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Financial Fragility in a General Equilibrium Model: The Brazilian Case

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Abstract

This paper employs a general equilibrium approach to model the Brazilian financial system. We show that the model is able to replicate the main characteristics of the data and to predict short-term trends. The model is calibrated for the 2002-2006 period. Empirical results suggest that the financial system is improving in terms of financial stability over time. Furthermore, the model has been proven useful to model the Brazilian banking system and could be employed to evaluate the impact of changes in financial regulation on the banking system.

Keywords: general equilibrium; financial stability; banking system; financial regulation; calibration.
JEL Classification: G01; G10; G15; G18; G21.

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1 Introduction

The past decades witnessed many banking crises around the world. These crises have important implications for the economy as a whole. Hoggarth et al. (2002) studied the costs of banking system instability and found that the cumulative output losses incurred during crises account, on average, for 15-20% of the annual GDP. Therefore, the analysis of potential banking crises and the identification of the source of financial stability are of utmost importance.

Recent research has introduced general equilibrium models with incomplete markets into the financial literature in order to shed some light on the complex relationships between banks, depositors, borrowers and economic authorities that determine the extent of financial stability. For example, Goodhart et al. (2006a) introduced a model with the possibility of capital requirements violation and consequent penalties extending the work of Tsomocos (2003), which already included heterogeneous commercial banks and capital requirements in a general equilibrium model with incomplete markets, money, and default.

In order to solve these models numerically, Goodhart et al. (2006a) simplified the problem and solved the case of three households, two banks (a well capitalized bank and a weakly capitalized bank), the Central Bank and a regulator. Using this framework, the authors analyze the effects of changes in the exogenous variables and the parameters of the model. They argue that the model was useful to characterize UK financial stability since it replicated time series properties of UK banking data and it allowed for contagion to occur between heterogeneous banks, elucidating how such contagion behaves over time as well.

In Goodhart et al. (2005), the authors introduced an additional bank that can be thought of as the aggregation of the remaining banks in the system. Furthermore, given the lack of disaggregated household and investors' portfolio data, they modeled household behavior via reduced-form equations which relate their actions to a variety of economic variables such as GDP, interest rates, aggregate credit supply, etc. In this sense, this is a partial general equilibrium model with microeconomic foundations. The main difference between Goodhart et al. (2004) and Goodhart et al. (2006a) is that while in Goodhart et al. (2004) and Goodhart et al. (2005) the agents' behavior is an optimizing behavior, in Goodhart et al. (2006a) the agents' behavior is calibrated.

The main intention of Goodhart et al. (2006b) was to extend the model presented in Goodhart et al. (2005) to an infinite-horizon setting. Actually, they only extended the model to a finite horizon. Goodhart et al. (2006b) argued that standard dynamic models, which have an active role for banks, usually assume the horizon over which rational banks maximize their expected discount profits is infinite, i.e., bank managers are assumed to behave as if they were shareholders and therefore care about the expected profits over the expected lifetime of banks. However, due to the standard conflict between bank managers and shareholders, the former usually only has an incentive to take into account the expected profits of their banks only up to a finite horizon, depending on the number of periods in which they expect to remain in charge of their banks. Therefore, they showed mathematically that this is equivalent to assuming that the values of the discount factors of these bank managers beyond a certain finite horizon approach zero. Thus, they assumed for simplicity that the time horizon is equal to one period, implying that banks at the end of time t make their optimal decisions on their portfolios in order to maximize the expected value of profits at time $t+1$.

By using this framework, it is possible to assess how these models based on general equilibrium with incomplete markets conform with the time series data of a given country. This model has been applied successfully to the UK (Goodhart et al., 2006b) and Colombian (Saade et al., 2007)[1] banking systems.

In this paper, following this literature, we apply this model to the Brazilian economy in the 2002-2006 period. One peculiarity of the Brazilian banking system is that it is the largest in Latin America. Moreover, as explained by Staub et al. (2010), this system went through major modifications due to the entry of foreign banks, merger and acquisition (M&A) activities and privatizations in this period. However, public banks are still predominant, owning approximately one third of Brazilian banking assets. Chang et al. (2008) also show that in 2002, Brazilian banks passed through a period of high non-performing loans associated with low profitability, which according to Tsomocos (2003), is the definition of financial fragility. Thus, our general equilibrium approach takes into consideration this crisis[2].

An interesting feature that differentiates our study, as well as the one by Saade et al. (2007), from Goodhart et al. (2006b) is that, in emerging

[1]The results of Saade et al. (2007) suggest that this model has a satisfactory performance, especially in the prediction of the short-run trend. There is an overestimation of several trends in the medium to long term.

[2]As in Goodhart et al. (2006b), this paper does not assess international contagion, since we consider a closed economy only. The ongoing world financial crisis (2008-present) has not been generated within the Brazilian economy, but it was imported from abroad. However, the crisis in 2002 was generated domestically, thus allowing us to analyze its effects. Therefore, our time period does not consider post-2006 periods. We leave the analysis of how this crisis has affected the financial fragility of Brazilian banks to future research.

markets, banks tend to have a bigger role in financial development, since the stock and corporate bond markets are usually underdeveloped. The analysis of the financial fragility of banking systems of developing countries is, therefore, more important to the economy as a whole. Furthermore, differences between the Brazilian and Colombian banking markets are also evident. For example, according to Saade et al. (2007), credit and deposits of Colombian banks appear to be, on average, stable over time. While, for Brazilian banks, these variables have a clear linear upward trend.

We found that this model (Goodhart et al., 2006b) is capable of modeling the dynamics of the Brazilian banking system. However, we also found that the dynamics generated by the model is strongly sensitive to the model's parameter values. Nonetheless, we are able to replicate the behavior of important variables using the model, which suggests that it can be very useful for policy making and understanding of structural economic relationships.

This paper proceeds as follows. In the next section, we review the model introduced in Goodhart et al. (2006b). In section 3, we describe the data used to calibrate the model. In section 4, we discuss the methodology used to calibrate the parameters of the model. In section 5, we present the main results of the application of this model to the Brazilian data. In section 5.5, we present a discussion about how this model can give some hints about financial fragility. In the last section, we present some final remarks.

2 Model

In this section, we revisit the general equilibrium model considered in Goodhart et al. (2006b), which is an extension of Goodhart et al. (2005).

2.1 Basic assumptions of the model

The model has three heterogeneous banks, $b \in B = \{\gamma, \delta, \tau\}$, four private sector agents $h \in \{\alpha, \beta, \theta, \phi\}$, a regulator and a Central Bank. The decisions of private agents and banks are considered to be endogenous in the model, while the Central Bank and the regulator have predefined strategies. The time horizon extends over infinite periods $t \in T = \{1, \cdots, \infty\}$. On each future date, it is assumed that there are two possible states of nature $s \in S = \{i, ii\}$. While state i is meant to be a good/normal state, state ii is meant to be an extreme/critical event. At time t, the probability of state i is denoted by p.

The time structure of the model has the same logic as Goodhart et al. (2006b). At the end of time t, loan, deposit and interbank markets open.

