111.37	92.28	89.38
VARIABLES			Long-run effects			
Δ*Policy rate*	-1.08*	-0.82**	-0.93**	-2.67***	-2.38	-2.86
Δ*FgnPolicy rate*	-2.09***	-2.75***	-3.04***	-1.48	-0.66	-1.05

This table presents regression results of Default correlation measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the Default correlation measure, taken as a proxy for systemic risk, whereas the explanatory variables are the domestic policy rate and the foreign policy rate. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. The sample for regressions 1 - 3 refers to the period from 2005 to 2014, and that for regressions 4 - 6, to the period from 2010 to 2014. All regressions control for macroeconomic conditions; regressions 2, 3, 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 7: *Default correlations regressions - Model with reserve requirements*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	2005-14	2005-14	2005-14	2010-14	2010-14	2010-14
Default corr$_{t-1}$	0.77***	0.73***	0.72***	0.71***	0.68***	0.67***
	(0.043)	(0.048)	(0.049)	(0.032)	(0.092)	(0.091)
Default corr$_{t-2}$	-0.01	-0.02	-0.02	0.02	0.04	0.04
	(0.022)	(0.021)	(0.021)	(0.023)	(0.044)	(0.027)
Default corr$_{t-3}$	-0.13***	-0.16***	-0.16***	-0.15***	-0.15	-0.15***
	(0.041)	(0.046)	(0.046)	(0.019)	(0.104)	(0.031)
Δ*Policy rate*$_t$	-0.65***	-0.66***	-0.76***	-1.35**	-1.45	-1.85**
	(0.199)	(0.211)	(0.224)	(0.560)	(2.824)	(0.864)
Δ*Policy rate*$_{t-1}$	0.26	0.28*	0.32*	0.41	0.94	1.23**
	(0.167)	(0.166)	(0.184)	(0.543)	(1.194)	(0.530)
Δ*Reserve req*$_t$	-0.07	-0.06	-0.08	-0.16	-0.27	-0.33*
	(0.046)	(0.049)	(0.055)	(0.112)	(0.240)	(0.183)
Δ*Reserve req*$_{t-1}$	0.00	-0.00	0.00	0.10	0.11	0.15
	(0.052)	(0.053)	(0.060)	(0.095)	(0.118)	(0.115)
Δ*FgnPolicy rate*$_t$	-0.52**	-0.80***	-0.83***	-0.22	0.27	0.46
	(0.248)	(0.274)	(0.297)	(0.626)	(1.208)	(0.781)
Δ*FgnPolicy rate*$_{t-1}$	-0.27	-0.44*	-0.54**	-0.54	-0.45	-0.62
	(0.217)	(0.240)	(0.250)	(0.477)	(0.576)	(0.668)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	4,465	4,215	3,816	2,211	2,064	1,890
Number of Banks	160	150	137	137	126	117
N. Instruments	121	125	125	114	118	118
m1	-7.70***	-7.38***	-7.21***	-6.64***	-4.47***	-4.82***
m2	-0.34	-0.56	-0.57	-0.16	-0.28	-0.40
Sargan	112.40	107.93	102.20	100.59	102.18	102.02
VARIABLES				Long-run effects		
Δ*Policy rate*	-1.02*	-0.84*	-0.96**	-2.25**	-1.18	-1.44
Δ*Reserve req*	-0.17	-0.14	-0.17	-0.14	-0.38	-0.42
Δ*FgnPolicy rate*	-2.10***	-2.76***	-3.01***	-1.82	-0.39	-0.35

This table presents regression results of Default correlation measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the Default correlation measure, taken as a proxy for systemic risk, whereas the explanatory variables are the domestic policy rate, the reserve requirements and the foreign policy rate. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. The sample for regressions 1 - 3 refers to the period from 2005 to 2014, and that for regressions 4 - 6, to the period from 2010 to 2014. All regressions control for macroeconomic conditions; regressions 2, 3, 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors. Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

For the post-crisis period, Table 6 shows that the coefficients of the estimates for the contemporaneous domestic and foreign policy rate variables are negative for all model specifications, although they are statistically significant only for the contemporaneous domestic monetary policy variable. These coefficients are also economically significant. The corresponding long-run effects are negative, but only that of the domestic policy rate for a model without bank-level variables is statistically significant. Summarizing the results that refer to the post-crisis period, we find evidence that only the domestic policy rate affects significantly the systemic risk indicator. For the foreign policy rate, the coefficients are smaller than the corresponding standard errors, thus, this variable, according to our models, is not accountable for effects on Default correlations.

The comparison between the analysis of both periods using the model without reserves requirements allows us to conclude for the evidence of the systemic risk-taking channel related to the domestic policy rate, however, for the foreign policy rate, the evidence found for the entire period disappears in the after-crisis period. After the crisis, the Central Bank of Brazil had to raise the reserve requirements to reduce the excess of liquidity along that period (see Figure 1). Possibly, that monetary policy measure affected the Default correlations indicator along the period, filtering effects that otherwise would reflect on that systemic risk indicator. There is also the possibility that the banks' roles in transmitting liquidity has decreased in the post global financial crisis environment.

We now analyze the sample for the entire period using model specifications with reserve requirement variables. The effects of domestic and foreign policy rates on the systemic risk indicator are negative, statistically and economically significant. The reserve requirements coefficients are near zero for all the regressions. The long-run effects are negative, being statistically significant only for domestic and foreign policy rates.

For the post-crisis period, the results of Table 7 show that the contemporaneous effect of the three monetary policy variables is mostly negative. We find statistically significant negative effects for the domestic exchange rate in model specifications (4) and (6), and for the reserve requirements, for model specification (6). The effects of the first lag of the domestic policy rate and of reserve requirements are positive and mostly statistically non-significant, whereas the effects of the same lag of the foreign policy rate are negative and statistically non-significant. Long-run effects of these variables are negative and statistically non-significant, with the exception of the domestic policy rates for model specification (4). These results show that there is evidence that the domestic policy rate affects the Default probabilities indicators through a systemic risk-taking channel. For the foreign policy rate, there is no evidence, and for the reserve requirements, the evidence is weak.

The comparison of the results for both periods, using models with reserve requirements, allows us to say that, for the entire sample, we find strong evidence for the systemic risk-taking channel associated to the domestic and foreign policy rates, and a weak evidence supporting this channel for reserve requirements. However, this evidence weakens in the post-crisis period, even for the domestic policy rate, which is the cleanest monetary policy variable that we use. As before, our explanation is that, after the crisis, the Brazilian economy suffered a liquidity increase, mostly, as a result of the unconventional monetary policies from the US, and the liquidity excess led the Brazilian monetary authority to take actions to reduce this effect. These measures may have interfered in the systemic risk-taking channel mechanisms under study.

