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The Role of Capital Requirements and Credit Composition in the Transmission of Macroeconomic and Financial Shocks*

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Abstract

This paper builds a general equilibrium model that incorporates banks, financial frictions, default and a capital requirements. Ex-ante heterogeneous households decide how much to save or borrow for the sake of consumption (consumer credit) or the provision of housing services(mortgages). These choices are subject to borrowing limits, which depend on the value of real estate assets (for mortgages) or labour income (for consumer loans). The model includes final goods producers who must borrow in order to finance working capital/labour requirements (business credit borrowing) and intermediate good producers subject to nominal rigidities. Saving and borrowing are intermediated by a bank facing different capital requirements for each credit category. Any shock that has an impact on bank capital (for instance, a default shock) directly affects the bank's income, the cost of external finance and, eventually, interest rates on loans. Changes in interest rates have second-round effects on labour and consumption through the borrowing limits. Simulations of the model suggest that the business cycle properties of credit and credit quality for each credit category are consistent with what is observed in the data.

Key Words: DSGE Models; Financial Frictions; Macroprudential Policy

JEL Codes: E5, G21 , G28

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What are the equilibrium effects of macroprudential policies on the real economy? How do macroprudential policies affect bank behavior along the business cycle? Are macroprudential policy instruments capable of delivering a more stable macroeconomic environment or higher welfare? From a practitioner's point of view, how do these effects depend on the exact characteristics of the policy instruments at hand? General interest on these questions has increased since the onset of the recent financial crisis, and particularly since the Basel Committee on Banking Supervision (BCBS) gave a prominent role to macroprudential policy tools in the principles established in the regulatory framework widely known as Basel III.

Empirical literature on the effects of macroprudential policy and its interaction with the business cycle has been limited due to the small number of countries that have adopted any form of macroprudential tool and to the yet relatively short experience with their use. Considering dynamic provisioning and countercyclical capital buffers (two widely discussed tools highlighted by Basel III), only 119 countries have adopted either of them (all of them after 2005), and only two have introduced both[1]. Up to this point, good sources of exogenous variation are relatively scarce, making it difficult to establish a successful empirical identification strategy. As a result, theoretical models offer more fertile grounds for obtaining insights into the functioning and effects of macroprudential policy tools.

This paper attempts to tackle those questions by building an equilibrium model of the macroeconomy that incorporates banks, financial frictions, default and a set of macroprudential and regulatory policy instruments. The model incorporates the decisions of patient and impatient households who make choices on optimal levels of consumption, work and enjoyment of housing services. Households also decide how much to save or borrow for the sake of consumption (consumer credit borrowing) or the provision of housing services (mortgage credit borrowing). Borrowing for either purpose is subject to credit constraints: the amount borrowed is constrained by the expected value of labour income or housing stock. The model also includes intermediate and final goods producers; it is assumed that the latter must borrow in order to finance working capital requirements (business or commercial credit borrowing). Saving and borrowing is intermediated by a monopolist bank who faces capital requirements that differ for each of the three credit categories (consumer, mortgage, business). The building up of bank capital entails adjustment costs; these costs depend on how far the bank is from the minimum regulatory capital. In addition, each type of borrowing has a different probability of default which depends on aggregate conditions. Finally, the

[1] Spain is the emblematic case of empirical research on the effects of dynamic provisioning. See Nogueira and Nakane [2015]

model includes a Central Bank/Regulator who provides liquidity services to the bank and exogenously decides on regulatory and macroprudential requirements.

Compared to earlier work on equilibrium models with financial frictions, the model in this paper introduces two novel features. On the one hand, the model introduces a non-trivial choice of credit composition for banks. Total credit in the model corresponds to the aggregation of consumer, business and mortgage loans. The choice of loan supply for each of these credit segments depends on their individual interest rates and on their (endogenous) default rates. Crucially, from the point of view of macroprudential policy, loan supply will also depend on the regulatory requirements of each credit segment in terms of capital and/or dynamic provisioning. For example, following the principles set out by the Basel Committee, regulatory capital requirements may potentially differ across credit categories due to, among others, different default probabilities or losses given default. On the other hand, the model provides sufficient flexibility with regard to the specific characteristics of macroprudential policy. In particular, the model is flexible enough to allow the introduction of different schemes of dynamic provisioning, state-contingent capital requirements or reserve requirements.

The propagation of shocks in the model results from interesting interactions between financial frictions, capital requirements, interest rates and default. Credit constraints affect labour/leisure and borrowing choices, thus affecting equilibrium interest rate. Any shock that affects the ability of household or firms to borrow will therefore affect aggregate output, which has an impact on the default rates of business, mortgage and consumer loans. Changes in the risk profile of loans will, in turn, affect interest rates and the willingness of banks to lend, creating a feedback effect on household and firms' borrowing.

Besides contributing to the understanding of the effects of macroprudential policy, the model also provides a framework for the quantitative analysis of the propagation of financial shocks in an emerging economy. The model is therefore useful to construct consistent scenarios after a shock which include the endogenous feedback effects between the real and the financial sectors of the economy. This is useful for stress testing exercises carried out by central banks and regulators which generally require some form of macroeconomic scenario as a starting point which ideally should include those feedback effects in a consistent fashion.

Related Literature

This paper builds on insights from two strands of the literature that have been thus far developed separately. Firstly, at least since Matsuyama [2008] there has been an active area of research on the implications of credit composition both for economic growth and the business cycle. According to Matsuyama [2008], the particular properties of the development process, and the volatility of the business cycle depended on the composition of credit between categories more or less pledgeable or collateralizable. Closer to the work in this paper, Saade et al. [2007] extend the model by Goodhart et al. [2006] to study the problem of financial stability in a general equilibrium framework with banks and default where there are different loan categories (consumer, mortgage and business) subject to different capital requirements and with different reduced form specifications for loan demand. They conclude that financial fragility is closely related to the equilibrium composition of banks' loan portfolio. From an empirical point of view, Haan et al. [2009] illustrate the differing responses that different credit categories (mortgage, business) exhibit after a monetary policy shock in Canada. They conclude that the composition of credit is therefore crucial to understand the transmission mechanisms of monetary policy. Finally, Aghion et al. [2010] study the effects of the composition of investment (and credit) between short-term and long-term projects, to conclude that long-lasting recessions can be explained by the switch from long-term to short-term credit after financial shocks[2].

This paper also follows recent work on the implications of finance in dynamic, stochastic, general equilibrium models of the macroeconomy. Models in this field generally include heterogeneous agents and financial frictions; more recently, work has been expanded to studythe role of macroprudential policies in preventing episodes of financial stability. The model in this paper is based on the work by Gerali et al. [2010], Agénor et al. [2013] and Agénor and Zilberman [2015]. Importantly, we borrow from Agénor et al. [2013] the strategy to model bank capital accumulation as the problem of choosing an optimal capital buffer taking into account both capital requirements and capital adjustment costs, and the idea of capturing equilibrium default rates using reduced forms[3]. It is on top of this model structure that we include several loan categories with different capital requirements and a richer structure for the probabilities of default of these categories. The welfare implications of different macroprudential policy rules in the context of general equilibrium models are studied by Nogueira and Nakane [2015], and the specific effects of dynamic provisioning on the prociclicality of the financial system is explored by Agénor and Zilberman [2015]. One crucial element of the model in this paper is the effect of capital requirements on loan supply and bank behaviour. Capital requirements, by inducing adjustment costs to the accumulation of bank capital, have effects on equilibrium interest rates, on the composition

[2]See Garicano and Steinwender [2013] for an empirical setting which demonstrates a similar idea.

[3]Reduced forms for the default rates of different loan categories was also used in the above-mentioned work by Goodhart et al. [2006].

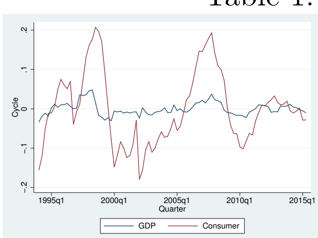
of the loan portfolio and on the propagation of shocks. Our paper therefore also builds on the findings by Meh and Moran [2010] regarding the importance of bank capitalization to understand the transmission of shocks across the macroeconomy.

This paper unfolds as follows. Section 1 study the main stylized fact about the financial cycle in the Colombian economy. Section 2 presents the structure of the model. Section 3 evaluates the performance of the model under different types of macro-shocks. Finally, section 4 offers some reflections as concluding comments.

