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Financial Accelerator Mechanism in a Small Open Economy*

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Abstract

Using Bayesian estimation techniques, we estimate a small open economy DSGE model with credit-market imperfections for the Colombian economy. Using the estimated model we investigate what are the sources of business cycle fluctuations. We show that balance-sheet effects play an important role in explaining recent Colombian business cycles. We then perform a counterfactual exercise that shows that fixed exchange rate regime could have exacerbated the financial distress in the economy between 1998-1999.

Key Words: DSGE modelling, Financial Accelerator, Bayesian Estimation.

JEL Clasification: C11, C15, E32, E44, E52.

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Resumen

Usando un enfoque Bayesiano, estimamos un modelo DSGE de economía pequeña y abierta con imperfecciones en el mercado de crédito para la economía colombiana. Usamos el modelo para investigar cuales son las fuentes de fluctuaciones del ciclo económico. Mostramos que los efectos de hoja de balance juegan un papel importante en la explicación de los ciclos económicos en Colombia. Finalmente, hacemos un ejercicio de simulación que muestra que tratar de establecer un regimen de tasa de cambio fija pudo haber exacerbado la crisis económica durante 1998-1999.

Palabras claves: Modelos de Equilibrio General, Acelerador Financiero, Estimación Bayesiana.

1 Introduction

In López and Rodríguez (2007) we tested if financial factors are important in explaining the recent behavior of investment in Colombia: Was the severity of the 1999 recession due to a financial accelerator mechanism a la Bernanke, Gertler and Gilshrist (1999)? To answer that question we focused our attention in the transmission mechanisms involved in a closed economy model with and without a financial accelerator mechanism developed by Dib and Christensen (2006). Following Gertler et al. (2007), in this paper, we extend the Dib and Christensen´s model in order to include an additional channel of monetary policy transmission: the effect of exchange rate on macroeconomic variables. Particularly, it is possible to examine the response of output to an increase in the country borrowing premium under both a flexible exchange rate regime and a fixed exchange rate regime.

The estimated model contains many shocks and frictions. It features sticky nominal price settings that allows for backward inflation indexation, investment adjustment costs, habit formation in exports demand and financial frictions. The stochastic dynamics is driven by ten orthogonal structural shocks: technology shocks, demand shocks (to preferences, investment and money demand shocks), foreign shocks (to transfers, foreign prices, country borrowing premium, foreign interest rate, and foreign demand), and monetary policy shocks. The model incorporates credit-market imperfections through the assumption that external funds and internal funds are not perfect substitutes; the external finance premium depends inversely on the value of entrepreneurs own net worth. Procyclical movements in entrepreneur´s net worth caused by unanticipated shocks then lead to countercyclical movements in the external finance premium, and thus make investment volatile. This mechanism is called the “financial accelerator”.

The objectives of the paper are twofold. First, it is important to verify whether

in this small open economy model the financial frictions continue to be significant in explaining the Colombian business cycle. The Bayesian estimation methodology provides a natural framework for testing the relevance of frictions and in our case we use it to compare a model with financial frictions with a model without them. Our finding is that credit market imperfections help to explain the business cycle in Colombia.

Second, using the estimated parameter values it is possible to compare the response of some macroeconomic variables to an increase in the country borrowing premium of the magnitude that was observed during 1998-1999 in order to assess the importance of the exchange rate regime to explain the financial distress of the economy. The fixed exchange rate regime is likely to be important in the explanation of the severity of the crisis in the Colombian economy.

In the next section, we present the model that is subsequently estimated. Section 3 reports on our implementation of Bayesian inference methods. Section 4 presents the results on estimates. Section 5 concludes.

2 The Model

The model we estimate is based on Bernanke, Gertler and Gilchrist (1999),(BGG hereafter), Dib and Christensen (2006), and Gertler et al. (2007). A micro financial contracting problem between firms and lenders is set into an open economy macroeconomic dynamic New Keynesian framework with sticky prices. In a first stage we describe the financial accelerator mechanism developed by BGG.