5.2 DebtRank

We use the same model used for the Default correlations systemic risk indicator to test, for the DebtRank indicators, the hypotheses regarding the systemic risk-taking channel of the monetary policy in Brazil. We perform this test for both DebtRank indicators defined in Sections 3.1.2 and 3.1.3. For both of them, as before, we treat the endogeneity of the domestic monetary policy variables and use the Arellano-Bond's test for serial correlations, m1 and m2, to identify the number of lags of DebtRank to include into the model. We include the first lag of this variable on the right hand side. The Sargan test does not reject any of the models presented in this Section. Our sample refers to the post-crisis period, from 2010 onwards which is the same period of Default correlations analyses.

We initially present the results of standard DebtRank regressions in Table 8. We see that, for models without reserve requirements, only the contemporary domestic policy rate has a statistically significant effect on DebtRank. This effect is also economically significant. The banks heterogeneity and the presence of state-owned banks in the sample do not change much neither the statistical significance nor the magnitude of the coefficients. The long-run effects analyses, presented in Table 8, show that only the domestic policy rate variables produce long-run effects. These results provide evidence that the domestic policy rate has a systemic risk-taking channel, but do not provide that evidence for the foreign policy rate.

Turning to standard DebtRank models with reserve requirement variables, that correspond to specifications (4), (5) and (6) in Table 8, we find that only model (6), with the full specification and only private banks, presents any statistically significant coefficients. In this regression, the coefficients of the domestic and foreign monetary policy variables are statistically significant and negative, supporting the evidence of systemic risk-taking channel for these variables. However, the assessment of long-run effects only find statistically significant effects for the domestic monetary policy variable. The regressions (4) and (5), that run on samples with all banks, do not present any statistically significant coefficients for the monetary policy variables possibly because the anti-cyclical play of the state-owned banks seems to reduce their coefficients (impact on systemic risk) while increasing their variance. All the statistically significant effects are also economically significant. Thus, we can say that we find evidence of the systemic risk-taking channel for these monetary policy variables only for the subsample composed by private banks. For that sample of banks, along the period from 2010 to 2014, a monetary easing increases the systemic stress.

We present results of collateral-sensitive DebtRank regressions in Table 9. The regressions for models without reserve requirements variables present statistically and economically significant coefficients for the contemporary domestic policy rate variable and for both contemporary and first lag of the foreign policy rate variable. The contemporary domestic policy variables' coefficients are negative, while the contemporary foreign policy variables' coefficients are positive but dominated by those of the first lag variables, which are negative. The long-run effects are negative for all variables, but only those of the domestic policy rate variables are statistically significant. These results support the evidence that both domestic and foreign policy rates has a systemic risk-taking channel. Regarding the models with reserve requirement variables, that correspond to specifications (4), (5) and (6) in Table 9, we see that the contemporary domestic policy rate variable has statistically and economically significant negative coefficients, while the other variables of interest do not present statistically significant coefficients. The domestic policy rate variable produces statistically significant negative long-run effects for model specifications with all banks but no micro controls and with only private banks but with micro controls. Additionally, the reserve requirements variable present a statistically significant positive long-run effect for the specification with all banks and micro controls. The results provide support for the evidence of systemic risk-taking channel for the domestic monetary policy variables, but indicate that the long-run effect of the reserve requirements variables must be interpreted with caution.

__Table 8:__ DebtRank regressions

	(1)	(2)	(3)	(4)	(5)	(6)
	Without reserve requirements			With reserve requirements		
VARIABLES	2010-14	2010-14	2010-14	2010-14	2010-14	2010-14
$DebtRank_{t-1}$	0.14	0.14	0.29**	0.14	0.14	0.29**
	(0.154)	(0.155)	(0.134)	(0.157)	(0.162)	(0.133)
$\Delta Policy\ rate_t$	-0.48**	-0.49***	-0.55***	-0.37	-0.28	-0.49**
	(0.193)	(0.176)	(0.194)	(0.247)	(0.227)	(0.203)
$\Delta Policy\ rate_{t-1}$	0.16	0.23	-0.54	-0.19	-0.10	-0.97**
	(0.517)	(0.519)	(0.384)	(0.638)	(0.663)	(0.495)
$\Delta Reserve\ req_t$				0.04	0.06	0.02
				(0.067)	(0.072)	(0.059)
$\Delta Reserve\ req_{t-1}$				-0.08	-0.08	-0.10**
				(0.064)	(0.070)	(0.052)
$\Delta FgnPolicy\ rate_t$	0.23	0.24	-0.14	0.06	0.06	-0.32
	(0.352)	(0.373)	(0.285)	(0.369)	(0.406)	(0.324)
$\Delta FgnPolicy\ rate_{t-1}$	0.17	0.24	-0.90	-0.00	0.18	-1.25*
	(0.885)	(0.928)	(0.702)	(1.069)	(1.105)	(0.730)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	2,152	1,920	1,767	2,152	1,920	1,767
Number of Banks	151	136	127	151	136	127
N Instruments	143	135	121	150	127	127
m1	-1.80*	-1.79*	-2.12**	-1.79*	-1.75*	-2.12**
m2	-0.52	-0.51	0.93	-0.50	-0.49	0.95
Sargan	146.06	130.02	118.71	147.86	124.15	118.90
VARIABLES	Long-run effects					
$\Delta Policy\ rate$	-0.37	-0.29	-1.53**	-0.65	-0.45	-2.07**
$\Delta Reserve\ req$				-0.04	-0.02	-0.11
$\Delta FgnPolicy\ rate$	0.46	0.56	-1.46	0.07	0.28	-2.21

This table presents regression results of DebtRank measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the proxy for systemic risk DebtRank. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. Regressions 1 - 3 assess the impact of domestic policy rate and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 2 and 3 also control for idiosyncratic features. Regressions 4 - 6 assess the impact of domestic policy rate, reserve requirements and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 9: *Collateral-sensitive DebtRank regressions*

	(1)	(2)	(3)	(4)	(5)	(6)
	Without reserve requirements			With reserve requirements		
VARIABLES	2010-14	2010-14	2010-14	2010-14	2010-14	2010-14
$DebtRank_{t-1}$	0.24***	0.21***	0.31***	0.24***	0.21**	0.30***
	(0.082)	(0.083)	(0.061)	(0.084)	(0.088)	(0.064)
$\Delta Policy\ rate_t$	-1.75***	-1.82***	-1.66***	-1.42**	-1.08*	-1.44**
	(0.347)	(0.368)	(0.399)	(0.657)	(0.652)	(0.684)
$\Delta Policy\ rate_{t-1}$	0.29	0.4	0.21	0.03	-0.05	0.06
	(0.376)	(0.416)	(0.430)	(0.462)	(0.484)	(0.523)
$\Delta Reserve\ req_t$				0.15	0.27	0.11
				(0.184)	(0.193)	(0.194)
$\Delta Reserve\ req_{t-1}$				0.05	0.03	0.11
				(0.087)	(0.091)	(0.082)
$\Delta FgnPolicy\ rate_t$	0.91**	0.99**	1.14***	0.46	0.09	0.75
	(0.386)	(0.428)	(0.429)	(0.650)	(0.665)	(0.698)
$\Delta FgnPolicy\ rate_{t-1}$	-1.44*	-1.54*	-1.63*	-1.07	-0.81	-1.39
	(0.761)	(0.834)	(0.855)	(0.962)	(0.961)	(0.948)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	2,152	1,920	1,767	2,152	1,920	1,767
Number of Banks	151	136	127	151	136	127
N. Instruments	143	135	121	150	127	120
m1	-3.30***	-3.22***	-3.94***	-3.24***	-3.13***	-3.88***
m2	-0.17	-0.20	0.21	-0.21	-0.23	0.18
Sargan	146.16	126.04	116.27	145.38	118.02	114.51
VARIABLES			Long-run effects			
$\Delta Policy\ rate$	-1.93**	-1.81**	-2.09**	-1.82**	-1.42	-1.98*
$\Delta Reserve\ req$				0.25	0.38**	0.31
$\Delta FgnPolicy\ rate$	-0.69	-0.7	-0.71	-0.81	-0.91	-0.92