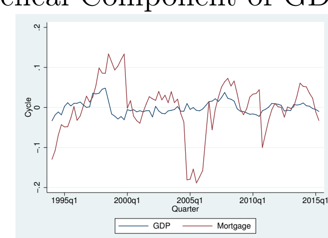
1 Motivation: Credit Composition and the Business Cycle

The importance of allowing for different credit categories (and for a non-trivial choice problem for banks as to the composition of their loan supply) is highlighted by the remarkable differences in the cyclical behaviour of consumer, business and mortgage credit and their rates of default. Table 1 presents the cyclical component of real GDP and real consumer (Panel A), mortgage (Panel B) and business credit (Panel C) in Colombia for the period between 1994 and 2015. All three credit categories are procyclical: the crash of the Colombian economy in 1999-2000 is reflected in steep falls of the cyclical component of credit. Credit also falls below trend during 2009-2010, a period which is associated with the financial crisis in developed economies[4].

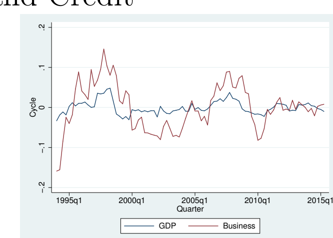
Table 1: Cyclical Component of GDP and Credit



Panel A: Consumer



Panel B: Mortgage



Panel C: Business

The contemporaneous prociclicality of all credit categories is also indicated by the correlation between the cyclical component of real GDP and total credit in Table 2, calculated using data from the same time window. The correlation is positive and statistically significant at three lags and leads. Table 3 indicates the correlation between the cyclical component of real

[4]Mortgage credit also suffered a long period of below-trend growth between 2003 and 2008.

Table 2: Prociclicality of Total Credit

τ	$\text{corr}(TotalCredit_t, GDP_{t+\tau})$	$p-value$
-3	0.675	0.000
-2	0.739	0.000
-1	0.727	0.000
0	0.626	0.000
1	0.501	0.000
2	0.502	0.000
3	0.199	0.070

Table 3: Prociclicality of Total Credit Quality

τ	$\text{corr}\left(\frac{NPL_t}{TotalCredit_t}, GDP_{t+\tau}\right)$	$p-value$
-4	0.146	0.189
-3	-0.040	0.715
-2	-0.261	0.016
-1	-0.465	0.000
0	-0.567	0.000
1	-0.525	0.000
2	-0.524	0.000
3	-0.447	0.070
4	-0.317	0.003

GDP and the ratio of nonperforming loans (NPL) to total credit, a measure of credit quality. Interestingly, although this correlation is negative and statistically significant at most lags, there is a positive correlation (although not statistically different from zero) between real GDP and NPL four quarters ahead. This may be an indication of relaxing credit standards during economic booms that end up reducing the quality of total credit afterwards.

The cyclical behavior of aggregate credit tends to hide wide variation among credit categories. Table 4 presents the relative (to GDP's) standard deviation of the cyclical component of consumer, business, mortgage and total credit, and credit quality (measured as described above) for each of the same categories. Total credit is observed to be more than three times as volatile as GDP, whereas total credit quality is somewhat smoother (its standard deviation is 69% that of GDP). Interestingly, of all credit categories, consumer credit seems to be the most volatile (5.6 times as volatile as GDP), followed by business credit. This is interesting so long as most business cycle research has found consumption to be one of the least volatile macroeconomic aggregates. At the other end of the spectrum, mortgage loans turn out to be the least volatile, again in contrast to residential investment, which is normally found to be more volatile than consumption. Possibly due to the difficult conditions faced by mortgage

Table 4: Relative Volatility

x	$\frac{\sigma_x}{\sigma_{GDP}}$
Total Credit	3.627
Consumer Credit	5.612
Business Credit	3.510
Mortgage Credit	4.182
Total Credit Quality	0.695
Consumer Credit Quality	1.030
Business Credit Quality	0.520
Mortgage Credit Quality	2.033

borrowers during the period of analysis, mortgage credit quality is twice as volatile as GDP, whereas consumer credit quality has the same standard deviation, and commercial credit is half as volatile.

In summary, the aggregate behavior of total credit at business cycle frequencies, although intuitive, masks wide variation in the cyclical component of subcategories of credit. This observation motivates the adoption of a model which is capable to include several credit types that differ in key respects. In particular, the model interprets differences in the cyclical behavior of mortgage, consumer or commercial credit as arising from different degrees of financial frictions, different borrower preferences or variation in the volatility of shocks to which different credit categories are exposed. It is against the backdrop of these stylized facts on credit categories that the model presented below is assessed.

2 The Model

The model is based on previous work by Gerali et al. [2010] and Agénor et al. [2013]. The economy is composed by ex-ante heterogenous households which differ in their discount factor. The discount factor for patient households, β_P, is higher than thar of impatient household, β_I. In the financial system, patient households save in the form of deposits whereas impatient households borrow for consumption and mortgages, the latter being collateralized.

There are also firms producing final goods who finance their working capital requirements (labor) by borrowing from banks. Intermediate goods are produced by monopolistically competitive retailers subject to , among others, nominal rigidities. Banks perform traditional intermediation activities: They raise funds from patient households (i.e deposits) and lend to impatient households and final goods producers. Crucially, banks are subject to capital requirements. As a consequence, the capital structure of the banks is endogenous and there is a trade-off between giving out profitable, risky loans and the necessity to comply with capital requirements. The central banks acts in a conventional fashion and follows a Taylor rule.

2.1 Patient Household

There is a continuum of patient households of mass one. The objective of household (i) is to maximize the following discounted sum of expected instantaneous utilities:

$$\max_{\left\{c_t^P(i),h_t^P(i),d_t^P(i),k_t^P(i),i_t^K(i),n_t^P(i)\right\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta_P^t \left[(1-a^P)\log(c_t^P\left(i\right) - a^P c_{t-1}^P) + \log h_t^P\left(i\right) - \frac{\left(n_t^P\left(i\right)\right)^{1+\phi_1}}{1+\phi_1} \right]$$

The patient agent chooses the paths of consumption, investment, capital accumulation and labor supply that maximize the present value of the expected utility. a^P is the parameter that controls the habit persistence and ϕ_1 represents the inverse of the Frisch labor supply elasticity. The patient household derives utility from individual consumption $c_t^P\left(i\right)$ and housing services $h_t^P\left(i\right)$, while lagged aggregate consumption c_{t-1}^P and working hours $n_t^P\left(i\right)$ generate disutility. The intertemporal budget constraint in real terms for a patient household is:

$$\begin{aligned} c_t^P\left(i\right) + i_t^K\left(i\right) + q_t^h \triangle h_t^P\left(i\right) + d_t^P\left(i\right) = w_t^P n_t^P\left(i\right) + (1+r_{t-1}^d) d_{t-1}\left(i\right)/\pi_t \\ +r_t^k k_t\left(i\right) + \pi_t^b + \pi_t^{BI} \end{aligned} \tag{1}$$

The patient households are the owners of the physical capital. The investment of each household (i) is given by:

$$i_t^K\left(i\right) = k_{t+1}^P\left(i\right) - (1-\delta)k_t^P\left(i\right) + \frac{\theta_k}{2}\left(\frac{k_{t+1}^P\left(i\right)}{k_t^P\left(i\right)} - 1\right)^2 k_t^P\left(i\right)$$

The LHS of equation 1 corresponds to the total expenditure for a patient household. It includes the consumption of final goods, investment in physical capital (with adjustment costs), purchase of new houses and deposits to financial intermediaries. Revenues are determined by wages for hours worked, real returns on deposits, capital returns and dividends that come from banks and intermediate goods firms.