Each bank then decides how much credit it will offer in the market and also the amount of deposits it will demand from households, depending on the expectations of the state of nature in the next period $(t+1)$. At time $t+1$, when one of the two possible states s (equal to i or ii) actually occurs, all the contracts signed in the last period are settled, and some default or capital requirement violations may also occur, which are then penalized by the authorities. Finally, banks' profit are realized and all the financial markets reopen.

As in Goodhart et al. (2004, 2005, 2006a,b), limited participation of the market is assumed, i.e., due to history or informational constraints, at the beginning of each period, bank borrowers are assigned to a single bank. Thus, householders α, β and θ borrow from banks γ, δ and τ, respectively. The agent ϕ represents the pool of depositors in the economy, implying that each bank in its respective deposit market interacts with the agent ϕ, who supplies funds to the banking system. Banks may also trade among themselves in an interbank market. The Central Bank intervenes in this market by setting an interest rate thus changing the money supply.

2.2 Banking sector

The banking sector is composed of three heterogeneous banks $b \in B = \{\gamma, \delta, \tau\}$, each one with a different portfolio, capital endowment and risk preference. If all banks were perfectly homogenous, there would be neither interbank trade nor contagion.

In each period $t \in \{0, \cdots, \infty\}$, the bank $b \in B$ maximizes its expected payoff, which is a quadratic function of its expected profitability in the next period minus non-pecuniary penalties that arise if the bank defaults on its deposits, interbank obligations, and capital requirement violations.

The optimization problem of bank $b \in B$ at time $t \in \{0, \cdots, \infty\}$ is formalized as

$$\begin{aligned} \max \quad & {}_{m_t^b, \mu_t^b, d_t^b, \mu_{d,t}^b, \nu_{t+1,s}^b, s \in S} E_t[\Pi_{t+1}^b] = \sum_{s \in S} p_s \{\pi_{t+1,s}^b - c_s^b (\pi_{t+1,s}^b)^2\} \\ - \quad & \sum_{s \in S} p_s \left(\lambda_{ks}^b \max[0, \overline{k}_{t+1,s}^b - k_{t+1,s}^b] + \lambda_s^b (1 - \nu_{t+1,s}^b)(\mu_t^b + \mu_{d,t}^b) \right) \end{aligned} \tag{1}$$

subject to the balance sheet constraint

$$\overline{m}_t^b + d_t^b + A_t^b = \frac{\mu_t^b}{1+\rho_t} + \frac{\mu_{d,t}^b}{1+r_{d,t}^b} + e_t^b + \text{others}_t^b \tag{2}$$

i.e., credit extension of bank B + interbank lending + market book investment = liabilities obtained from interbank + liabilities obtained from deposit borrowing + liabilities obtained from equity + residual,

and to the positive expected profitability

$$\begin{aligned}(1+\rho_t)\nu^b_{t+1,s}\mu^b_t &+ (1+r^b_{d,t})\nu^b_{t+1,s}\mu^b_{d,t} + \text{others}^b_t + e^b_t \\ &\leq \nu^{h^b}_{t+1,s}(1+r^b_t)\overline{m}^b_t + (1+r^{b,A}_t)A^b_t + \tilde{R}_{t+1,s}d^b_t(1+\rho_t) \quad s \in S \end{aligned} \tag{3}$$

[i.e. amount of money that bank b repays on its liabilities (interbank market, deposit market, residual, equity)$\leq$ amount of money that bank b receives from its asset investment (deposit market, market book investment, interbank market)]

where

$$\begin{aligned}\pi^b_{t+1,s} &= \nu^{h^b}_{t+1,s}(1+r^b_t)\overline{m}^b_t + (1+r^{b,A}_t)A^b_t + \tilde{R}_{t+1,s}d^b_t(1+\rho_t) \\ &- ((1+\rho_t)\nu^b_{t+1,s}\mu^b_t + (1+r^b_{d,t})\nu^b_{t+1,s}\mu^b_{d,t} + \text{others}^b_t + e^b_t) \quad s \in S\end{aligned} \tag{4}$$

$$e^b_{t+1,s} = e^b_t + \pi^b_{t+1,s} \quad s \in S \tag{5}$$

$$k^b_{t+1,s} = \frac{e^b_{t+1,s}}{\overline{\omega}\nu^{h^b}_{t+1,s}(1+r^b_t)\overline{m}^b_t + \tilde{\omega}(1+r^{b,A}_t)A^b_t + \omega\tilde{R}_{t+1,s}d^b_t(1+\rho_t)}, \forall s \in S \tag{6}$$

and

μ^b_t: is the bank b's debt in the interbank market at time t;
d^b_t: bank b's interbank lendings;
$\mu^b_{d,t}$: bank b's deposits;
$\nu^b_{t+1,s}$: repayment rate of bank b at $t+1$ and $s \in S$;
$\overline{m}^b_t$: amount of credit that bank b offers at time t;
A^b_t: other assets of bank b;
e^b_t: bank b's capital;
r^b_t: lending rate offered by bank b;
$r^b_{d,t}$: deposit rate offered by bank b;
$r^{b,A}_t$: return on other assets of bank b;

ρ_t: interbank rate at time t;
$\nu^{h^b}_{t+1,s}$: repayment rate of h^b at $t+1$ and $s \in S$;
$\tilde{R}_{t+1,s}$: repayment rate expected by banks from their interbank lending at $t+1$ and $s \in S$;
$k^b_{t+1,s}$: capital adequacy ratio;
$\overline{k}^b_{t+1,s}$: capital adequacy requirement (CAR);
p_s: probability of state $s \in S$ occurring at $t+1$;
c^s_b: risk aversion coefficient in the utility function;
λ^b_s: default penalties for bank b at $s \in S$;
$\lambda^b_{k,s}$: capital adequacy violation penalty for bank b at $s \in S$;
$\overline{\omega}$: risk weight on consumer loans;
$\tilde{\omega}$: risk weight on market book;
ω: risk weight on investment;
others^b_t: residual

2.3 Private agent sector

As mentioned before, there are four private sector agents $h \in \{\alpha, \beta, \theta, \phi\}$. While householders α, β and θ borrow from banks γ, δ and τ, respectively, the agent ϕ represents the pool of depositors in the economy, implying that each bank in its respective deposit market interacts with the agent ϕ, who supplies funds to the banking system. In Goodhart et al. (2006b), instead of explicitly considering the optimization problem faced by the private sector, the behavior of this sector is modeled by real data. Therefore, the householders' decisions are endogenized by assuming the following reduced-form equations.

2.3.1 Household borrowers' demand for loans

Due to the limited participation assumption in every consumer loan market, each household's demand for loans at time t is a negative function of the corresponding lending rate offered by the selected lending bank. Furthermore, it is assumed that loans also depend on the expected GDP in the subsequent period[3]. Finally, a linear time trend is included in order to improve the empirical fit.

The following form for household h^b's loan demand is specifically assumed

[3]It is explicitly assumed that household borrowers rationally anticipate GDP in both states in the next period, which then determines their expected income and adjusts their loan demand in this period accordingly in order to smooth their consumption over time.

$$\ln(\mu_t^{h^b}) = a_{h^b,1} + a_{h^b,2}\text{trend} + a_{h^b,3}\ln[pGDP_{t+1,i} + (1-p)GDP_{t+1,ii}] + a_{h^b,4}r_t^b \quad (7)$$

where

$\mu_t^{h^b}$ is the amount of money that agent $h^b \in H^b$ chooses to owe in the loan market of bank $b \in B$ at time t;

$GDP_{t+1,s}$ is the gross domestic product at time $t+1$ if state $s \in S$ occurs.