This table presents regression results of collateral-sensitive DebtRank measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the proxy for systemic risk collateral-sensitive DebtRank. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. Regressions 1 - 3 assess the impact of domestic policy rate and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 2 and 3 also control for idiosyncratic features. Regressions 4 - 6 assess the impact of domestic policy rate, reserve requirements and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

We summarize our results from the results obtained for DebtRank and Default correlations systemic risk indicators as follows. The results obtained for the after-crisis period are similar: there is evidence that the domestic policy rate has a systemic risk-taking channel; for the other monetary policy variables, we find, at most, a weak evidence supporting the hypothesis. That is the case of the reserve requirements variable. In the case of the domestic policy rate variable, the evidences are stronger for models without reserve requirements. From this set of results we see that the easing of the domestic policy rate leads to an increase of the stress within the banking system network, which is related, on average, to the increase of the banks' leverage. From the point-of-view of the Default correlation, the individual banks default probabilities increase, leading to an increase of the default correlation[6] indicator. For the entire period, we have only data for Default correlations: we find strong evidence that both domestic and foreign policy rate variables have a systemic risk-taking channel, but no evidence for the channel for the reserve requirement variable. In the next section, we perform robustness tests.

6 Robustness

Along this section, we perform two robustness tests in which we assess the stability of these results under alternative variables and model specifications[7]. In the first robustness test, presented in Section 6.1, we use the average of US Fed and ECB shadow policy rates as the model's metric for foreign monetary policy, instead of using the US Fed shadow policy rate alone. We have chosen the US Fed shadow policy rate to represent the foreign monetary policy in the base model as the Brazilian economy is mostly subject to the influence of the US monetary policy, however, the ECB's monetary policy decisions influence are also relevant. The second robustness test is related to the influence of measures aimed at the mitigation of systemic risk related to the loosening of the domestic monetary policy, and related to speculative cross-border capital flows arising from domestic and/or foreign monetary policy decisions. We set up an index that summarizes tightening and loosening conditions stemming from these measures and add it as a control variable into the base model, presenting the results in Section 6.2.

[6]This happens for default probabilities below 0.5, if the banks' joint probabilities do not decrease.

[7]We also perform a robustness test considering as interest variable only the domestic policy rate, given that this variable presents the strongest evidence supporting the risk-taking channel of monetary policy hypothesis. The results are similar to the base case tests, both in sign and statistical / economic significance, in both short- and long-run. We also note that in this robustness test the evidence found for the post-crisis sample is weaker than that found for the entire sample, as it is in the base case test. These results are available upon request to the authors.

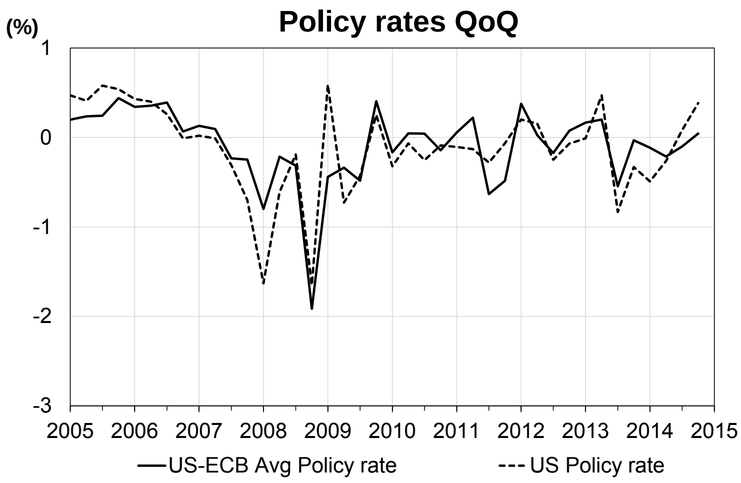


Figure 7: *Quarterly changes of foreign policy rates: US Fed and ECB average and US Fed.*

6.1 Alternative Foreign Policy Rate

In this section, we test an alternative foreign monetary policy interest rate variable by substituting the average between the US Fed and the European Central Bank shadow policy rate for the US Fed shadow policy rate. We present these variables in Figure 7.

Initially, we perform this robustness test on default correlations models without and with reserve requirement variables. The test results for models without reserve requirement variables are presented in Table 10, which we compare to those from the base model, in Table 7.

The results of regressions (1) and (2), that consider the entire period with all banks, are similar with respect to the magnitude and statistical significance of the coefficients of the domestic and foreign policy rate variables. The same occurs for the corresponding long-run effects. Regarding regression (3), run for a sample with only private banks, there are some differences: in the robustness test, the coefficients have the same sign as in the base case test, but the statistical significance is lost for both the domestic policy rate and the long-run effects. Concerning the results of regressions (4) to (6), that refer to the post-crisis period, they are similar in that both policy rate variables do not have statistically significant long-run effects, but different concerning the signs of the coefficients of the foreign policy rate. To assess the economic significance of the statistically significant coefficients, we check if $R_E \geq 5\%$ in Equation 21. To compute R_E, we use as inputs the mean of the absolute values of the foreign policy rate (0.293 for the period 2005-14, and 0.193, for 2010-14) and data from Table 5. We find that the statistically significant coefficients are also economically significant.