The optimal conditions for patient households for consumption, housing demand, labor supply and capital accumulation are given by:

$$\frac{1}{c_t^P(i)} = \beta_P E_t \left(\frac{1}{c_{t+1}^P(i)} \right) \left(1 + r_t^d\right) \tag{2}$$

$$\frac{q_t^h (1 - a^p)}{c_t^P(i)} = \frac{1}{h_t^P(i)} + \beta_P E_t \left(\frac{(1 - a^p) q_{t+1}^h}{c_{t+1}^P(i)} \right) \tag{3}$$

$$\frac{w_t^P (1 - a^p)}{c_t^P(i)} = \left(n_t^P(i)\right)^{\phi_1} \tag{4}$$

$$\lambda_t^P \left[1 + \theta_K \left(\frac{k_{t+1}^P(i)}{k_t^P(i)} - 1 \right) \right] = \beta E_t \left[\lambda_{t+1}^P \left(1 + r_{t+1}^K - \delta - \frac{\theta_k}{2} \left(\frac{k_{t+2}^P(i) - k_{t+1}^P(i)}{\left(k_{t+1}^P(i)\right)^2} \right) \right) \right] \tag{5}$$

Equation 2 is the standard Euler condition for consumption for a patient household. Equation 3 determines the intertemporal optimal demand for houses. Equation 4 shows that the labor supply is positively related to real wages. Finally equation 5 establishes the optimal condition for capital accumulation (net of adjustment cost). Notice that combining these conditionswe obtain the non-arbitrage condition in which the deposit rate has the same return that the expected rate for capital accumulation.

2.2 Impatient Household

There is also a continuum of impatient households (j) of mass one which maximizes the following sum of expected instantaneous utilities:

$$\max_{\left\{c_t^I(i), h_t^I(i), l_t^c(j), l_t^h(j), n_t^P(i)\right\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta_I^t \left[(1 - a^I) \log(c_t^I(j) - a^I c_{t-1}^I) + \log h_t^I(j) - \frac{\left(n_t^I(j)\right)^{1+\phi_1}}{1+\phi_1} \right]$$

The intertemporal choices for the impatient household are given by plan for consumption, investment in housing services, loans for consumption and mortgages and labor supply that maximize its expected discounted utility. The impatient household (j) has labor income, consumer and mortgage debt, and does not hold deposits. Its expenses are consumption, home purchases and interest payments for each type of loan:

$$c_t^I(j) + q_t^h \triangle h_t^I(j) + (1+r_{t-1}^c) l_{t-1}^c(j) + (1+r_{t-1}^h) l_{t-1}^h(j) + t_t(j) \leq$$
$$w_t^P n_t^P(j) + l_t^c(j) + l_t^h(j)$$

Additionally, the impatient household faces two constraints: firstly, a collateral constraint that determines the limit of mortgage debt according to the value of real estate assets; secondly, a borrowing constraint that establishes the limit of consumer debt, which depends on labor income.

$$(1+r_t^h) l_t^h \leq m_t^h E_t \left[q_{t+1}^h h_t^I \right]$$

$$(1+r_t^c) l_t^c \leq m_t^c w_t^I n_t^I$$

Where m_t^h y m_t^c are the loan to value for each type of loans, and they are modeled as exogenous AR1 process. Therefore, the optimal conditions for the impatient household are:

$$\frac{(1-a^I)}{c_t^I(j)} = \beta_I E_t \left[(1+r_t^c) \left(\frac{(1-a^I)}{c_{t+1}^I(j)} + \mu_t^{I,B} \right) \right] \tag{6}$$

$$\frac{(1-a^I)}{c_t^I(j)} = \beta_I E_t \left[(1+r_t^h) \left(\frac{(1-a^I)}{c_{t+1}^I(j)} + \mu_t^{I,C} \right) \right] \tag{7}$$

$$\frac{q_t^h (1-a^p)}{c_t^P(i)} = \frac{1}{h_t^P(i)} + \beta_P E_t \left[\frac{q_{t+1}^h \left((1-a^p) + \mu_t^{I,C} m_t^h \right)}{c_{t+1}^P(i)} \right] \tag{8}$$

$$w_t^I \left(\frac{(1-a^p)}{c_t^P(i)} + \mu_t^I m_t^c \right) = \left(n_t^P(i) \right)^{\phi_1} \tag{9}$$

Financial frictions affect in a substantial way the resource allocation for the impatient agent. Collateral and borrowing constraints distort the intertemporal consumption for impatient households. One can notice that dividing equation 6 by equation 7, there emerges an endogenous spread between mortgage and consumption interest rates in the case that both constraints are binding.

$$\frac{(1+r_t^h)}{(1+r_t^c)} = E_t \frac{\left(\frac{(1-a^I)}{c_{t+1}^I(j)} + \mu_t^{I,B} \right)}{\left(\frac{(1-a^I)}{c_{t+1}^I(j)} + \mu_t^{I,C} \right)} \tag{10}$$

Naturally, the collateral constraint affects housing demand. In a frictionless environment, as is shown in equation 3, housing demand is determined by two interacting forces. If there is a contemporary increase in housing prices, it reduces the demand for real estate services. However, if this increase in prices persists over time, there is an incentive to increase the housing demand since its value as an asset rises. This effect is amplified by the fact that, when the collateral constraint is binding, the pecuniary effect relaxes the collateral constraint. It allows the impatient household to have higher consumption smoothing.

The third effect of financial frictions is through the labor supply. When the borrowing constraint is binding, increases in the real wage relax equation 9. The final effect on labor supply depends on the standard trade-off between income and substitution effect on labor supply.

2.3 Final good firm

There are a continuum of intermediate goods which are indexed by $z \in [0, 1]$, producing differentiated output $y_{z,t}$ at prices $p_{z,t}$. Intermediate goods are aggregated according to a Dixit-Stiglitz technology:

$$y_t = \left[\int_0^1 (y_{z,t})^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}.$$

Where θ is the elasticity of substitution among goods. Each firm has to solve the following problem:

$$\max_{\{y_{z,t}\}} \quad p_t y_t - \int_0^1 p_{z,t} y_{z,t} dz$$
$$s.t. \quad y_t = \left[\int_0^1 (y_{z,t})^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}.$$

The first order condition gives the standard demand curve for each intermediate good:

$$y_{z,t} = \left(\frac{p_{z,t}}{P_t} \right)^{-\theta} y_t \tag{11}$$

where P_t is the standard price index:

$$P_t = \left(\int_0^1 (p_{z,t})^{1-\theta} dz \right)^{\frac{1}{1-\theta}}$$

2.4 Intermediate Good Firm

Each intermediate goods firm z faces two problems: The first is related to the value added, mainly the demand of capital and labor. The second concerns the price formation; in our case there is an intertemporal adjustment following the Calvo' approach.

In order to construct the added value, in a first stage, each firm z combines patient and impatient labor. Then let $n_{z,t}, w_t^0$ be the composite labor and wages respectively. The problem that solve each firm z in the first stage is to chooses the demand for patient and impatient labor such that minimize the total labor cost subject to the composite labor technology:

$$\min_{n_t^P, n_t^I} w_t^P n_t^P + w_t^I n_t^I$$

subject to:

$$n_t = \left(n_t^P\right)^{\alpha_2} \left(n_t^I\right)^{1-\alpha_2} \tag{12}$$

Where α_2 is the elasticity of substitution between the two types of labor. From first order conditions with respect to $n_t^p$and n_t^p:

$$w_t^P = \alpha_2 \lambda_{w,t} \frac{n_t}{n_t^P}; w_t^I = (1-\alpha_2)\lambda_{w,t}\frac{n_t}{n_t^I}$$

Getting $n_t^P$and $n_t^I$and substituting in 12:

$$n_t = \left(\lambda_{w,t}\alpha_2 \frac{n_t}{w_t^P}\right)^{\alpha_2} \left((1-\alpha_2)\lambda_{w,t}\frac{n_t}{w_t^I}\right)^{1-\alpha_2}$$

From the first order conditions we can obtain the wage index:

$$w_t^0 = \left(\frac{w_t^P}{\alpha_2}\right)^{\alpha_2} \left(\frac{w_t^I}{(1-\alpha_2)}\right)^{1-\alpha_2} \tag{13}$$

In a second stage, the added value is the combination between compound labor income and capital income subject to technology. The credit constraint for each firm z acts as working capital constraint on the labor input. Thus, the problem solved by each firm is choosing intermediate goods and capital such that minimize the total cost:

$$\min_{n_{z,t}, k_{z,t}} (1+r_t^e) w_t^0 n_{z,t} + r_t^k k_{z,t}$$

Subject to:

$$y_{z,t} = a_t^e k_{z,t}^{\alpha_1} n_{z,t}^{1-\alpha_1}$$

Where a_t^e is productivity shock that follows an AR(1) process.