2.1 Financial Accelerator Mechanism

The financial accelerator mechanism explains how credit-market imperfections help to propagate and magnify initial shocks to the economy. First we model the capital-purchasing decisions of entrepreneurs. At this level, there are also external capital producing firms. Entrepreneurs purchase capital from capital producers. In order to finance their investment, they have access to external funds in addition to their own wealth. Capital producers, on the other hand, purchase consumption goods and transform it into capital to sell to entrepreneurs.

2.1.1 Entrepreneurs

Entrepreneurs purchase capital in each period, k_t , and use it in combination with hired labor, h_t , to produce the output goods, y_t , following a constant-returns-to-scale technology

$$y_t \leq k_t^\alpha (A_t h_t)^{1-\alpha}, \quad \alpha \in (0, 1) \quad (1)$$

where A_t is an exogenous technology shock that is assumed to follow the autoregressive process

$$\log A_t = (1 - \rho_A) \log(A) + \rho_A \log(A_{t-1}) + \varepsilon_{A_t} \quad (2)$$

where $\rho_A \in (0, 1)$, $A > 0$, and ε_{A_t} is normally distributed with mean zero and standard deviation σ_A

The entrepreneurs choose k_t and h_t to maximize profits subject to the production technology. The first-order conditions are

$$r_{kt} = \alpha \xi_t^h \frac{y_t}{k_t} \quad (3)$$

$$w_t = (1 - \alpha) \xi_t^h \frac{y_t}{h_t} \quad (4)$$

where ξ_t^h is real marginal cost; w_t is the real wage; and r_{kt} is the real rental rate on capital, all in terms of domestic goods.

We now consider the capital acquisition decision. The entrepreneur finances the acquisition of capital partly with its own net worth available at the end of period t , n_t , and partly with issuing nominal bonds, B_{t+1} . Then capital financing is divided between net worth and debt, as follows:

$$q_t k_{t+1} = n_{t+1} + \left(\frac{B_{t+1}}{P_t} \right) \quad (5)$$

where q_t is the relative price of a unit of capital which varies depending on the capital production technology¹. Entrepreneur's demand for capital is determined by comparing the expected marginal return to holding capital with its expected marginal financial cost. The expected gross return to holding a unit of capital from t to $t + 1$, $E_t f_{t+1}$ is defined as

$$E_t f_{t+1} = E_t \left[\frac{r_{kt+1} x_h + (1 - \delta) q_{t+1}}{q_t} \right] \quad (6)$$

The parameter δ represents the capital depreciation rate. The first term in the numerator, r_{kt+1} , is the marginal productivity of capital. The second term is the capital gain enjoyed by entrepreneurs and x_h is the price of domestic goods relative to the household consumption index, $x_t^h = p_t^h / p_t$.

The financial cost condition for purchasing capital is the main feature of this model. BGG assume that there exist credit market imperfections that make external finance more expensive than internal funds. Additional costs (the premium) over riskless interest rate, R_{t+1} , are imposed on borrowers if they demand external funds. According to BGG, lenders must pay a fixed "auditing cost" if they wish to observe borrower's realized returns. This auditing cost is interpretable as the cost of bankruptcy or de-

¹ q_t is in units of the household consumption index

fault. Since competitive lenders must receive an expected return to lending equal to the opportunity cost of their funds, the borrower's expected rate of return, $E_t f_{t+1}$, must exceed the riskless interest rate. The default risk depends on the degree in which the entrepreneurs depend on external funds, debt, and this leads to a relationship between two important ratios: The ratio of $E_t f_{t+1}$ to R_{t+1} and the ratio of net worth to assets, as follows

$$E_t f_{t+1} = E_t \left[R_{t+1} S \left(\frac{n_{t+1}}{q_t k_{t+1}} \right) \right] \quad \text{with} \quad S(1) = 1 \quad S'(\cdot) < 0 \quad (7)$$

where n_t is entrepreneur's own wealth. When the ratio of internal funds is low the default risk is high and in this case the cost of borrowing rises.