2.3.2 Mr. ϕ's supply of deposits

Since it is not assumed that there is limited participation in the deposit market, Mr ϕ's deposits are diversified in every bank. Therefore, Mr. ϕ's deposit supply with bank b at time t depends on the rate offered by bank b and the rate offered by the other banks. Moreover, since banks can default on their deposit obligations, the expected rate of return on deposit investment of Mr. ϕ with bank b has to be adjusted appropriately for its corresponding expected default rate. Finally, Mr. ϕ's deposit supply is a positive function of the expected GDP in the subsequent period. Thus, Mr. ϕ's deposit supply function with bank b, $\forall b \in B$ at time t is given by

$$\begin{aligned}\ln(d_{b,t}^{\phi}) &= z_{b,1} + z_{b,2}\ln[pGDP_{t+1,i} + (1-p)GDP_{t+1,ii}] + z_{b,3}[r_{d,t}^{b}(pv_{t+1,i}^{b} \\ &+ (1-p)v_{t+1,ii}^{b})] + z_{b,4}\sum_{\forall b' \in B-b}[r_{d,t}^{b'}(pv_{t+1,i}^{b'} + (1-p)v_{t+1,ii}^{b'})] \quad (8)\end{aligned}$$

where

$d_{b,t}^{\phi}$ is the amount of money that agent ϕ chooses to deposit with bank b at time t.

2.3.3 Household's loan repayment rates

It is assumed that each household's repayment rate on its loan obligation to its selected bank for each of the two possible states at time $t+1$ and state $s \in S$ is a positive function of the corresponding GDP level as well as the aggregate credit supply in the previous period[4]. Thus, the functional form of the repayment rate of household h^b to its selected bank is given by

$$\ln(v_{t+1,s}^{h^b}) = g_{h^b,s,1} + g_{h^b,s,2}\ln(GDP_{t+1,s}) + g_{h^b,s,3}[\ln(\overline{m}_t^{\gamma}) + \ln(\overline{m}_t^{\delta}) + \ln(\overline{m}_t^{\tau})] \quad (9)$$

[4]This variable captures the effect of credit crunch in the economy whereby a fall in the overall credit supply in the economy aggravates the default probability of every household.

2.4 The Central Bank and the Regulator

At time t, the regulator sets the capital requirements for each bank ($\overline{k}^b_{t+1,s}, b \in B, s \in S$), defines the penalties for failing to meet such requirements ($\lambda^b_{k,s}, b \in B, s \in S$) and regulates the penalties that banks will incur if they default ($\lambda^b_s, b \in B, s \in S$). It also sets the risk weight on market book, loans and interbank loans ($\overline{\omega}, \tilde{\omega}, \omega$), used to calculate the capital adequacy ratio.

The Central Bank participates in the interbank market conducting open market operations (OMOs) and therefore determining the level of the policy rate ρ_t.

2.5 *GDP*

Equations (7) through (9) assume that households' behavior depends on the expected GDP of the subsequent period. There is, therefore, the need to endogenize the GDP in each state at time $t+1$, which is assumed to be a positive function of the aggregate credit supply in the previous period. Furthermore, a linear time trend is introduced to improve the empirical fit. Thus, the following function for GDP in state $s \in S$ at time $t+1$ is given by

$$\ln(GDP_{t+1,s}) = u_{s,1} + u_{s,2}\text{trend} + u_{s,3}[\ln(\overline{m}^{\gamma}_t) + \ln(\overline{m}^{\delta}_t) + \ln(\overline{m}^{\tau}_t)] \tag{10}$$

2.6 Market clearing conditions

There are seven active markets in the model (three consumer loan markets, three deposit markets and one interbank market). Each of these markets determines an interest rate that balances demand and supply.

$$1 + r^b_t = \frac{\mu^{h^b}_t}{\overline{m}^b_t}, h^b \in H^b, \forall b \in B \tag{11}$$

i.e. bank b's loan market clears.

$$1 + r^b_{d,t} = \frac{\mu^b_{d,t}}{d^{\phi}_{b,t}}, \forall b \in B \tag{12}$$

i.e. the deposit market clears.

$$1 + \rho_t = \frac{\overline{B}_t + \sum_{b \in B} \mu^b_t}{M_t + \sum_{b \in B} d_t{}^b} \tag{13}$$

i.e. the interbank market clears.

where

$\overline{B}_t$ are government bonds;

M_t is the money issued by the Central Bank.

2.7 Equilibrium

The monetary equilibrium with commercial banks and default at time t is a set of endogenous variables such that

a) All banks maximize their expected payoff subject to their budget constraints;

b) All markets clear;

c) Banks correctly build their expectations about the repayment rate they receive from interbank lending

$$\tilde{R}_s = \frac{\sum_{b \in B} \nu_{t+1}^b \mu_t^b}{\sum_{b \in B} \mu_t^b}, s \in S \tag{14}$$

d) The reduced-form equations for GDP, deposit supply, credit demands and household repayment rates are satisfied.

It is interesting to note that conditions (a) - (c) are consistent with the properties of a competitive equilibrium with rational expectations.

3 Data

This section summarizes the data used to calibrate the Goodhart et al. (2006b) model. The Brazilian banking system was divided into three different pools of banks namely "Public", "Private" and "Foreign" which depends on the type of ownership of each bank at each point of time[5]. There are indications that each of these three types of banks has specific characteristics and behavior. Cajueiro and Tabak (2008), for example, show that while Brazilian state-owned banks are net lenders in the interbank market, foreign-owned banks are net borrowers[6].

[5]For instance, if a bank ceases operations at time t, it will no longer be a part of anyone of these three categories at time $t+1$. In addition, when a state-owned bank is privatized, it will begin to be aggregated in the "Private" pool, no longer in the "Public" pool of banks. Intra-ownership acquisitions, intuitively, do not change the aggregation.

[6]This fact brings our model in line with Goodhart et al. (2006b), who assume, in their calibration methodology, two net lender banks and one net borrower bank in the interbank market.

In table 1, one may find the real values of d_t^b, μ_t^b, $\mu_{t,d}^b$, $1-\nu_{t+1,s}^{h^b}$, e_t^b, $\overline{m}_t^b$, others$_t$, where d_t^b is bank b's interbank lending, μ_t^b is bank b's debt in the interbank market at time t, $\mu_{d,t}^b$ is bank b's deposits, $\overline{m}_t^b$ is the amount of credit that bank b offers at time t, A_t^b are the other assets of bank b[7], e_t^b is bank b's capital (equity), $\nu_{t+1,s}^{h^b}$ is the repayment rate of h^b at $t+1$ and $s \in S$ and others$_t^b$ is the residual, were obtained from the Central Bank of Brazil (BACEN) database. Moreover, $b = Pu$ means the pool of public banks, $b = Pr$ means the pool of private banks and $b = Fo$ means the pool of foreign banks.