$$a_t^e = (1-\rho_{a^e})\widetilde{a}^e + \rho_{a^e} a_{t-1}^e + \xi_t^{a^e}$$

The optimal capital-labor ratio is given by

$$\frac{k_{z,t}}{n_{z,t}} = \left(\frac{\alpha_1}{1-\alpha_1}\right)\left[\frac{w_t^0(1+r_{z,t}^e)}{r_t^k}\right]$$

Therefore the marginal cost for each firm z is:

$$mc_t = \frac{\left[(1+r_t^e)w_t^0\right]^{\alpha_1} r_t^k}{\alpha_1{}^{\alpha_1}(1-\alpha_1)^{(1-a_1)} a_t^e}$$

The financing cost affects the marginal cost and the optimal allocation of capital. Thus, we can have an expression of total output that depends on the financial friction trough the way of financing.

$$y_{z,t} = a_t^e \left[\frac{\alpha_1}{1-\alpha_1}\frac{(1+r_t^e)w_t^0}{r_t^k}\right]^{\alpha_1} n_{z,t}$$

The price formation of the firms is according to Calvo price-setting. Each period, there is a constant probability that the firm can adjust price. The problem for each firm is to choose the path of prices such that it maximizes the expected profit, subject to the inverse demand function:

$$\max_{\{p_{z,t}\}} \qquad E_t \sum_{i=0}^{\infty} \varepsilon^i \frac{\lambda_{t+i}^P}{\lambda_t^P}\left[\frac{p_{z,t+i}}{p_{t+i}} - mc_{t+i}\right] y_{z,t+i}$$

$$s.t. \quad y_{z,t+i} = \left(\frac{p_{z,t+i}}{p_{t+i}}\right)^{-\theta} y_{t+i},$$

Where $\frac{\lambda_{t+i}^P}{\lambda_t^P} = \beta_P \log(c_{t+i}^I - a^I c_{t+i-1}^I)$ is the discount factor. The first order condition entails the optimal adjustment of the prices:

$$\frac{p_t^*}{P_t} = \frac{\theta}{1-\theta}\frac{E_t \sum_{i=0}^{\infty}(\beta_P\varepsilon)^i \log(c_{t+i}^I - a^I c_{t+i-1}^I) mc_{t+i}\left(\frac{p_{t+i}}{P_t}\right)^{\theta}}{E_t \sum_{i=0}^{\infty}(\beta_P\varepsilon)^i \log(c_{t+i}^I - a^I c_{t+i-1}^I)\left(\frac{p_{t+i}}{P_t}\right)^{\theta-1}} \tag{14}$$

2.5 The Bank Problem

There is a large number of banks that behave competitively. The expected profits are given by the difference between their expected income and the expected cost net of bank capital requirement. The bank expected revenue for each type of loan is adjusted by the probability of repayment: $(1-\varpi_t^c)(1+r_t^c)l_t^c + (1-\varpi_t^e)(1+r_t^e)l_t^e$.

In addition, there is a liquidation value which is the part of the collateral value that can be recovered by the bank in case of default. This is especially true for commercial and mortgage loans which have collaterals (i.e capital, and houses). In the case of commercial loans it is given by $\varpi_t^e \psi_k k_t$ and for mortgages it is $\varpi_t^h \psi_h q_t^h h_t^I$. The default probabilities are endogenous and depend on the output gap, the leverage gap for each type of loan and a shock that reflects the financial fragility of the banks[5].

$$\varpi_t^c = \varpi_0^c \left(\frac{y_t}{\tilde{y}}\right)^{\delta_{yc}} \left(\frac{n_t w_t / l_t^c}{\widetilde{nw/l^c}}\right)^{\delta_{nc}} \exp(\xi_t^c)$$

$$\varpi_t^e = \varpi_0^e \left(\frac{y_t}{\tilde{y}}\right)^{\delta_{ye}} \left(\frac{r_t^K k_t / l_t^e}{\widetilde{k/l^e}}\right)^{\delta_{ne}} \exp(\xi_t^e)$$

$$\varpi_t^h = \varpi_0^h \left(\frac{y_t}{\tilde{y}}\right)^{\delta_{yh}} \left(\frac{q_t^h h_t^I / l_t^h}{\widetilde{q^h h^I / l^h}}\right)^{\delta_{c}} \exp(\xi_t^h)$$

Bank costs are made up of interest payments to depositors $(1+r_t^d)d_t$ and to the central bank $(1+r_t^m)\sum_{i\in\{c,e,h\}} l_t^i$. Crucially, macroprudential policy is modeled as an adjustment cost between the the capital adequacy ratio and the level of bank leverage:

$$\Gamma^{KR}\left(\mu_v, \frac{K_t^b}{b_t}\right) = \left(\mu_v - \nu_b \frac{K_t^b}{b_t}\right)\frac{K_t^b}{b_t}$$

In this sense, if the level of bank capital to total loans is above the capital adequacy ratio, this will ease the flow of bank income, generating a hedge against the total loans issued to the different agents in the economy. On the contrary, if the bank capital is below to the capital adequacy ratio, it increases the costs of external financing and therefore the interest rate of each type of loans. The capital requirement is defined as the risk weight on loans:

[5] The leverage gap are: In the case of consumption loans the ratio between labor income to the level of consumption loan. For firms, is the value of capital over firms loans. In similar manner, for mortagages, the leverage gap is defined as the market value of houses to the mortagages.

$$K_t^R = \mu_v(\sigma^c l_t^c + \sigma^e l_t^e + \sigma^h l_t^h)$$

Where $\sigma^i, i \in \{c, e, h\}$ is the risk weight to the repayment probability estimated by the financial regulatory authority. The financial policymaker determines the level capital adequacy ratio, and banks adjust their capital structure in order to achieve the policy. The problem solved by each bank is chosen such that it maximizes the expected profits:

$$\max_{\{l_t^c, l_t^e, l_t^f, K_t^b\}_{t=0}^{\infty}} (1-\varpi_t^c)(1+r_t^c)l_t^c + (1-\varpi_t^e)(1+r_t^e)l_t^e + \varpi_t^e \psi_k k_t \tag{15}$$

$$+(1-\varpi_t^h)(1+r_t^h)l_t^h + \varpi_t^h \psi_h q_t^h h_t^I$$

$$-(1+r_t^d)d_t - (1+r_t^m)\left[\sum_{\{c,e,h\}} l_t^i - \left(1-\mu^R\right) d_t^P - K_t^b\right] - \Gamma^{KR}\left(\mu_v, \frac{K_t^b}{b_t}\right)$$

Therefore, the first oder conditions are:

$$1 + r_t^c = \frac{\vartheta^c}{(1-\varpi_t^c)(\vartheta^c - 1)}\left((1+r_t^d) + \mu^R(1+i_t) + \frac{\partial \Gamma^{KR}\left(\mu_v, \frac{K_t^b}{b_t}\right)}{\partial l_t^c}\right)$$

$$1 + r_t^e = \frac{\vartheta^e}{(1-\varpi_t^e)(\vartheta^e - 1)}\left((1+r_t^d) + \mu^R(1+i_t) + \frac{\partial \Gamma^{KR}\left(\mu_v, \frac{K_t^b}{b_t}\right)}{\partial l_t^e}\right)$$

$$1 + r_t^h = \frac{\vartheta^h}{(1-\varpi_t^h)(\vartheta^h - 1)}\left((1+r_t^d) + \mu^R(1+i_t) + \frac{\partial \Gamma^{KR}\left(\mu_v, \frac{K_t^b}{b_t}\right)}{\partial l_t^h}\right)$$

Where $\vartheta^c = \frac{\partial l^i}{\partial r_t^i}\frac{r_t^i}{l_t^i}; i \in \{c, e, h\}$ is the interest elasticity of the demands for each type of loans. In equilibrium, interest rates for each type of loan must offset the expected opportunity cost of deposits, bank reserves and the marginal effect of each of the types of credit on macroprudential policy. In this sense, macroprudential policy affects the financial system along changes in the adjustment cost of the policy, generating a pass through on the interest rate for loans.