Table 10: *Default correlations regressions - foreign policy rate: average between US and ECB rates - Model without reserve requirements*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	2005-14	2005-14	2005-14	2010-14	2010-14	2010-14
Default corr$_{t-1}$	0.75***	0.72***	0.71***	0.70***	0.71***	0.70***
	(0.047)	(0.048)	(0.093)	(0.178)	(0.236)	(0.117)
Default corr$_{t-2}$	-0.02	-0.02	-0.02	0.02	0.04	0.04
	(0.020)	(0.020)	(0.020)	(0.024)	(0.040)	(0.043)
Default corr$_{t-3}$	-0.15***	-0.18***	-0.19	-0.16***	-0.11***	-0.11***
	(0.042)	(0.045)	(0.214)	(0.050)	(0.029)	(0.037)
Δ*Policy rate*$_t$	-0.47***	-0.43**	-0.46	-0.97	-0.83	-1.03*
	(0.159)	(0.166)	(0.552)	(0.888)	(0.644)	(0.582)
Δ*Policy rate*$_{t-1}$	0.08	0.09	0.09	0.12	0.27	0.32
	(0.114)	(0.115)	(0.159)	(0.837)	(0.894)	(0.717)
Δ*FgnPolicy rate*$_t$	-1.09***	-1.37***	-1.52***	-0.02	0.26	0.43
	(0.313)	(0.354)	(0.420)	(2.502)	(2.362)	(1.027)
Δ*FgnPolicy rate*$_{t-1}$	-0.29	-0.53*	-0.64*	0.02	0.43	0.39
	(0.255)	(0.271)	(0.365)	(2.468)	(2.352)	(0.585)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	4,356	4,113	3,727	2,211	2,064	1,890
Number of Banks	160	150	137	137	126	117
N Instruments	119	122	122	124	107	106
m1	-7.77***	-7.61***	-6.00***	-3.59***	-2.82***	-4.38***
m2	-0.64	-1.02	-0.32	-0.30	0.22	0.18
Sargan	112.45	108.07	102.98	110.72	93.28	90.48
VARIABLES	Long-run effects					
Δ*Policy rate*	-0.93*	-0.70*	-0.74	-1.97	-1.55	-1.92
Δ*FgnPolicy rate*	-3.30***	-3.92***	-4.34	0.01	1.9	2.24

This table presents regression results of Default correlation measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. As a robustness check, we consider as the foreign policy rate variable the average of the shadow policy rates of US Fed and ECB. The dependent variable in all regressions is the Default correlation measure, taken as a proxy for systemic risk, whereas the explanatory variables are the policy rate and the foreign policy rate. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. The sample for regressions 1 - 3 refers to the period from 2005 to 2014, and that for regressions 4 - 6, to the period from 2010 to 2014. All regressions control for macroeconomic conditions; regressions 2, 3, 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 11: *Default correlations regressions - foreign policy rate: average between US and ECB - With reserve requirements*

VARIABLES	(1) 2005-14	(2) 2005-14	(3) 2005-14	(4) 2010-14	(5) 2010-14	(6) 2010-14
Default corr$_{t-1}$	0.75***	0.72***	0.71***	0.71***	0.68***	0.67***
	(0.046)	(0.048)	(0.050)	(0.080)	(0.092)	(0.119)
Default corr$_{t-2}$	-0.02	-0.02	-0.02	0.02	0.04	0.04
	(0.020)	(0.020)	(0.020)	(0.029)	(0.044)	(0.055)
Default corr$_{t-3}$	-0.16***	-0.18***	-0.18***	-0.15***	-0.15	-0.15
	(0.043)	(0.046)	(0.046)	(0.034)	(0.104)	(0.108)
Δ*Policy rate*$_t$	-0.57***	-0.55***	-0.62***	-1.50	-1.70	-2.12
	(0.182)	(0.202)	(0.215)	(0.932)	(2.287)	(2.450)
Δ*Policy rate*$_{t-1}$	0.24	0.23	0.27	0.67	1.13*	1.41**
	(0.153)	(0.155)	(0.170)	(0.589)	(0.621)	(0.657)
Δ*Reserve req*$_t$	-0.07*	-0.08*	-0.10**	-0.24	-0.31*	-0.36
	(0.041)	(0.045)	(0.049)	(0.166)	(0.169)	(0.246)
Δ*Reserve req*$_{t-1}$	0.02	0.02	0.02	0.09	0.10	0.13
	(0.046)	(0.049)	(0.054)	(0.115)	(0.186)	(0.169)
Δ*FgnPolicy rate*$_t$	-0.97***	-1.21***	-1.30***	-0.17	0.55	0.78
	(0.324)	(0.363)	(0.376)	(1.192)	(1.103)	(1.289)
Δ*FgnPolicy rate*$_{t-1}$	-0.46	-0.68**	-0.84**	-0.92	-0.82	-1.03
	(0.282)	(0.310)	(0.332)	(0.851)	(0.795)	(1.332)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	4,356	4,113	3,727	2,211	2,064	1,890
Number of Banks	160	150	137	137	126	117
N Instruments	118.00	122.00	122.00	114.00	118.00	118.00
m1	-7.80***	-7.61***	-7.38***	-5.65***	-4.52***	-3.81***
m2	-0.63	-0.92	-0.96	-0.13	-0.27	-0.34
Sargan	109.46	107.27	100.77	100.52	103.27	102.31
VARIABLES	Long-run effects					
Δ*Policy rate*	-0.79*	-0.67*	-0.72*	-2.00	-1.32	-1.63
Δ*Reserve req*	-0.13	-0.13	-0.16	-0.33	-0.49	-0.54
Δ*FgnPolicy rate*	-3.38***	-3.93***	-4.32***	-2.62	-0.64	-0.58

This table presents regression results of Default correlation measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. As a robustness check, we consider as the foreign policy rate variable the average of the shadow policy rates of US Fed and ECB. The dependent variable in all regressions is the Default correlation measure, taken as a proxy for systemic risk, whereas the explanatory variables are the policy rate, the reserve requirements and the foreign policy rate. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. The sample for regressions 1 - 3 refers to the period from 2005 to 2014, and that for regressions 4 - 6, to the period from 2010 to 2014. All regressions control for macroeconomic conditions; regressions 2, 3, 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors. Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

The comparison above supports the evidence of a systemic risk-taking channel related to the domestic policy rate. However, for the foreign policy rate, the evidence found for the entire period disappears for the after-crisis period. This is true for not only the US Fed shadow policy rate, but also for the average of the US Fed and ECB rates.

Next, we analyze test results of models with reserve requirement variables, presented in Table 11, comparing them to the base case results in Table 7.

The results presented on columns (1) to (3) of both tables refer to regressions for the entire period, and are similar in sign and magnitude for all domestic policy variables. Regarding the foreign policy variables, coefficient signs are the same, but coefficient levels are different, reflecting the differences of the variables themselves. In both tables, the coefficients of these variables are negative and statistically significant. As for the reserve requirements coefficients, they are negative and next to zero for all the regressions in the two tables, being statistically significant only in the robustness test regressions. Concerning the long-run effects, the base case and the robustness test present similar results, both in sign and statistical significance.

For the post-crisis period, columns (4) to (6) of both Tables show regression coefficients with the same sign, but different magnitudes and statistical significance. Long run effects for both test cases are negative and statistically non-significant for almost all variables. The statistically significant variables are economically significant and are not the same for both test cases, which suggests that, for models with reserve requirements, along the post-crisis period, the effects from monetary policy variables are sensitive to the influence exerted by each jurisdiction. In the case of Brazil, which is mostly subjected to the influence from the US monetary policy, we suggest that we follow the results presented on Table 7. These results show that there is evidence that the domestic policy rate affects the Default probabilities indicators through a systemic risk-taking channel. For the foreign policy rate, there is no evidence, and for the reserve requirements, the evidence is weak.