Place Table 1 About Here

As in Goodhart et al. (2006b), these balance sheet items are calibrated against real data of Brazilian banks in the initial period, i.e. 2002. The intention is to represent the realistic features of the Brazilian banks and at the same time obtain a numerical solution to the model, i.e. to equal the number of equations and the number of unknown variables.

Furthermore, data on the average lending rate[8] offered by the banks of the system, the average interbank rate offered by all pools of banks of the system and the GDP data were also obtained from the Central Bank of Brazil database and IPEADATA, and are shown in table 2.

Place Table 2 About Here

4 Methodology used to calibrate the model

This section presents the methodology used to calibrate the model of Goodhart et al. (2006b) to assess whether this model can be used to represent the structure and organization of the Brazilian financial system. In order to construct the balance sheet of Brazilian banks we build an aggregate

[7]There is a problem with the data of A_t^b when one considers the balance sheet constraint given by equation (2) which was introduced in (Goodhart et al., 2006b). In fact A_t^b is not large enough to fund the right side of this equation for any acceptable values of the rates ρ_t and $r_{d,t}^b$. Therefore, instead of using the value provided by the BACEN, we proceed as follows: $A_t^b = \frac{\mu_t^b}{1+\rho_t} + \frac{\mu_{d,t}^b}{1+r_{d,t}^b} + e_t^b + \text{others}_t^b - \overline{m}_t^b - d_t^b$.

[8]The only restriction found with the data is that instead of providing the lending rate (r_t^b) per pool of banks, the BACEN only provided the averaged lending rate of all pool of banks. However, since this rate was evaluated endogenously by the model (Goodhart et al., 2006b), this was not a problem at all.

balance sheet for each type of bank - private domestic, foreign and state-owned. Therefore, the balance sheet of each of these representative banks is comprised of the sum of all banks operating in the Brazilian economy, with credit and deposit operations, i.e., commercial banks.

Since we have a model with more unknown variables than equations, there is the need to arbitrarily choose some variables or calibrate some others against real data, until the number of equations equals the unknown variables. Thus, a single numerical solution to the model can be obtained. It is worth commenting that in order to implement this model the main idea behind the methodology of Goodhart et al. (2006b) and Saade et al. (2007) was followed, i.e. the endogenous variables of the models are not necessarily the endogenous variables of the systems of equations[9]. The values of some endogenous variables in the initial period have therefore to be imposed exogenously from real data values.

In the tables below, we explicitly present the variables which are endogenous, calibrated and arbitrarily selected in order to solve the systems of equations introduced by Goodhart et al. (2006b). Furthermore, for the variables in tables 3 (endogenous) and 4 (calibrated), the methodology (the equation or the steps) used to calculate them is explicitly presented.

Place Table 3 About Here
Place Table 4 About Here
Place Table 5 About Here

As already stated, banks' balance sheet items - such as d_t^b, μ_t^b, $\mu_{t,d}^b$, $1 - \nu_{t+1,s}^{h^b}$, e_t^b, $\overline{m}_t^b$, others_t - are calibrated using real Brazilian annual data in the initial period. Futhermore, as in Saade et al. (2007), the values of the coefficients of equation (10) were estimated through econometric techniques. In this equation, the GDP is assumed to be a positive function of the amount of credit. Equations (7) through (9) also had their coefficients arbitrarily chosen in order to reduce the deviations in the predicted and real values. These parameters are common to all types of households.

The probability p that state i (good) will occur is assumed to be 0.95, since it reflects a regular event. Accordingly, the chance that state ii (bad) will occur is equal to 0.05. In the first period, all agents of the model interact with each other in an atmosphere of uncertainty about the state of nature of the next period. However, they are assumed to be rational and therefore

[9]In fact, if one considers that the endogenous variables of the model are necessarily the endogenous variables of the systems of equations, it is very difficult to calibrate the model, and a bias persists over time.

know the probability of good and bad states happening. In the second period, the real state of nature is revealed and the uncertainty is resolved.

In state i, the bank repayment rate in both deposit and interbank markets is set to be 0.99, which is based on real data. However, in state ii, repayment rates are more variable across the different types of banks. As can be seen, public banks appear to be those with the lower repayment rates in this state. As in Goodhart et al. (2006a), these values were chosen to be higher than the household repayment rate in state ii (which is equal to 0.9), since banks are supposed to have a high probability to repay their obligations than the private sector. The household repayment rate in state i is based on Brazilian banks' non-performing loans.

The interbank rate, ρ_t, was set to be equal to 24.9, which is equal to the value of Brazilian basic interest rate (SELIC) at the end of 2002. The risk weight for consumer loans is set as 5, while the corresponding values for the market book and investment are both 0.05. These variables are higher than in Goodhart et al. (2006b) since it is assumed that Brazilian banks face more risks. In addition, since the values of λ_s^b and $\lambda_{k,s}^b$ (default penalties and capital adequacy violation penalty, respectively) are unobservable, we choose values consistent with the fact that the banks' utility function is concave and that, if state ii occurs, bank b will have lower capital in the subsequent period. Finally, all banks' coefficients of risk aversion (c_s^b) are set to be positive, i.e. the bank's utility function is well behaved.

5 Results

The results of the calibrated model are presented in this section. In the first subsection, the prediction of the GDP is presented, where we assume that the aggregate credit supply of time t increases the GDP at time $t+1$. The following subsection demonstrates the results related respectively to the pool of public banks, the pool of private banks and the pool of foreign banks. In subsection 5.4, some remarks and discussions about our findings are introduced.

It is important to mention here that all the flow variables were divided by 10^9.

5.1 GDP prediction

The predicted GDP versus real GDP in state i is shown in Figure 1. Moreover, the parameters of equation (10) are in Table 6. The real GDP is assumed to be the GDP when there is no extreme default. This is reasonable in Goodhart since there were no interbank defaults in the period covered by the data. This is also reasonable in Brazil as there were no interbank defaults in the 2002-2006 period. The crisis in 2002 raised default probabilities and decreased bank profits, but there were no bank defaults.

Place Figure 1 About Here
Place Table 6 About Here

5.2 Pool of banks

The main variables of the pool of public, private and foreign banks are presented in Figures 2, 3, and 4, respectively. Their remaining parameters are shown and in Table 7.

Place Figure 2 About Here
Place Figure 3 About Here
Place Figure 4 About Here
Place Table 7 About Here

5.3 Other variables

Table 8 shows the remaining variables of the banking system.

Place Table 8 About Here

5.4 Some remarks about the results

From Figures 1 to 4, it is easy to note that the model (Goodhart et al., 2006b) is capable of modeling the dynamics of the Brazilian banking system. Furthermore, these results seem to be as good as the ones presented by Goodhart et al. (2006b) when modeling the UK banking system and much better than the ones presented by Saade et al. (2007) when modeling the Colombian system.

However, the results of the predicted μ_t^b, which comes from the bank's optimization problem, were found to be very sensitive to the parameters and calibrated variables, meaning that very small variations in variables such as λ_s^b, $\nu_{t,ii}^b$ and c_s^b produced very different results. Furthermore, it should be clear that without slightly varying the values of $\nu_{t,ii}^b$ (see Table 7) it is impossible to find values of μ_t^b that make sense for all steps t.