2.6 Central Bank

The behavior of the central bank is determined by the following standard Taylor rule:

$$1 + i_t = \left(\frac{i_{t-1}}{\bar{i}}\right)^{\rho_i} E_t \left(\frac{\pi_{t+1}}{\overline{\pi}}\right)^{\rho_\pi} \left(\frac{y_t}{\overline{y}}\right)^{\rho_y} \exp\left\{z_t^{pol}\right\}$$

Central bank loans to the banks are equivalent to the amount of bank reserves:

$$l_t^m = \mu_t^R d_t^P$$

3 Calibration and Results

The model is calibrated to replicate the main long-term values of the Colombian economy. The average values of real variables are taken of the steady-state value for the DSGE-Forecast model for Colombian Economy (see González et al. [2011]). The values of financial variables are taken from the information financial stability department of the Central bank of Colombia for the period 1996-2015. Table 5 shows the values taken as a reference as steady state values calculated by the model. Tables 12 and 13 at the end of the paper present the full set of values calibrated for the full set of parameters.

Table 5: Steady-State Values

Variable	Description	Model Value	Benchmark Value
c/y	Consumption to GDP ratio	0.73	0.82
k/y	Capital to GDP ratio	6.83	6.79
x/y	Investment to GDP ratio	0.19	0.22
B^k/y	Bank Capital to GDP ratio	0.03	0.05
d/y	Deposits to GDP ratio	0.28	0.30
b/y	Total Loans to GDP ratio	0.31	0.28
b^h/y	Mortgage Loan to GDP ratio	0.09	0.04
b^e/y	Entrepreneurial Loan to GDP ratio	0.13	0.16
b^c/y	Consumption Loan to GDP ratio	0.08	0.06
k^R/y	Capital Requirement to GDP ratio	0.02	0.02

In what follows we discuss the results of the impact of productivity, monetary and financial shocks on main real and financial variables for the artificial economy calibrated as discussed.

3.1 Monetary Shock

Tables 6 and 7 at the end of the paper present the set of impulse response functions to a one standard deviation shock to the policy rate. The response of aggregate variables is consistent with what is traditionally found for a monetary policy shock. Specifically, both output and inflation fall on impact, which induces a subsequent endogenous fall in the policy rate. Total consumption falls, as does investment, and the consequent reduction in the demand for labor reduces employment and the real wage. Finally, the increase in the policy rate induces a transfer of wealth from borrowers (impatient households) to savers (patient households), which manifests itself (among others) in a reduction in the enjoyment of housing services by the former and an increase by the latter.

The response of aggregate financial variables is also consistent with the findings of previous literature. Total loans fall with the increase in the interest rate, whereas deposits (although falling in impact consistently with the reduction in the size of the balance sheet of the bank) increase so long as interest rate remain well above steady state. The effects of the shock on credit subcategories offers interesting insights into the functioning of the model. Interest rates track closely the behavior of the policy rate, but consumer credit rates exhibit the largest response. Consistent with this, consumer credit presents the largest negative response to the policy shock. The fact that consumer credit turns out to be the most volatile form of credit after a monetary policy shock is consistent with the evidence on the cyclical behavior of credit components described in Section 2. Interestingly, although increasing on impact, the repayment probability of consumer credit is the faster to fall after the policy shock. Thus, the strong fall in consumer credit after a policy shock is a result of borrower preferences, a stronger transmission mechanism on consumer credit rates, and a stronger sensitivity of the default rate of consumer loans to aggregate conditions. Last but not least, the increase in the policy rate induces a switch in the sources of funding of the bank. In particular, while deposits increase, the use of bank capital falls as capital requirements fall (the size of the balance sheet is smaller and the quality of total credit remains stable). As a consequence, bank leverage increases as a result of a contractionary monetary policy shock.

3.2 Productivity Shock

Tables 8 and 9 at the end of the paper present the impulse responses functions for productivity shock. A positive productivity shock (1std) leads to increase in the level of output and fall in prices. The total consumption increases, being more important the effect on patient consumption rather than impatient consumption. The dynamic between the two types of households is explained by the behavior of real wages. For example, for the impatient household the borrowing constraint becomes binding due to the fall in real wages. This limits the capacity to borrow and therefore their level of consumption.

On the other hand, the increase in productivity leads to rise in the marginal productivity of capital and thus fall in the level of investment. Real wages for both types of households initially are reduced with a subsequent recovery. This generates a fall in the equilibrium level of employment. The working capital constrains increase the labor cost reducing the labor demand. At the same time, the interest rate for mortgage arise and making the collateral constraint binding. In equilibrium, for impatient households the demand for new houses is reduced. By contrast, patient household, the demand for new houses increases since it serves as a mechanism to smooth consumption.

In the case of financial variables, there is a reduction in the level of funding for the financial system (deposits and bank capital). It leads to a fall in the aggregate lending. when we analyze the financial system fragility we found an increase in the default probability for commercial and mortgage loans. The total capital requirement is initially reduced because non-performing loans are falling. As a summary: the productivity shock leads to an increase in the cost of financing that reduces the amount of credit and increase the financial fragility.

3.3 Financial Shock

Finally, tables 10 and 11 at the end of the paper present the set of impulse response functions to a one standard deviation shock to the default rate of each of the three categories of credit considered in the model (mortgage, consumer, business). Consistent with this, the probability of repayment falls for each of consumer, business and mortgage credit. The fall on impact is different for each category as the probability of repayment is also affected by other aggregate variables in an instantaneous fashion, and this latter response is different for each category. An immediate consequence of higher risk is higher interest rates for all credit categories, a result which is consistent with the first order conditions of the bank (marginal revenue from each credit category falls if interest rates remain constant). The reduction in marginal revenue and the increase in interest rates is consistent in equilibrium with a strong reduction in credit.

As is the case with the previous shock, this fall is stronger for consumer credit, a result which is consistent with observed cyclical behavior of credit categories. The fall in total credit reduces capital requirements so long as the size of the balance sheet of the bank is smaller after the shock. However, unlike the case of a contractionary monetary policy shock, a default shock induces a reduction in leverage, as bank capital increases whilst deposits fall. The latter is associated with a reduction in the deposit rate (which is consistent with the fall in marginal revenue for banks). Finally, the responses after a financial shock corroborate what is observed for monetary shocks: a recessionary shock induces a redistribution of wealth evident in the increase in housing services for only the patient households (savers).

The default shock, in reducing business and consumer credit, acts in the direction of reducing both output and inflation, and is therefore akin to a negative demand shock. The effects of this shock are similar to the ones of the monetary policy shock for consumption, labor and the real wage. Investment, however, recovers very quickly due to the fall in the structure of interest rates of the economy, which also brings down the rental rate of capital.

4 Concluding Remarks

In this paper, we present a DSGE model with financial sector for the Colombian economy. The model explores the interaction of real and financial variables taking into account multiple types of loans and macroprudential policy based on capital requirements. We assess the impact of monetary shocks, productivity and financial shocks on the Colombian economy. In general, we find that monetary shocks generate a contraction in output and the level of credit, with improvements in the probability of repayment loans. In contrast, productivity shocks are expansionary, but lead to an increase in the cost of external financing and financial fragility. Financial shocks (based on increased likelihood of default), are found to be contractionary with greater financial fragility.

It is important to highlight that the transmission channel of macroprudential policy (capital requirements) works through the interest rate for each of credit category. This model is sufficiently flexible to consider alternative tools of macroprudential policy: one possible extension of the model would be to consider dynamic provisioning scheme or marginal reserve requirements to study its impact on the economy and its differences with conventional capital requirements. The comparison of the several macroprudential policies would help achiecve a better understanding of the equilibrium interaction of monetary and macroprudential policies.