__Table 12:__ DebtRank regressions - foreign policy rate: average between US and ECB rates

	(1)	(2)	(3)	(4)	(5)	(6)
	Without reserve requirements			With reserve requirements		
VARIABLES	2010-14	2010-14	2010-14	2010-14	2010-14	2010-14
$DebtRank_{t-1}$	0.14	0.14	0.29**	0.14	0.14	0.29**
	(0.153)	(0.155)	(0.134)	(0.157)	(0.162)	(0.133)
$\Delta Policy\ rate_t$	-0.55***	-0.56**	-0.51**	-0.37	-0.27	-0.62**
	(0.207)	(0.223)	(0.225)	(0.345)	(0.321)	(0.267)
$\Delta Policy\ rate_{t-1}$	0.02	0.04	-0.23	-0.20	-0.20	-0.35
	(0.255)	(0.267)	(0.243)	(0.244)	(0.274)	(0.238)
$\Delta Reserve\ req_t$				0.05	0.08	-0.05
				(0.114)	(0.119)	(0.073)
$\Delta Reserve\ req_{t-1}$				-0.08	-0.08	-0.11**
				(0.064)	(0.069)	(0.053)
$\Delta FgnPolicy\ rate_t$	0.02	-0.05	0.19	0.08	-0.06	0.51
	(0.455)	(0.504)	(0.443)	(0.506)	(0.520)	(0.457)
$\Delta FgnPolicy\ rate_{t-1}$	-0.12	-0.13	-0.65	0.01	0.15	-1.03*
	(0.513)	(0.557)	(0.479)	(0.889)	(0.921)	(0.605)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	2,152	1,920	1,767	2,152	1,920	1,767
Number of Banks	151	136	127	151	136	127
N Instruments	143	135	121	150	127	127
m1	-1.82*	-1.81*	-2.12**	-1.79*	-1.75*	-2.12**
m2	-0.51	-0.50	0.94	-0.50	-0.49	0.95
Sargan	145.97	128.84	119.18	147.86	124.15	118.90
VARIABLES	Long-run effects					
$\Delta Policy\ rate$	-0.61*	-0.60**	-1.04***	-0.67	-0.54	-1.37***
$\Delta Reserve\ req$				-0.03	-0.01	-0.22
$\Delta FgnPolicy\ rate$	-0.12	-0.21	-0.65	0.1	0.11	-0.74

This table presents regression results of DebtRank measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. As a robustness test, we consider as the foreign policy rate variable the average of the shadow policy rates of US Fed and ECB. The dependent variable in all regressions is the proxy for systemic risk DebtRank. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. Regressions 1 - 3 assess the impact of domestic policy rate and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 2 and 3 also control for idiosyncratic features. Regressions 4 - 6 assess the impact of policy rate, reserve requirements and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.

Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 13: *Collateral-sensitive DebtRank regressions - foreign policy rate: average between US and ECB rates*

	(1)	(2)	(3)	(4)	(5)	(6)
	Without reserve requirements			With reserve requirements		
VARIABLES	2010-14	2010-14	2010-14	2010-14	2010-14	2010-14
$DebtRank_{t-1}$	0.24***	0.21**	0.30***	0.24***	0.21**	0.30***
	(0.081)	(0.082)	(0.061)	(0.085)	(0.088)	(0.064)
$\Delta Policy\ rate_t$	-1.92***	-2.02***	-1.77***	-1.41***	-1.10**	-1.36**
	(0.330)	(0.368)	(0.346)	(0.538)	(0.551)	(0.580)
$\Delta Policy\ rate_{t-1}$	0.39	0.53	0.21	0.01	0.12	-0.13
	(0.425)	(0.466)	(0.420)	(0.451)	(0.499)	(0.457)
$\Delta Reserve\ req_t$				0.15	0.26	0.13
				(0.168)	(0.173)	(0.169)
$\Delta Reserve\ req_{t-1}$				-0.07	-0.01	-0.07
				(0.103)	(0.112)	(0.107)
$\Delta FgnPolicy\ rate_t$	1.06**	1.12*	1.23**	0.86	0.49	1.13*
	(0.536)	(0.586)	(0.503)	(0.668)	(0.664)	(0.638)
$\Delta FgnPolicy\ rate_{t-1}$	-1.91***	-2.11***	-2.22***	-1.23	-0.79	-1.73
	(0.686)	(0.758)	(0.679)	(1.262)	(1.250)	(1.218)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	2,152	1,920	1,767	2,152	1,920	1,767
Number of Banks	151	136	127	151	136	127
N. Instruments	143	135	121	150	127	120
m1	-3.28***	-3.21***	-3.92***	-3.23***	-3.13****	-3.88***
m2	-0.21	-0.26	0.17	-0.21	-0.23	0.18
Sargan	147.58	126.49	112.61	146.25	117.84	114.44
VARIABLES	Long-run effects					
$\Delta Policy\ rate$	-2.02***	-1.89**	-2.22***	-1.83*	-1.24	-2.14*
$\Delta Reserve\ req$				0.12	0.31	0.08
$\Delta FgnPolicy\ rate$	-1.12	-1.26	-1.42	-0.48	-0.39	-0.85

This table presents regression results of collateral-sensitive DebtRank measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. As a robustness test, we consider as the foreign policy rate variable the average of the shadow policy rates of US Fed and ECB. The dependent variable in all regressions is the proxy for systemic risk collateral-sensitive DebtRank. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. Regressions 1 - 3 assess the impact of domestic policy rate and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 2 and 3 also control for idiosyncratic features. Regressions 4 - 6 assess the impact of domestic policy rate, reserve requirements and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Turning to the standard DebtRank regressions analyzed in Section 5.2, we now compare the results from that section, presented in Table 8 with those from the present test, presented in Table 12. Firstly, we note that, excluding the model specifications (3) and (6), which sample has only private banks, we see that the coefficients of the foreign policy rate variables are close to zero and non-significant for both the contemporaneous variable and its first lag. The coefficients of other interest variables have roughly the same magnitude and statistical significance for models both with and without reserve requirements. Regarding the model specifications (3) and (6), the coefficients of the foreign policy rate variables are not as close to zero but remain mostly non-significant. However, the robustness test results for the other interest variables and the long-run effects have the same sign and statistical significance as the base case test. All the statistically significant coefficients are also economically significant. The above results do not provide evidence against our previous conclusions regarding the standard DebtRank indicator, drawn in Section 5.2.

We also perform this robustness test on collateral-sensitive DebtRank regressions, presenting the results in Table 13. We also compare these results with those in Table 9 in Section 5.2 for the model specifications without and with reserve requirements variables. The statistically significant coefficients are the same in both tables, and they present the same sign. These coefficients are also economically significant. We also compare the long-run effects presented in both tables and find that the results for both domestic and foreign policy rate variables are the same in statistical significance and sign, and that for the reserve requirement variables, the results are the same in sign but there is a difference in statistical significance. These results also do not provide evidence against our previous conclusions regarding the collateral-sensitive DebtRank indicator.