It is worth making some comments about the discount rates $r_{d,t}^b$ and r_t^b. From Figures 2, 3 and 4, it is easy to note that these discount rates are decreasing functions of t. This result is of quite interest since this was really the phenomenon that happened in Brazil in the last five years. It can be explained by a series of interdependent facts. The reduction in interbank costs by the Central Bank of Brazil in these years made banks borrow more money from the interbank market, extending more credit to the household sector, which can explain the rise in the offer of aggregate credit in Figures 2, 3 and 4.

The debt in the interbank market (μ_t^b) appears to differ among the three types of bank ownership. Private banks are those with higher debt in this market, and public banks are the least indebted. The reason may be that public banks tend to have high liquidity - due to the large number of public servants who hold accounts with these banks - that can be channeled to the interbank market. On the other hand, private banks may have, in general, high liabilities, and thus they must resort to the interbank market to borrow money from other banks. Foreign banks may have borrowing facilities in international markets, which can explain the intermediate levels of debt in the Brazilian interbank market. Therefore, we conclude, as in Cajueiro and Tabak (2008), that it is important to take into account banks with different ownerships when we analyze financial stability, since their positions in the interbank network structure differ from each other. Both works of Saade et al. (2007) and Goodhart et al. (2006b) use other criteria to classify banks in their general equilibrium model.

Moreover, according to the results of equation 10 shown in Table 6, the credit supply elasticity ($u_{s,3}$) is found to be equal to 0.0329, $\forall$ s $\in$ S. Thus, an increase in the credit supply means that the GDP increases as well, which confirms our previous assumption. In addition, the time parameter ($u_{s,2}$) is found to be positive, showing that the Brazilian economy has improved in this period. All things considered, from Figure 1, we see that the predicted GDP has followed the same upward trend as the real GDP. Mr. θ (the pool of depositors) anticipates higher income in subsequent periods and thus lends more money to the banks, reducing the deposit rates, which is also in line with our results.

5.5 A discussion about financial fragility

An interesting feature of the model implemented in this work is the analysis of the behavior of different markets and the interaction between them, allowing for the assessment of how the behavior of one market affects the behavior of another. In our general equilibrium approach, heterogeneous commercial banks and capital requirements are incorporated in the model as in Tsomocos (2003) and extended by Goodhart et al. (2006a). General equilibrium models that do not take into account heterogeneous types of banks in their specifications are unable to satisfactorily represent the real economy, due to the fact that aggregating all banks together does not consider the interbank market and the differences in portfolio composition and in other characteristics among these banks. Such models could not explain events like, for example, the recent financial crisis, since contagion between banks would not exist.

We also adopt the definition of financial fragility employed by Tsomocos (2003) and Goodhart et al. (2006b), in which fragility is considered a combination of high risks with low profits. An interesting fact is that several past financial crises are characterized by this definition, including the recent subprime crisis of 2008. This definition is an improvement over last studies, in which some defined financial fragility by high risks and others defined it by low profits. These factors alone do not necessarily mean financial stability, since they may be determined by risk preferences and strategies of the agents involved, i.e., in order to achieve higher profits, a bank might be willing to face higher risks (Aspachs et al., 2007).

This model is essentially apt to model the direction of the main variables of the system when a market is subjected to shocks as was shown in Goodhart et al. (2004). For instance, in the latter, the effect of an increase in loan risk weights applied to capital requirements is discussed. However, since the calibration of the model based on Goodhart et al. (2006b) is very sensitive to the choice of the parameters and since, in the calibration process, the endogenous variables of the system are not necessarily the endogenous variables of the systems of equations, the ability of modeling financial stability is strongly reduced.

Furthermore, based on the results of the model, it is possible to provide some interesting remarks about the behavior of the Brazilian economy in the 2002-2006 period in which this model was applied:

(1) The discount rates $r^b_{d,t}$ and r^b_t are decreasing functions of t. This result in general is seem as a good signal in terms of financial fragility since it reduces the presence of moral hazard in the credit market. If the interest rates are smaller, this means that firms accept to borrow money to invest in "good" technologies[10] with increasing probability of loan repayment. However, if no moral hazard is present in the Brazilian credit market, this is bad news in terms of financial stability, since lower interest rates reduce the spreads of the banks weakening the financial stability of the system. The reduction of bank spreads may imply a reduction i bank profits, which may serve as a

[10]The banking literature assumes that firms have a choice between "good" G and "bad" B technologies, where $\pi_G G > \pi_B B$, but $B > G$. See, for instance, Section 2.5.1 of Freixas et al. (2000).

cushion for losses in periods of stress. Therefore, a reduction in bank spreads may also be associated with higher default probability.

(2) The GDP has increased slowly in this period meaning that the Brazilian economy is being slowly improved.

(3) Other variables such as the repayment rate of households and the profits of the banks have signaled that the economy is stable. Taking these aspects into account, our results show that the Brazilian financial system between 2002 and 2006 appears to be more developed than Colombia's in the period between 1997 and 2002 as presented by Saade et al. (2007). Due to extensive reforms perpetrated in the 1990s, the Brazilian financial system has, in fact, become more stable and solid.

(4) Bank ownership structure matters when we analyze the Brazilian financial fragility. Public, private and foreign banks differ from each other in terms of profitability, risks, efficiency (Staub et al., 2010) and position in the interbank market (Cajueiro and Tabak, 2008).

Finally, the theoretical model of Goodhart et al. (2004) suggests how the financial variables are related to each other, indicating how these variables affect financial stability. The Goodhart et al. (2006b) calibrated model provides the size and the signal of the model's parameters. However, due to the strong sensitivity of the model to the choice of the parameters and path used to calibrate this model, the analysis of financial stability is limited, as remarked before.

In fact, this literature on how to apply this model appropriately to take financial stability into account is still working. For instance, Aspachs et al. (2007) analyze the welfare of agents in a simplified version of Goodhart et al. (2006a) and propose that a measure of financial fragility should be built using a combination of probability of default and bank profitability. Furthermore, this measure of financial fragility is investigated using panel VAR techniques, showing evidence in line with that of the simulations. Additionally, motivated by the recent financial crisis, Goodhart et al. (2010) uses the framework of Goodhart et al. (2006a) and show that restrictions on the payout of dividends by banks reduce their default, while increasing liquidity in the interbank market, and improving overall welfare. Finally, Pederzoli et al. (2010) extends the analysis of Catarineu-Rabell et al. (2005) regarding the effects of different Basel II rating systems on banks' portfolios, by also assuming some heterogeneity in banks behavior and portfolio, and thus taking into account the contagion effects on financial stability (Goodhart et al., 2005).

6 Final remarks

In this paper, we applied the Goodhart et al. (2006b) model to Brazilian data. We found that it is capable of predicting the dynamics of the Brazilian banking system. Furthermore, these results are in line with the findings presented by Goodhart et al. (2006b) when modeling the UK banking system and presented by Saade et al. (2007) when modeling the Colombian system. An innovation in relation to previous papers, however, consists in the fact that we pooled banks into three groups based on their ownership type, due to the existence of specific differences among public, private and foreign Brazilian banks.