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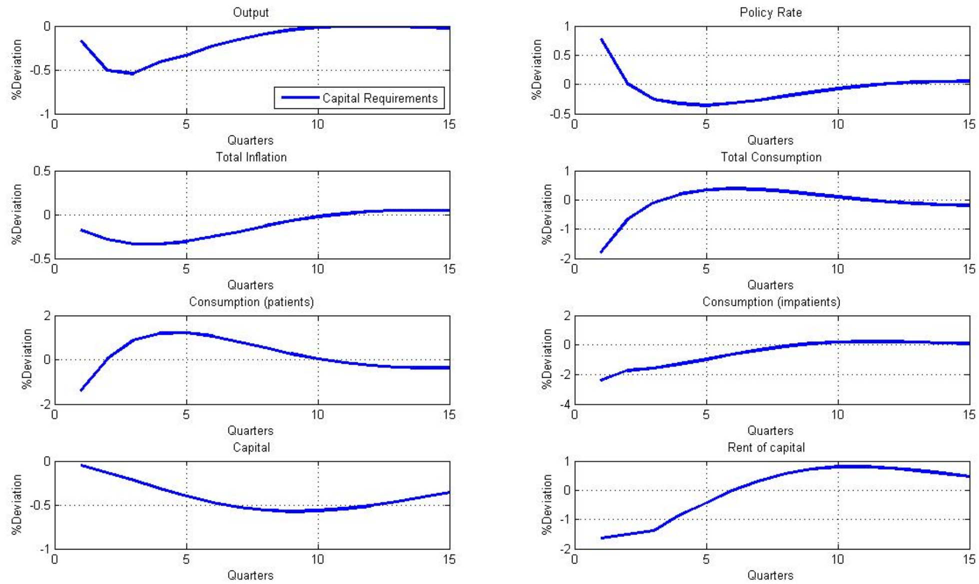
Table 6: Monetary Shock (I)



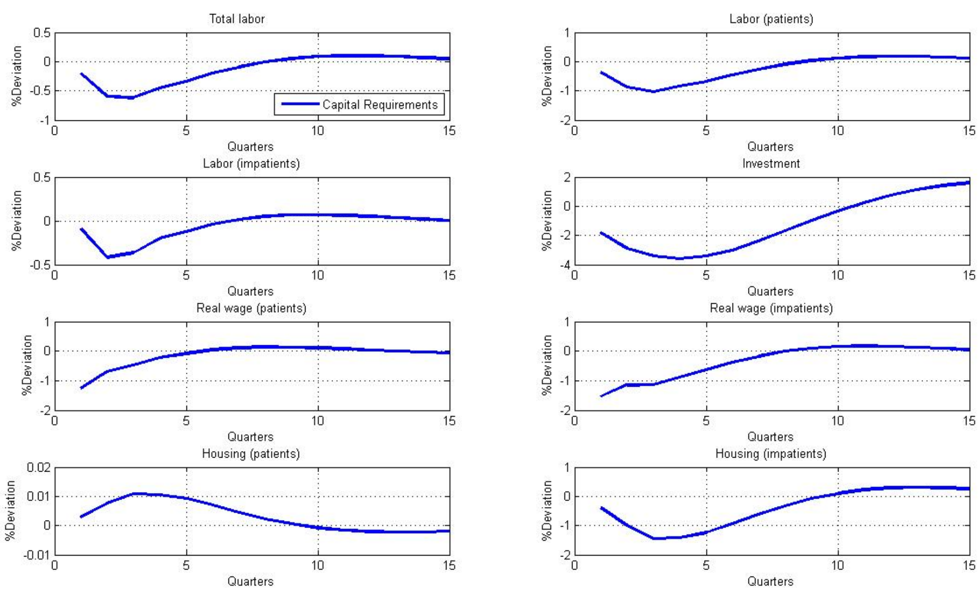


Table 7: Monetary Shock (II)

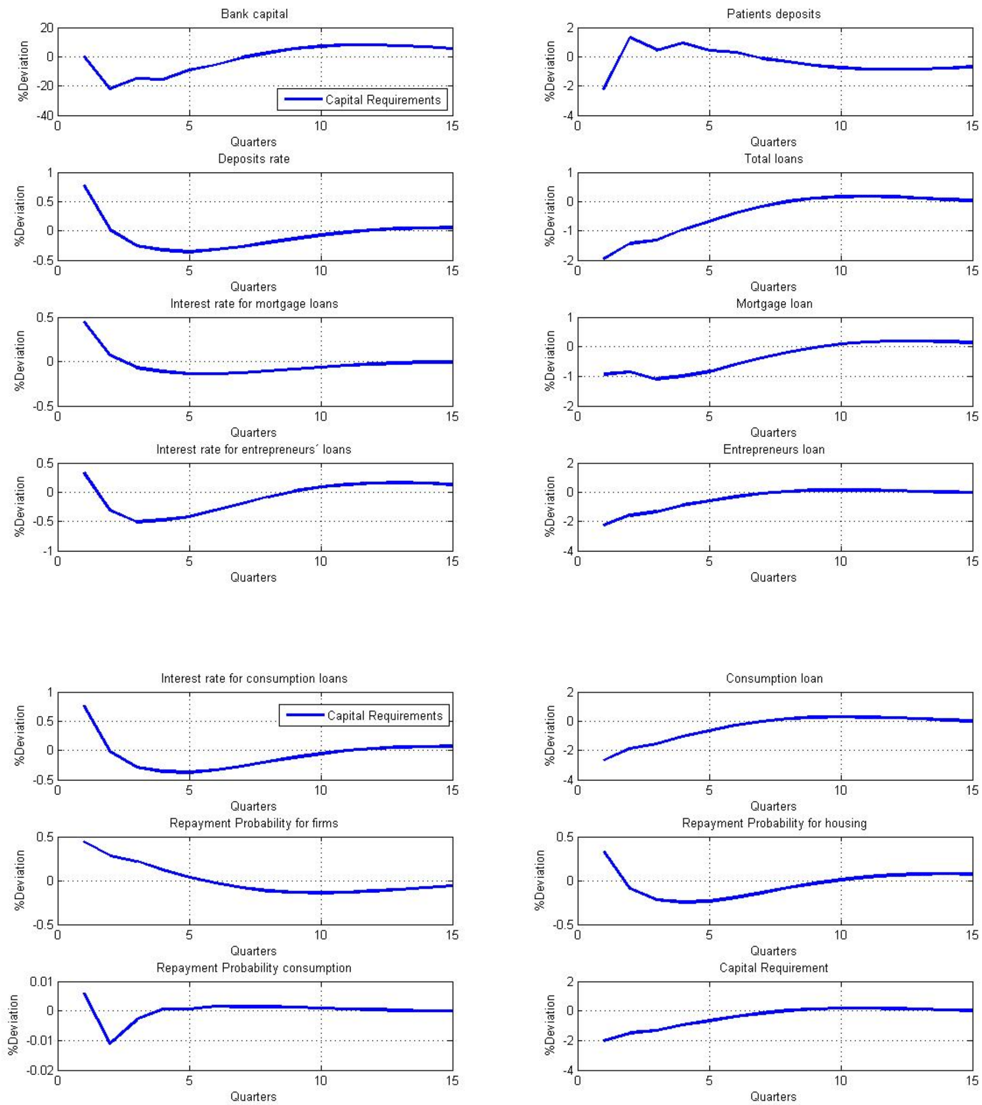
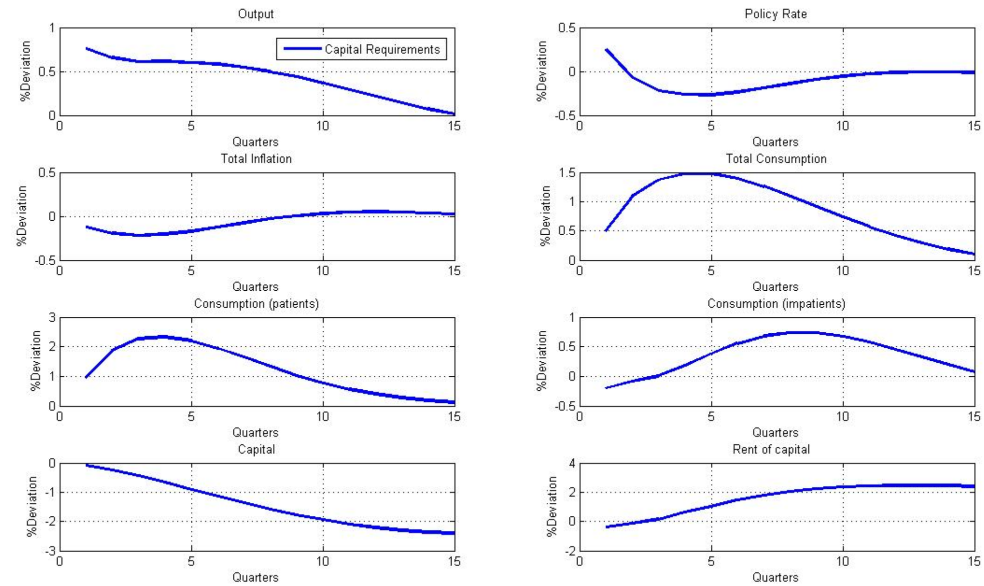