The log-linearized equation for the external finance premium is

$$f_{t+1} - R_{t+1} = -\psi n_{t+1} + \psi k_{t+1} + \psi q_t \quad (8)$$

where ψ represents the elasticity of the external finance premium with respect to a change in the leverage position of entrepreneurs, $-\frac{S'(\cdot)}{S(\cdot)} \left(\frac{n_t}{q_t k_t} \right)$. The agency cost and the external finance premium vary with borrowers's financial health. Higher monitoring costs imply a higher elasticity of the premium on external funds to a change in the balance sheet position. Hence the higher the monitoring costs the greater will be the volatility owing to financial market imperfections.

Finally, we need to describe the evolution of net worth of entrepreneurs. Entrepreneurs borrow $q_{t-1} k_t - n_t$ at an expected interest rate $E_t f_t = R_t S \left(\frac{n_t}{q_{t-1} k_t} \right)$ and receive the ex-post return f_t . Net worth evolves according to

$$n_{t+1} = f_t q_{t-1} k_t - R_t S \left(\frac{n_t}{q_{t-1} k_t} \right) (q_{t-1} k_t - n_t) \quad (9)$$

The introduction of net worth as an additional state variable allows us to explain the propagation and magnifications of monetary shocks (and other shocks) to real activity. Shocks to net worth relative to total finance requirements generate endogenous changes in agency costs and in the financial external premium charged above risk-free rates. Furthermore, net worth may be highly sensitive to unexpected shifts in the asset prices, specially if firms are leveraged. This is a kind of multiplier effect. An unanticipated rise in asset prices raises net worth more than proportionately (decreasing external premium) which stimulates investment and, in turn, raises assets prices even further (as we will show below).

2.1.2 Capital producers

The price of capital is determined by a q -theory of investment. Capital producers purchase consumption goods as a material input, i_t , and combine it with rented capital, k_t , to produce new capital. Following Dib and Christensen (2006), we assume that capital producers are subject to quadratic capital adjustment costs. Their optimization problem, in real terms, consists of choosing the quantity of investment to maximize profits, so that:

$$\max_{i_t} \left[q_t x_t i_t - i_t - \frac{\chi}{2} \left(\frac{i_t}{k_t} - \delta \right)^2 k_t \right] \quad (10)$$

The disturbance, x_t is as in Greenwood et al. (1988), a shock to the marginal efficiency of investment. The first order condition is

$$q_t x_t - 1 - \chi \left(\frac{i_t}{k_t} - \delta \right) = 0 \quad (11)$$

The inclusion of adjustment costs makes the price of capital volatile, therefore asset

price volatility contributes to volatility in entrepreneurial net worth.

The aggregate capital stock evolves according to

$$k_{t+1} = x_t i_t + (1 - \delta)k_t \quad (12)$$

where the marginal efficiency of investment, x_t , evolves according to:

$$\log(x_t) = \rho_x \log(x_{t-1}) + \varepsilon_{x_t} \quad (13)$$

where $\rho_x \in (0, 1)$ is a first order autoregressive coefficient, and ε_{x_t} is a random Gaussian variable distributed with mean zero and standard deviation σ_x .

2.2 The complete model

We now present a dynamic New Keynesian framework that completes the economic model, adding households, retailers and foreign sector. Retailers buy output from entrepreneurs and slightly differentiate it at no resource cost. The differentiation of output gives the retailers some market power. Households and firms then purchase CES aggregates of these retail domestic goods. Retailers are introduced to motivate sticky prices and we follow Calvo (1983) in introducing price inertia.