6.2 Macroprudential Measures

In this section, we consider the influence of measures aimed at the mitigation of systemic risk related: 1) to the loosening of the domestic monetary policy, and 2) to speculative cross-border capital flows arising from domestic and/or foreign monetary policy decisions. We consider this influence by adding a macro environment control variable to the original model specification in Equation 1. We define this variable as a macroprudential index that increases one unit when a new measure that restrain cross-border capital flows or restricts liquidity comes into effect and decreases one unit when these constraints are relaxed.

We compute the macroprudential index as an average of two variables: 1) capital flow macroprudential measures, aimed at reducing cross-border speculative capital flows by levying taxes on financial transactions with non-residents, foreign loans, foreign ex-

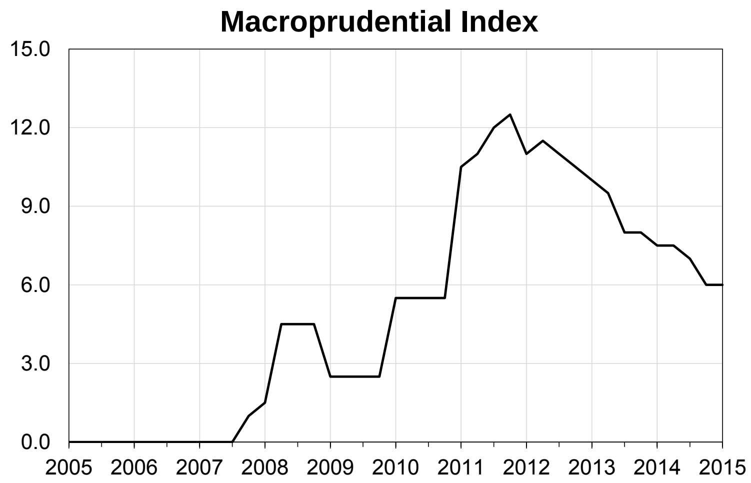


Figure 8: *Macroprudential index. Increases represent tightening measures.*

change derivatives and foreign direct investments, and 2) macroprudential domestic measures, which are those not included in the previous category. We get a relation of these measures from Silva and Harris (2012) and complement it with data from the Central Bank of Brazil's regulation information system (see CBB (2015)). We present the index built from these data in Figure 8. The means of absolute values of the quarterly variations of this index, used for the assessment of the economic significance of the statistically significant coefficients are 0.600, for the 2005-14 period, and 0.875, for the period 2010-14.

We run a robustness test using the macroprudential index defined above and present its results, for the default correlations risk indicator, in Tables 14 and 15, and for the DebtRank risk indicators, in Tables 16 and 17.

Initially, we perform this robustness test on default correlation models without reserve requirement variables, comparing the results in Table 14 with those from the corresponding base model. The results of regressions (2) and (3), that consider the entire period with bank-level controls, are similar with respect to the magnitude and statistical significance of the coefficients of the domestic and foreign policy rate variables. The same occurs for the corresponding long-run effects. The coefficients of the Macroprudential index control variable are also negative and statistically / economically significant, which means that a tightening of these measures reduces systemic risk. The robustness test of regression (1), that do not considers bank-level controls presents a difference with respect to the base model: the foreign policy rate coefficients have the same sign as in the base case model, but the statistical significance is lost, including that of long-run effects. The results of regressions (4) to (6), which refer to the post-crisis period, are similar to the base case ones, in magnitude, sign and statistical/economic significance of both policy rate variables. These regressions and regression (1) present negative and not-significant

Macroprudential index coefficients.

We analyze the test results of models with reserve requirement variables, presented in Table 15, comparing them to the corresponding base case results. The pattern of similarities between test and base case models is almost the same as those for models without reserve requirements variables. First, regressions (2) and (3) present similarities with respect to the magnitude and statistical significance of the coefficients of the domestic and foreign policy rate variables, including their long-run effects. Second, Macroprudential index control variable coefficients are also negative and statistically / economically significant for these regressions. Third, for regression (1), the foreign policy rate coefficients have the same sign as in the base case model, but the statistical significance is lost, including that of long-run effects, and fourth, the results of regressions (4) to (6) are similar to the base case ones, in magnitude, sign and statistical/economic significance of both policy rate variables. For all the test regressions, the sign and statistical / economic significance of the Reserve requirements variables' coefficients are the same as in the base case. Finally, the Macroprudential index coefficients are not statistically significant for regressions (1) and (4) to (6), being negative for the first regression and positive for the last ones. These results do not provide evidence against the base case results.

We now analyze the robustness test results of standard DebtRank models, presented in Table 16. Regarding the models without reserve requirements variables, we find that the contemporary domestic policy rate variable coefficients are negative and statistically / economically significant. The lagged variable ones are mostly positive and not statistically significant. None of the coefficients of the foreign policy rate variables is statistically significant, being most of them positive. The long run effects of these variables and the Macroprudential index coefficients are not statistically significant. Comparing these results with the base case ones, we find that the magnitude, sign and statistical / economic significance of the contemporary domestic policy rate variable are very similar, while, for the other variables, they are similar to the base case ones only in the lack of statistical significance. Regarding the models with variables of reserve requirements, comparing the test results with those from the base case, we note that for model specifications (4) and (5), all the coefficients of the variables of interest are statistically non significant in both results. For the model specification (6), the test result has at least one negative and statistically / economically significant coefficient for each variable of interest, which also happens for the base case model. In both models, only the domestic policy rate variable has a significant (and negative) long-run effect. These results are consistent with a systemic risk-taking channel of the domestic monetary policy variable, but do not provide such evidence of the existence of this channel for the other variables of interest.

Finally, we analyze the robustness test results of collateral-sensitive DebtRank models, presented in Table 17.For models without reserve requirements variables, the test supports the evidence of a systemic risk-taking channel for the domestic and foreign monetary policy variables. Their long-run effects are negative and significant. The Macroprudential index has positive coefficients, mostly not statistically significant. Considering the models with reserve requirements variables, the test results are mostly similar, in sign and statistical significance for the domestic and foreign policy variables. As for the reserve requirements variable, the sum of the coefficients of its two lags is positive for all model specifications of the test and the base case models. Besides, the test model also presents a positive and statistically significant long-run effect for this variable, along with negative and non statistically significant coefficients for the Macroprudential index variable. Likewise the base case model, there are evidences in favor of a systemic risk-taking channel for the domestic and foreign monetary policy variables in models without reserve requirements and Macroprudential index variables. In models with these variables, the evidence is substantially weakened. Additionally, results regarding the reserve requirements variable should be interpreted with caution.