Table 8: Productivity Shock



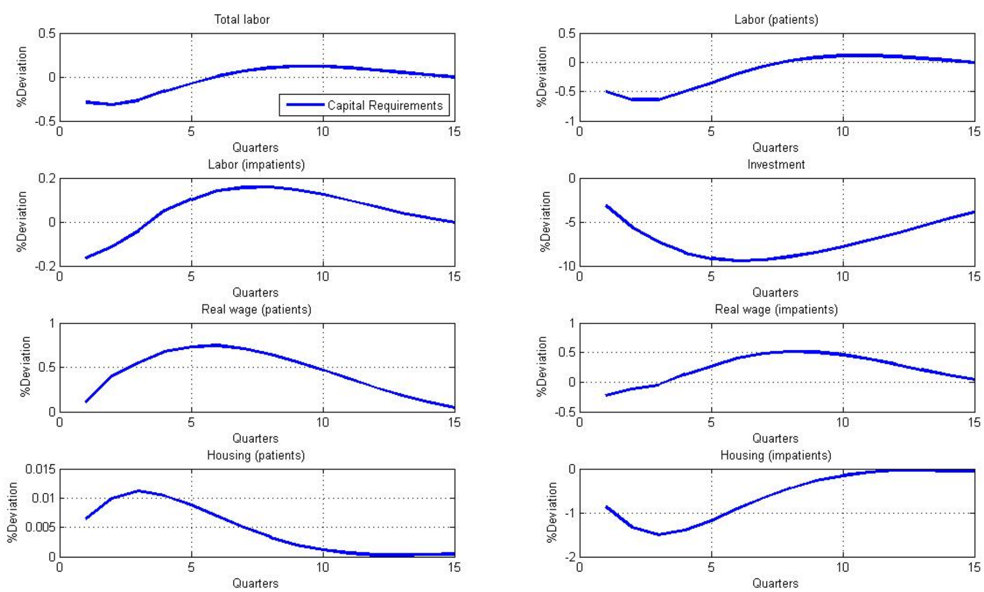


Table 9: Productivity Shock (II)

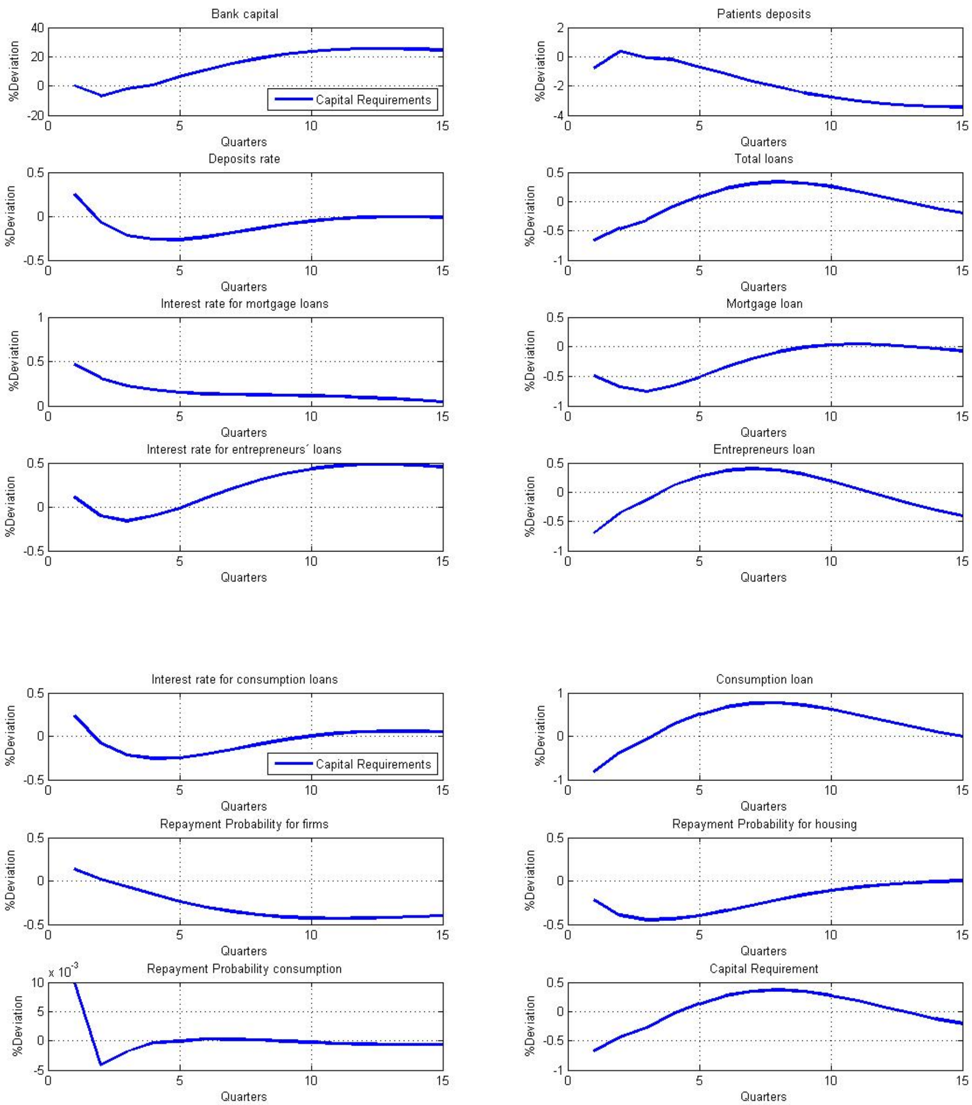
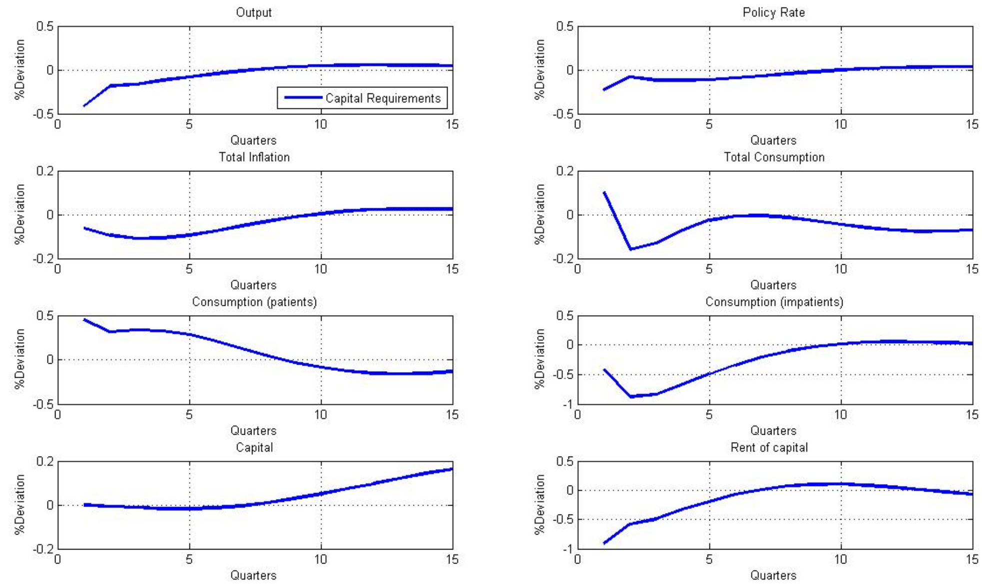


Table 10: Financial Shock



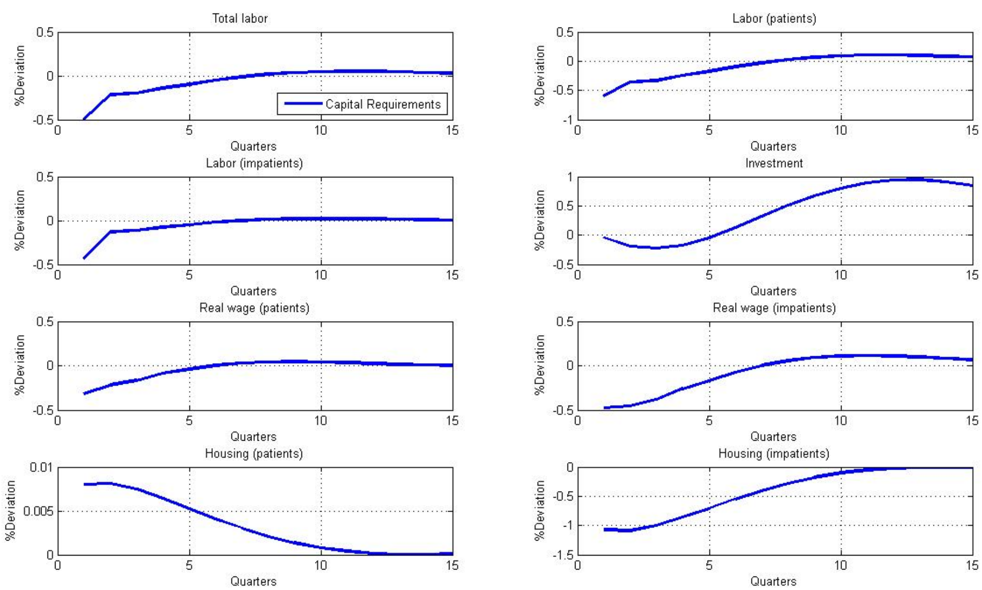


Table 11: Financial Shock (II)