This model essentially is apt to explain the direction of the main variables of the system when a market is subjected to shocks. Empirical results suggest that financial fragility has decreased over time in recent years in the Brazilian banking system. Further research could explore more in depth specific idiosyncracies of the the Brazilian banking system, but the model does seem to be promising in terms of helping to evaluate the impact of changes in financial regulation on the banking system. One may conclude, therefore, that the Goodhart et al. (2006b) model has been relevant to explain banking systems from both developing and developed countries.

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Year	Bank type	d_t^b	μ_t^b	$\mu_{t,d}^b$	$1-\nu_{t+1,s}^{h^b}$	e_t^b	$\overline{m}_t^b$	A_t	$others_t$
2002	Public	8.86E+09	4.37E+09	2.99E+11	1.85E-02	2.52E+10	1.61E+11	1.6808E+11	2.43E+11
2002	Private	2.92E+10	2.96E+10	3.21E+11	1.98E-02	8.82E+10	2.74E+11	1.65E+11	2.46E+11
2002	Foreign	1.81E+10	1.36E+10	1.51E+11	1.12E-02	6.59E+10	1.63E+11	6.79E+10	2.49E+11
2003	Public	2.97E+10	9.25E+09	3.31E+11	1.46E-02	3.78E+10	1.93E+11	1.85E+11	2.89E+11
2003	Private	4.80E+10	4.83E+10	3.49E+11	1.47E-02	1.20E+11	3.01E+11	2.16E+11	2.60E+11
2003	Foreign	1.59E+10	1.56E+10	1.53E+11	1.10E-02	6.72E+10	1.49E+11	8.72E+10	1.71E+11
2004	Public	1.51E+10	6.99E+09	3.61E+11	1.25E-02	4.41E+10	2.24E+11	1.88E+11	2.81E+11
2004	Private	7.35E+10	6.23E+10	4.16E+11	1.29E-02	1.29E+11	3.51E+11	2.55E+11	2.69E+11
2004	Foreign	2.23E+10	1.97E+10	2.05E+11	9.23E-03	7.24E+10	1.75E+11	1.22E+11	1.68E+11
2005	Public	2.29E+10	6.94E+09	4.30E+11	1.64E-02	5.18E+10	2.61E+11	2.27E+11	2.77E+11
2005	Private	9.81E+10	1.12E+11	5.28E+11	1.58E-02	1.53E+11	4.36E+11	3.66E+11	3.20E+11
2005	Foreign	2.61E+10	2.82E+10	2.68E+11	1.22E-02	7.33E+10	2.27E+11	1.43E+11	1.96E+11
2006	Public	1.43E+10	7.24E+09	4.95E+11	1.19E-02	6.12E+10	3.33E+11	2.31E+11	2.93E+11
2006	Private	1.15E+11	1.90E+11	6.45E+11	1.92E-02	1.99E+11	5.39E+11	4.95E+11	4.24E+11
2006	Foreign	2.12E+10	2.94E+10	3.09E+11	1.25E-02	7.49E+10	2.64E+11	1.49E+11	2.60E+11

Table 1: This table presents the annual balance sheet variables per pool of banks. Source: Central Bank of Brazil (BACEN)

Year	r_t^b	ρ_t	GDP/10^6
2002	0.5097	24.9	15360
2003	0.4582	16.35	15536
2004	0.4458	17.74	16423
2005	0.4593	18.04	16907
2006	0.3982	13.19	17533

Table 2: This table presents the averaged lending rate of all pool of banks and all kinds of loans (r_t^b), the averaged interbank rates of all pool of banks (ρ_t) and the Annual GDP. Sources: BACEN and IPEADATA.

Variables	Methodology
r_t^b	Using r_t^b as a function of all the other variables of equation (11)
$r_{d,t}^b$	Educated guessed until the other variables behave well
μ_t^b	Solving problem (1) s.t. (3) and $\mu_t^b \in [0, \overline{m}_t^b + d_t^b + A_t^b - \frac{\mu_{d,t}^b}{1+r_{d,t}^b} - e_t^b]$
$d_{b,t}^{\phi}$	Using equation (8)
$k_{t+1,s}^b$	Using equation (6)
$\pi_{t+1,s}^b$	Using equation (4)
$e_{t+1,s}^b$	Using equation (5)
$\tilde{R}_{t+1,s}^b$	Educated guessed until the other variables behave well
$\mu_t^{h^b}$	Solving numerically $\ln(\mu_t^{h^b}) - \frac{\mu_t^{h^b}}{\overline{m}_t^b} = a_{h^b,1} + a_{h^b,2}\text{trend} + a_{h^b,3}\ln[pGDP_{t+1,i} + (1-p)GDP_{t+1,ii}] - a_{h^b,4}$ which is another form of (7)
$others_t^b$	Using $others_t^b$ as a function of all other variables of equation (2)
$g_{h^b,s,1}$	Educated guessed until the other variables behave well using the mean value as starting value
$a_{h^b,1}$	Educated guessed until the other variables behave well using the mean value as starting value
$z_{b,1}$	Educated guessed until the other variables behave well using the mean value as starting value
$u_{s,1}$	Educated guessed until the other variables behave well using the mean value as starting value
c_s^b	Educated guessed until the other variables behave well

Table 3: Endogenous variables of the system of equations. The subscript b denotes "Pu" for public banks, "Pr" for private or "Fo" for foreign banks and s stands for the good (i) or bad state of nature (ii).

Variable	Source
$\overline{m}_t^b$	Brazilian data: bank b's lendings
$\mu_{d,t}^b$	Brazilian data: bank b's deposits
A_t^b	Equation (2) and Brazilian data
d_t^b	Brazilian data: interbank lendings
e_t^b	Brazilian data: equity
ρ_t	Brazilian data: averaged interbank rate
$GDP_{t,i}$	Brazilian data: GDP
$a_{h^b,4}$	Brazilian data and estimation using equation (7)
$\nu_{t,i}^{h^b}$	Brazilian data: non performing loans
$\nu_{t,ii}^b$	Educated guessed based on the values of real data
$\overline{\omega}$	Educated guessed based on the values of real data
$\tilde{\omega}$	Educated guessed based on the values of real data
ω	Educated guessed
$g_{h,s,2}$	Educated guessed in order to reduce the error of the predicted $\nu_{t,i}^{h^b}$ using equation (9) and real $\nu_{t,i}^{h^b}$
$g_{h,s,3}$	Educated guessed in order to reduce the error of the predicted $\nu_{t,i}^{h^b}$ using equation (9) and real $\nu_{t,i}^{h^b}$
$\overline{k}_{t+1,s}^b$	Educated guessed in order to reduce the error of the predicted μ_t^b and real μ_t^b
λ_{ks}^b	Educated guessed in order to reduce the error of the predicted μ_t^b and real μ_t^b
λ_s^b	Educated guessed in order to reduce the error of the predicted μ_t^b and real μ_t^b
$u_{s,2}$	Educated guessed in order to reduce the error of the predicted GDP using equation (10) and real GDP
$u_{s,3}$	Educated guessed in order to reduce the error of the predicted GDP using equation (10) and real GDP
$z_{b,2}$	Educated guessed in order to reduce the error of the predicted $\mu_{d,t}^b$ using equation (10) (replacing $d_{b,t}^{\phi}$ by $\frac{\mu_{d,t}^b}{1+r_{d,t}^b}$) and real GDP
$z_{b,3}$	Educated guessed in order to reduce the error of the predicted $\mu_{d,t}^b$ using equation (10) (replacing $d_{b,t}^{\phi}$ by $\frac{\mu_{d,t}^b}{1+r_{d,t}^b}$) and real GDP
$z_{b,4}$	Educated guessed in order to reduce the error of the predicted $\mu_{d,t}^b$ using equation (10) (replacing $d_{b,t}^{\phi}$ by $\frac{\mu_{d,t}^b}{1+r_{d,t}^b}$) and real GDP
$a_{h^b,2}$	Educated guessed

Table 4: Calibrated variables of the system of equations. The subscript b denotes "Pu" for public banks, "Pr" for private or "Fo" for foreign banks and s stands for the good i or bad state of nature ii.