7 Conclusion

The evidence generally supports our hypotheses. First, there is strong evidence that domestic policy rate has an inverse relation with systemic risk, consistent with the risk-taking channel of monetary policy hypothesis, extended here for correlated risks and network externalities. Results are statistically and economically significant on both short and long runs for the long sample. For the sample comprising only the post-crisis period, evidence is weaker, presenting statistically and economically significant results only on the short run, for most of the regressions. Second, there is evidence that foreign policy rate has an inverse relation with systemic risk for the long sample, however, for the post-crisis sample, it is much weaker: effects are similar, although mostly not statistically significant, consistent with a lesser role of banks in the transmission of foreign shocks. Third, the evidence of a risk-taking channel of monetary policy related to reserve requirement rates is weak, consistent with its operation on a narrower transmission channel. Regardless of statistical and economic significance, the signs of the effects of domestic and foreign monetary policies on systemic risk found along this paper are mostly consistent with our hypotheses. These results apply for the systemic risk indicators considered in the paper, namely, the Default Correlation and the DebtRank ones (the standard DebtRank and the collateral-sensitive DebtRank), which summarize, respectively, the joint default probability of financial institutions and the stress propagated through the interbank market given a default event. Our findings also point point to the need for further research to investigate the generality of the results under different contexts. Additionally, these results open opportunities for coordination of monetary and macro prudential policies.

Table 14: *Default correlations regressions - Model with macroprudential measures index without reserve requirements*

	(1)	(2)	(3)	(4)	(5)	(6)
VARIABLES	2005-14	2005-14	2005-14	2010-14	2010-14	2010-14
Default corr$_{t-1}$	0.73***	0.71***	0.70***	0.71***	0.70***	0.70***
	(0.089)	(0.050)	(0.050)	(0.035)	(0.065)	(0.062)
Default corr$_{t-2}$	-0.02	-0.02	-0.02	0.02	0.03	0.03
	(0.027)	(0.021)	(0.021)	(0.024)	(0.029)	(0.028)
Default corr$_{t-3}$	-0.17*	-0.18***	-0.18***	-0.16***	-0.12***	-0.12***
	(0.089)	(0.046)	(0.047)	(0.019)	(0.026)	(0.027)
Δ*Policy rate*$_t$	-0.61**	-0.66***	-0.72***	-1.05***	-0.85*	-0.98**
	(0.296)	(0.170)	(0.182)	(0.363)	(0.458)	(0.405)
Δ*Policy rate*$_{t-1}$	0.25	0.26**	0.28**	-0.03	0.01	-0.03
	(0.668)	(0.122)	(0.136)	(0.379)	(0.446)	(0.487)
MacroPrud Index$_t$	-0.1	-0.11**	-0.11*	-0.14	-0.01	0.01
	(0.268)	(0.053)	(0.057)	(0.165)	(0.188)	(0.215)
Δ*FgnPolicy rate*$_t$	-0.64	-0.82***	-0.92***	-0.09	-0.36	-0.43
	(0.666)	(0.256)	(0.265)	(0.740)	(0.651)	(0.759)
Δ*FgnPolicy rate*$_{t-1}$	-0.24	-0.33	-0.39*	0.19	0.23	0.16
	(1.098)	(0.219)	(0.224)	(0.703)	(0.611)	(0.753)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	4,465	4,215	3,816	2,211	2,064	1,890
Number of Banks	160	150	137	137	126	117
N Instruments	121	125	125	127	109	108
m1	-5.84***	-7.32***	-7.15***	-6.54***	-5.67***	-5.71***
m2	-0.61	-0.89	-0.91	-0.32	0.26	0.23
Sargan	113.39	109.38	104.04	114.07	93.320.93	88.44
VARIABLES			Long-run effects			
Δ*Policy rate*	-0.79	-0.81**	-0.89**	-2.49**	-2.20	-2.61
Δ*FgnPolicy rate*	-1.91	-2.34***	-2.64***	0.23	-0.35	-0.71

This table presents regression results of Default correlation measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the Default correlation measure, taken as a proxy for systemic risk, whereas the explanatory variables are the domestic policy rate and the foreign policy rate. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. The sample for regressions 1 - 3 refers to the period from 2005 to 2014, and that for regressions 4 - 6, to the period from 2010 to 2014. All regressions control for macroeconomic conditions; regressions 2, 3, 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 15: *Default correlations regressions - Model with macroprudential measures index and reserve requirements*

VARIABLES	(1) 2005-14	(2) 2005-14	(3) 2005-14	(4) 2010-14	(5) 2010-14	(6) 2010-14
Default corr$_{t-1}$	0.74***	0.71***	0.70***	0.71***	0.68***	0.68***
	(0.090)	(0.050)	(0.050)	(0.032)	(0.032)	(0.035)
Default corr$_{t-2}$	-0.02	-0.02	-0.02	0.02	0.04	0.04
	(0.023)	(0.021)	(0.021)	(0.023)	(0.025)	(0.025)
Default corr$_{t-3}$	-0.17*	-0.18***	-0.17***	-0.15***	-0.15***	-0.13***
	(0.101)	(0.048)	(0.047)	(0.019)	(0.020)	(0.021)
Δ*Policy rate*$_t$	-0.70***	-0.74***	-0.84***	-1.44**	-1.79**	-2.23***
	(0.227)	(0.219)	(0.236)	(0.662)	(0.699)	(0.733)
Δ*Policy rate*$_{t-1}$	0.34	0.34**	0.38**	0.46	1.39*	1.77**
	(0.632)	(0.166)	(0.185)	(0.590)	(0.794)	(0.865)
Δ*Reserve req*$_t$	-0.04	-0.05	-0.07	-0.17	-0.36**	-0.47**
	(0.105)	(0.050)	(0.056)	(0.128)	(0.177)	(0.182)
Δ*Reserve req*$_{t-1}$	0.04	0.01	0.02	0.12	0.24	0.31
	(0.198)	(0.054)	(0.061)	(0.130)	(0.187)	(0.195)
MacroPrud Index$_t$	-0.1	-0.11**	-0.10*	0.05	0.26	0.42
	(0.214)	(0.052)	(0.056)	(0.192)	(0.279)	(0.282)
Δ*FgnPolicy rate*$_t$	-0.51	-0.73**	-0.77**	-0.33	0.09	0.1
	(0.512)	(0.285)	(0.309)	(0.680)	(0.701)	(0.829)
Δ*FgnPolicy rate*$_{t-1}$	-0.33	-0.41*	-0.51**	-0.73	-1.19	-1.64*
	(1.215)	(0.246)	(0.254)	(0.843)	(0.964)	(0.967)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	4,465	4,215	3,816	2,211	2,064	1,890
Number of Banks	160	150	137	137	126	117
N Instruments	121	125	125	114	118	105
m1	-6.01***	-7.31***	-7.14***	-6.64***	-6.22***	-6.13***
m2	-0.49	-0.79	-0.81	-0.15	-0.34	-0.19
Sargan	112.88	109.27	103.72	100.59	104.02	92.83
VARIABLES			Long-run effects			
Δ*Policy rate*	-0.80	-0.84*	-0.94**	-2.34**	-0.93	-1.12
Δ*Reserve req*	-0.01	-0.07	-0.10	-0.12	-0.29	-0.39
Δ*FgnPolicy rate*	-1.86	-2.37***	-2.64***	-2.52	-2.58	-3.73