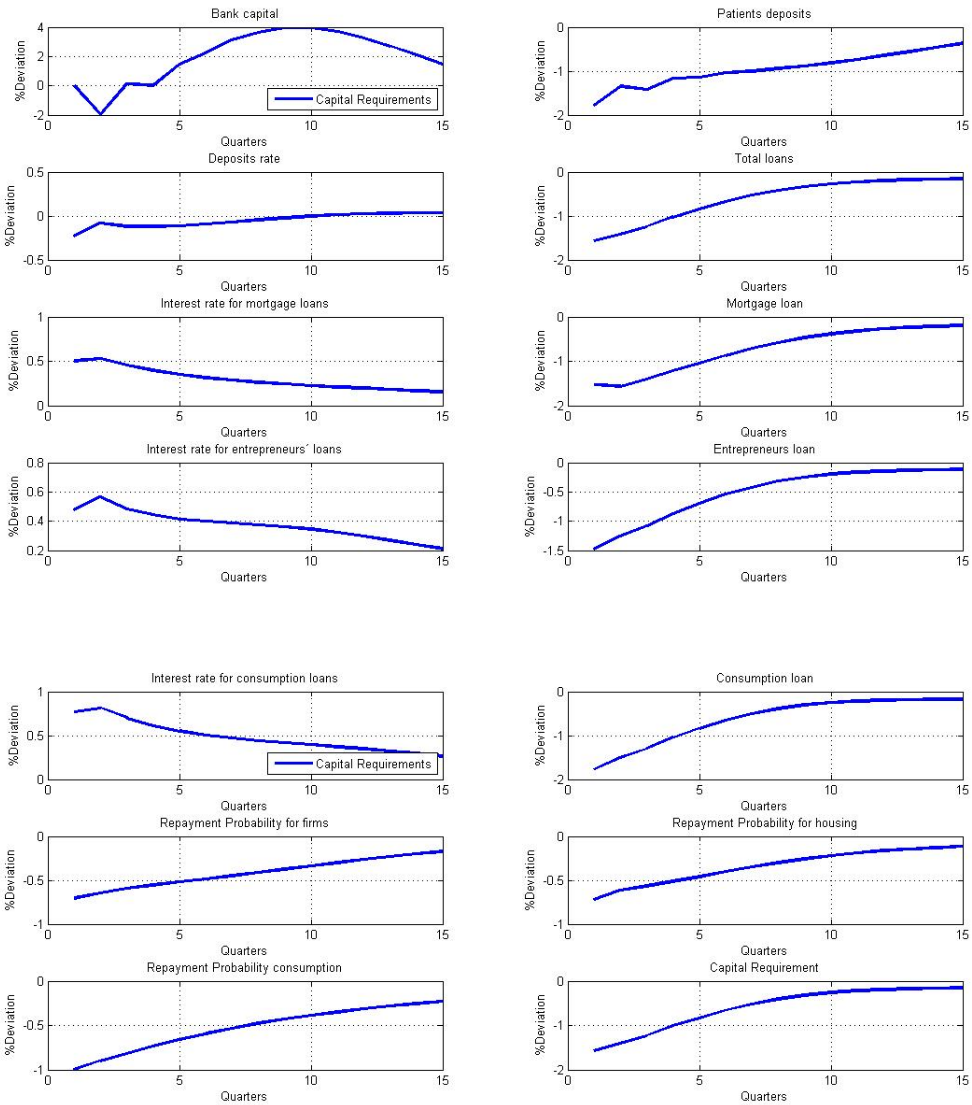


Table 12: Parameter values (I)

Parameter	Description	Value
σ	Inverse of intertemporal elasticity of substitution.	0.5
β_P	Discount factor (patient)	0.99
β_I	Discount factor (impatient)	0.97
m^I	Households loan-to-value mean	0.98
α	Capital share of product	0.16
δ	Capital depreciation rate	0.02
Θ	Elasticity of substitution in the goods market	6
μ	Share of patients hhs	0.38
ϕ_1	Inverse of Frisch elasticity	1
ψ_k	Investment adjustment cost parameter	10.26
ρ_π	Response to inflation deviations from target	1.5
ρ_i	Interest rate smoothing	0.5
ρ_y	Response of monetary policy to GDP	0.9
a^P	Habit coefficient	0.2
ρ_{mI}	Persistence of hhs-ltv shocks	0.12
ρ_{mE}	Persistence of entre-ltv shocks	0.99
ρ_a	Technology shock persistence	0.93
ϵ_q	Probability of not adjust prices	0.8
$\overline{\pi}$	Inflation target	1
$\overline{a}$	Mean of technology	1
$\overline{H}$	Housing (fixed) supply	15
$\bar{i}$	Interest rate steady state	1.03
ω_{gb}	Share of bank's profits retained to accumulate bank capital	0.3
$\overline{\tau_d}$	Mean of reserve requirement	0.02
ρ_{τ_d}	Persistence of interest rate shocks	0.9
$\overline{\delta_{bC}}$	Haircut Consumption Debt	0.2

Table 13: Parameter Values (II)

Parameter	Description	Value
δ_{kb}	Bank Capital depreciation rate	0.05
κ_k	Effective Capital collateral-loan ratio	0.25
κ_h	Effective Household collateral-loan ratio	0.4
ψ^1_{qf}	Elasticity of repayment prob wrt collateral (Entrepreneurs)	0.01
ψ^1_{qh}	Elasticity of repayment prob wrt collateral (Mortgage)	0.01
ψ^1_{qc}	Elasticity of repayment prob wrt collateral (Consumption)	0.01
ψ^2_{qf}	Elasticity of repayment prob wrt capital-loan ratio (Entrepreneurs)	0.2
ψ^2_{qh}	Elasticity of repayment prob wrt capital-loan ratio (Mortgage)	0.6
ψ^3_{qf}	Elasticity of repayment prob wrt cyclical output (Entrepreneurs)	0.01
ψ^3_{qh}	Elasticity of repayment prob wrt cyclical output (Mortgage)	0.01
ψ^3_{qc}	Elasticity of repayment prob wrt cyclical output (Consumption)	0.01
$\rho_{\delta_{bC}}$	Haircut Consumption Debt persistence	0.9
ρ_p	Probability shock persistence	0.9
$\overline{p}$	Mean of Preobability Shock	1
ζ_{bC}	Elasticity Consumption Interest Rate wrt Consumption Loan	10
ζ_{bF}	Elasticity Entrepreneurs Interest Rate wrt Entrepreneurs Loan	-40
ζ_{bH}	Elasticity Mortgage Interest Rate wrt Mortgage Loan	30
κ	Adjustment cost of Invertment parameter	0.5
ρ_C	Capital Adequacy Ratio Consumption Loan	1
ρ_H	Capital Adequacy Ratio Mortgage Loan	0.75
ρ_F	Capital Adequacy Ratio Entrepreneurs Loan	1
σ_C	Perception of default risk Consumption Loan	0.09
σ_H	Perception of default risk Mortgage Loan	0.09
σ_F	Perception of default risk Entrepreneurs Loan	0.09
κ_{kb}	Effective Bank Capital Collateral-Loan Ratio	10.82
$\overline{\delta_{bE}}$	Haircut Entrepreneurs Debt	0.12
$\rho_{\delta_{bE}}$	Haircut Entrepreneurs Debt persistence	0.9
ν^b	Capital/loans ratio in steady state	0.18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