Variable
$\nu_{t,i}^b$
$\nu_{t,ii}^{h^b}$
r_t^A
p

Table 5: Arbitrarily selected variables of the system of equations. The subscript b denotes "Pu" for public banks, "Pr" for private or "Fo" for foreign banks and s stands for the good i or bad state of nature ii.

$u_{i,1}$	2.1907
$u_{i,2}$	0.0189
$u_{i,3}$	0.0329
$u_{ii,1}$	2.1499
$u_{ii,2}$	0.0189
$u_{ii,3}$	0.0329

Table 6: The parameters of equation (10).

	b = Pu	b= Pr	b = Fo
$\nu^b_{t,i}$, $\forall t$	0.99	0.99	0.99
$\nu^{h^b}_{t,ii}$, $\forall t$	0.90	0.90	0.90
ν^b_{ii}	(0.95,0.9599,0.9559,0.9572,0.9581)’	(0.9802,0.9853,0.9871,0.9842,0.9808)’	(0.9500,0.9702,0.9707,0.9773,0.9767)’
$g_{h^b,i,1}$	0.0504	0.0487	0.0540
$g_{h^b,ii,1}$	0.0266	0.0266	0.0266
$g_{h^b,i,2}$	0.0005	0.0005	0.0005
$g_{h^b,ii,2}$	0.0005	0.0005	0.0005
$g_{h^b,i,3}$	-0.01	-0.01	-0.01
$g_{h^b,i,3}$	-0.02	-0.02	-0.02
$\overline{k}^b_{t,s}$, $\forall s,t$	0.15	0.2	0.3
λ^b_{ks}, $\forall s$	0.1	0.1	0.1
λ^b_i	0.56	0.29	0.37
λ^b_{ii}	0.60	0.33	0.45
$z_{b,1}$	-9.0644	-8.9196	-13.8081
$z_{b,2}$	5.315	5.5000	6.8
$z_{b,3}$	0.01	0.0100	0.05
$z_{b,4}$	-0.001	-2	-0.001
$a^{h^b}_{b,1}$	64.3729	64.7531	63.2311
$a^{h^b}_{b,2}$	0	0	0
$a^{h^b}_{b,3}$	-18.2274	-18.2726	-17.9449
$a^{h^b}_{b,4}$	-17.7726	-17.2667	-17.3807
c^b_i	0.00105	0.0008	0.0022
c^b_{ii}	0.0101	0.015	0.022

Table 7: Other variables of the pool of public, private and foreign banks.

$\tilde{R}_{t,i}$, $\forall t$	0.99
$\tilde{R}_{t,ii}$, $\forall t$	0.95
rA	0.0775
p	0.95
$\overline{\omega}$	5
$\tilde{\omega}$	0.05
ω	0.05

Table 8: Other variables of the banking system.