This table presents regression results of Default correlation measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the Default correlation measure, taken as a proxy for systemic risk, whereas the explanatory variables are the domestic policy rate, the reserve requirements and the foreign policy rate. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. The sample for regressions 1 - 3 refers to the period from 2005 to 2014, and that for regressions 4 - 6, to the period from 2010 to 2014. All regressions control for macroeconomic conditions; regressions 2, 3, 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors. Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 16: *DebtRank regressions - Model with macroprudential measures index*

	(1)	(2)	(3)	(4)	(5)	(6)
	Without reserve requirements			With reserve requirements		
VARIABLES	2010-14	2010-14	2010-14	2010-14	2010-14	2010-14
$DebtRank_{t-1}$	0.14	0.14	0.29**	0.14	0.14	0.29**
	(0.157)	(0.162)	(0.134)	(0.157)	(0.162)	(0.133)
$\Delta Policy\ rate_t$	-0.48**	-0.46**	-0.52**	-0.14	-0.12	0.21
	(0.201)	(0.200)	(0.214)	(0.270)	(0.313)	(0.262)
$\Delta Policy\ rate_{t-1}$	0.4	0.46	-0.13	-0.37	-0.24	-1.50**
	(0.530)	(0.585)	(0.462)	(0.960)	(0.984)	(0.746)
$\Delta Reserve\ req_t$				0.12	0.12	0.26**
				(0.117)	(0.123)	(0.109)
$\Delta Reserve\ req_{t-1}$				-0.12	-0.11	-0.22**
				(0.127)	(0.133)	(0.103)
$\Delta MacroPrud\ Index_t$	-0.04	0.02	-0.17	-0.17	-0.13	-0.52**
	(0.367)	(0.394)	(0.299)	(0.324)	(0.325)	(0.256)
$\Delta FgnPolicy\ rate_t$	0.66	0.55	0.7	0.15	0.12	-0.06
	(0.909)	(0.986)	(0.856)	(0.257)	(0.294)	(0.272)
$\Delta FgnPolicy\ rate_{t-1}$	0.53	0.44	-0.03	0.57	0.61	0.5
	(1.501)	(1.667)	(1.416)	(0.405)	(0.445)	(0.427)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	2,152	1,920	1,767	2,152	1,920	1,767
Number of Banks	151	136	127	151	136	127
N. Instruments	147	132	124	149	134	126
m1	-1.79*	-1.75*	-2.12**	-1.79*	-1.75*	-2.13*
m2	-0.50	-0.49	0.95	-0.50	-0.49	0.95
Sargan	147.97	125.27	118.85	147.97	125.15	118.84
VARIABLES			Long-run effects			
$\Delta Policy\ rate$	-0.10	-0.00	-0.91	-0.59	-0.42	-1.82**
$\Delta Reserve\ req$				0.01	0.01	0.05
$\Delta FgnPolicy\ rate$	1.37	1.15	0.94	0.84	0.84	0.63

This table presents regression results of DebtRank measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the proxy for systemic risk DebtRank. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. Regressions 1 - 3 assess the impact of domestic policy rate and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 2 and 3 also control for idiosyncratic features. Regressions 4 - 6 assess the impact of domestic policy rate, reserve requirements and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 17: *Collateral-sensitive DebtRank regressions - Model with macroprudential measures index*

	(1)	(2)	(3)	(4)	(5)	(6)
	Without reserve requirements			With reserve requirements		
VARIABLES	2010-14	2010-14	2010-14	2010-14	2010-14	2010-14
$DebtRank_{t-1}$	0.24***	0.21**	0.30***	0.24***	0.21**	0.30***
	(0.084)	(0.088)	(0.063)	(0.084)	(0.088)	(0.063)
$\Delta Policy\ rate_t$	-1.92***	-1.97***	-1.86***	-0.81**	-0.83*	-0.43
	(0.357)	(0.399)	(0.414)	(0.391)	(0.436)	(0.361)
$\Delta Policy\ rate_{t-1}$	-0.66	-0.86	-1.13	-1.04	-0.5	-1.75
	(0.682)	(0.768)	(0.709)	(1.454)	(1.481)	(1.475)
$\Delta Reserve\ req_t$				0.36**	0.36*	0.47***
				(0.179)	(0.184)	(0.181)
$\Delta Reserve\ req_{t-1}$				-0.13	-0.04	-0.18
				(0.195)	(0.202)	(0.198)
$\Delta MacroPrud\ Index_t$	0.62	1.03*	0.65	-0.33	-0.13	-0.55
	(0.540)	(0.579)	(0.584)	(0.467)	(0.467)	(0.457)
$\Delta FgnPolicy\ rate_t$	-1.05	-2.1	-1.23	-0.04	-0.11	-0.09
	(1.362)	(1.493)	(1.513)	(0.466)	(0.466)	(0.526)
$\Delta FgnPolicy\ rate_{t-1}$	-3.99**	-5.39**	-4.74**	-0.44	-0.56	-0.38
	(1.992)	(2.231)	(2.225)	(0.650)	(0.706)	(0.707)
Macro Controls	Yes	Yes	Yes	Yes	Yes	Yes
Micro Controls	No	Yes	Yes	No	Yes	Yes
Only Private Banks	No	No	Yes	No	No	Yes
Observations	2,152	1,920	1,767	2,152	1,920	1,767
Number of Banks	151	136	127	151	136	127
N. Instruments	147	132	124	149	134	126
m1	-3.24***	-3.13***	-3.88***	-3.24***	-3.13***	-3.89***
m2	-0.21	-0.23	0.18	-0.21	-0.23	0.18
Sargan	146.74	118.20	115.80	146.74	117.86	115.80
VARIABLES	Long-run effects					
$\Delta Policy\ rate$	-3.38***	-3.59***	-4.29***	-2.42	-1.68	-3.13*
$\Delta Reserve\ req$				0.31**	0.41***	0.42**
$\Delta FgnPolicy\ rate$	-6.60	-9.48**	-8.55*	-0.62	-0.85	-0.68

This table presents regression results of collateral-sensitive DebtRank measures on monetary policy variables using a two-step linear dynamic panel-data model, estimated with generalized method of moments (GMM), as proposed by Arellano and Bond (1991), with fixed effects for banks and robust standard errors. The dependent variable in all regressions is the proxy for systemic risk collateral-sensitive DebtRank. The sample for regressions 1, 2, 4 and 5 comprises all banks, while for regressions 3 and 6 it is composed only by private banks. Regressions 1 - 3 assess the impact of domestic policy rate and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 2 and 3 also control for idiosyncratic features. Regressions 4 - 6 assess the impact of domestic policy rate, reserve requirements and foreign policy rate variables on systemic risk controlling for macroeconomic conditions. From these, regressions 5 and 6 also control for idiosyncratic features. m1 and m2 are the results from Arellano-Bond test for serial correlation in the first-differenced errors. Sargan test statistic comes from two-step dynamic panel-data without robust standard errors.
Robust standard errors are in parentheses. ***, ** and * indicate significance at the 1%, 5%, and 10% levels, respectively.

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