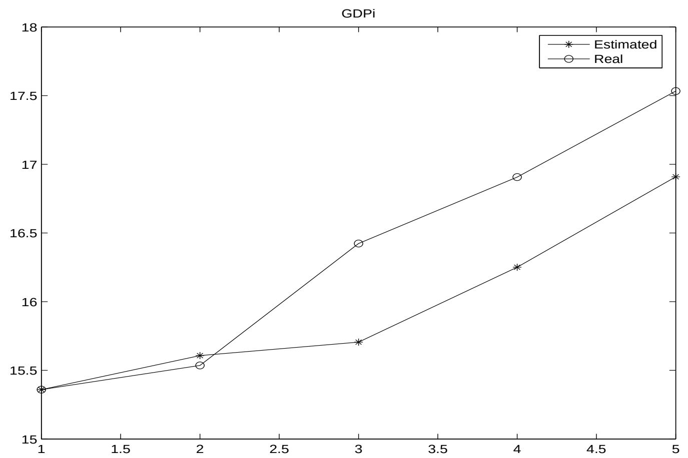

Figure 1: GDP

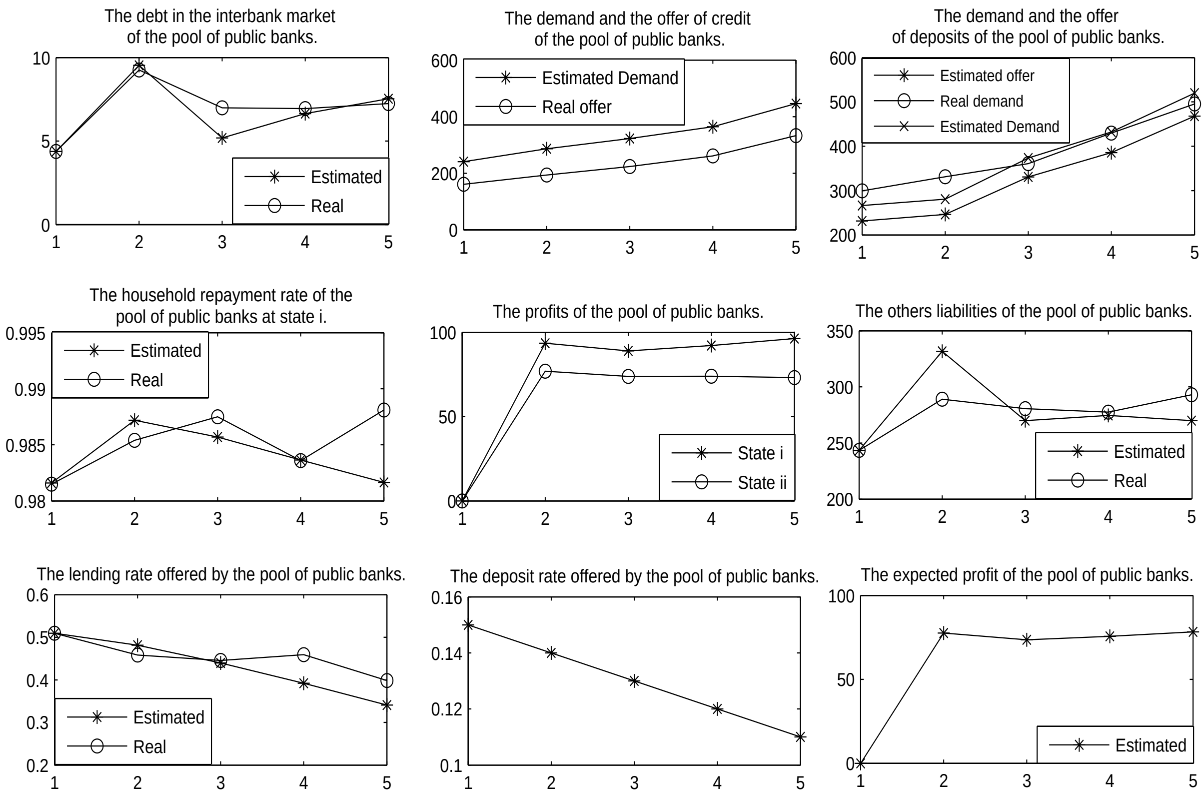

Figure 2: Public banks

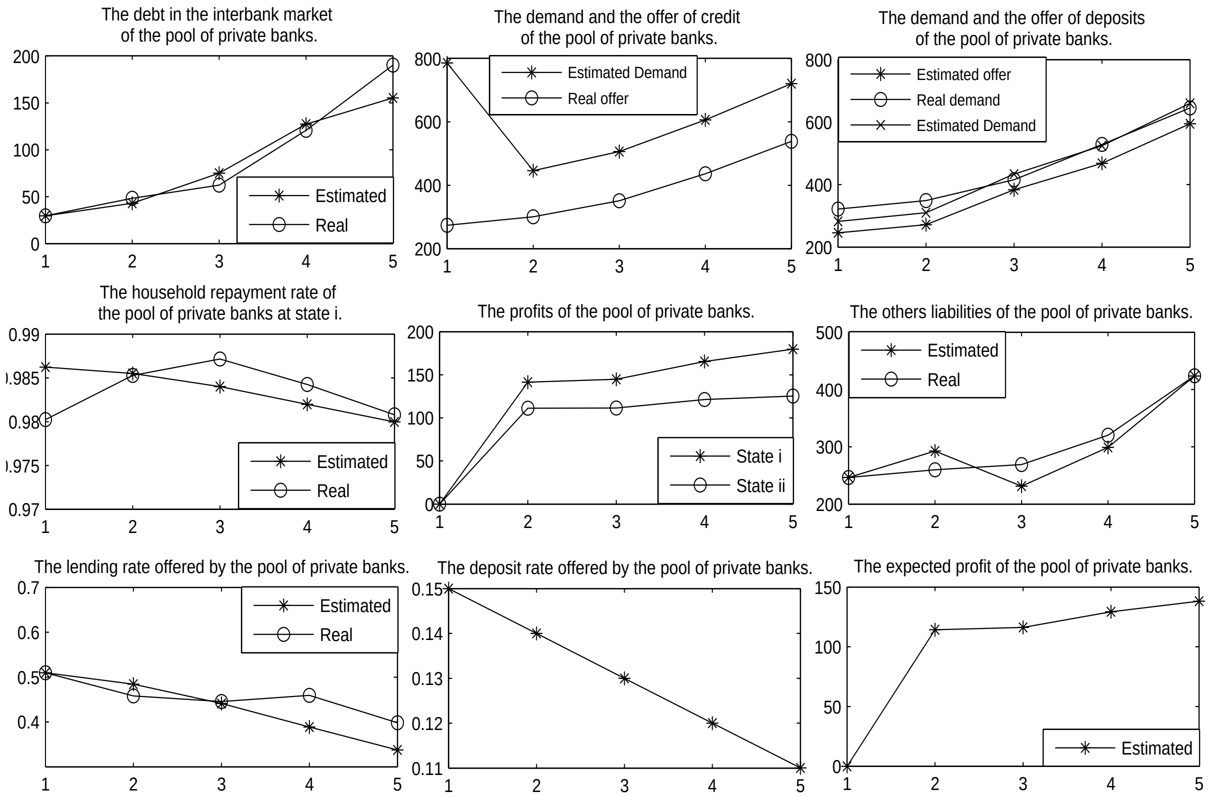

Figure 3: Private banks

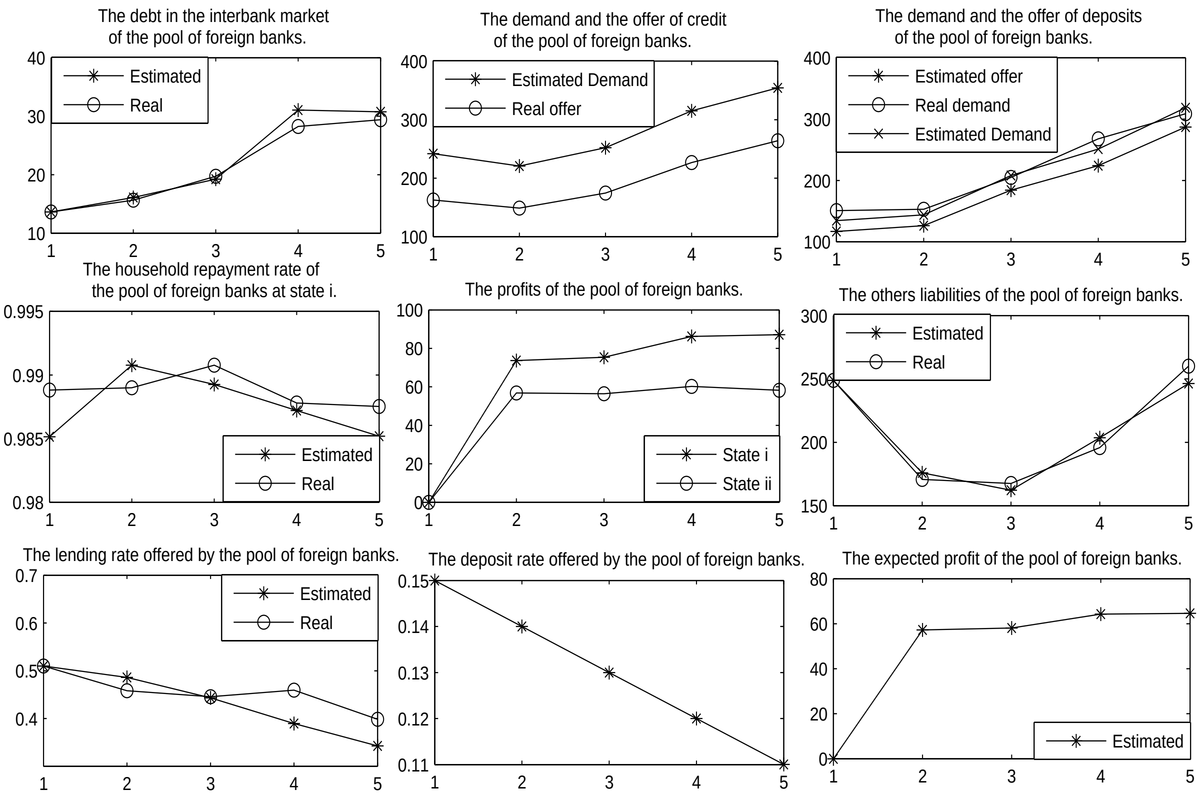

Figure 4: Foreign banks

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