2.2.1 Households

Let c_t be a composite of tradable consumption goods. Then the following CES index defines households preferences over home consumption, c_t^h , and foreign consumption, c_t^f :

$$c_t = [(\nu)^{\frac{1}{\rho}} (c_t^h)^{\frac{\rho-1}{\rho}} + (1 - \nu)^{\frac{1}{\rho}} (c_t^f)^{\frac{\rho-1}{\rho}}]^{\frac{\rho}{\rho-1}} \quad (14)$$

The corresponding consumer price index, p_t , is given by:

$$p_t = [(\nu)(p_t^h)^{1-\rho} + (1-\nu)(p_t^f)^{1-\rho}]^{\frac{1}{1-\rho}} \quad (15)$$

Our treatment of consumer's preferences is standard. Instantaneous utility depends on consumption, real balances and leisure. The utility function is as follows:

$$U(c_t, M_t/p_t, h_t) = \frac{\gamma e_t}{\gamma - 1} \log \left\{ c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} \left(\frac{M_t}{p_t} \right)^{\frac{\gamma-1}{\gamma}} \right\} + \eta \log(1 - h_t) \quad (16)$$

where c_t represents consumption, M_t/p_t real money balances, $(1 - h_t)$ leisure. The parameters γ and η are positive structural parameters that denote the constant elasticity of substitution between consumption and real balances, and the weight on leisure in the utility function, respectively.

The shock e_t is a taste or preferences shock for consumption while b_t is a money-demand shock. These shocks follow the processes

$$\log(e_t) = \rho_e \log(e_{t-1}) + \varepsilon_{e_t} \quad (17)$$

and

$$\log(b_t) = (1 - \rho_b) \log(b) + \rho_b \log(b_{t-1}) + \varepsilon_{b_t} \quad (18)$$

with $\rho_e \in (0, 1)$ and $\rho_b \in (0, 1)$.

The representative household is assumed to maximize the expected discounted sum of its utility flows:

$$E_t \left(\sum_{k=0}^{\infty} \beta^k U(c_t, M_t/p_t, h_t) \right) \quad (19)$$

subject to budget constraint:

$$c_t \leq \frac{W_t h_t}{p_t} + \frac{T_t}{p_t} + \frac{\Omega_t}{p_t} - \frac{M_t - M_{t-1}}{p_t} - \frac{B_{t+1} - R_{t-1} B_t}{p_t} - \frac{s_t B_{t+1}^* - s_t \varphi_{t-1} R_{t-1}^* B_t^*}{p_t} + \frac{s_t T_t^*}{p_t} \quad (20)$$

where s_t denote the nominal exchange rate; B_t and B_t^* represents the household's nominal bonds denominated in domestic and foreign currency, respectively; R_t and R_t^* the domestic and foreign gross nominal interest rate, respectively and W_t the nominal wage. The household receive a lump-sum transfer, T_t , from the monetary authority, transfers from abroad, T_t^* as well as dividend payments, Ω_t , from retailers. In addition, φ_t represents a gross borrowing premium that domestic residents must pay to obtain funds from abroad. As in Gertler et. al (2007), the country borrowing premium, φ_t , depends on total net foreign indebtedness and a random shock. It is introduced for technical reasons. Without it net foreign indebtedness may be non-stationary. In particular,

$$\varphi_t = \left(\frac{B_t^*}{\bar{B}^*} \right)^{-\varrho} \exp \epsilon_{\varphi_t} \quad (21)$$

where \bar{B}^* is steady-state net foreign indebtedness .

Solving the household 's problem yields the first-order conditions for the consumption allocation, money demand, labor supply, and the consumption/saving decision

$$\frac{c_t^h}{c_t^f} = \frac{\nu}{1 - \nu} \left(\frac{p_t^h}{p_t^f} \right)^{-\rho} \quad (22)$$

$$\frac{e_t c_t^{-\frac{1}{\gamma}}}{c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} m_t^{\frac{\gamma-1}{\gamma}}} = \lambda_t \quad (23)$$

$$\frac{e_t b_t^{\frac{1}{\gamma}} m_t^{-\frac{1}{\gamma}}}{c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} m_t^{\frac{\gamma-1}{\gamma}}} = \lambda_t - \beta E_t \left(\frac{\lambda_{t+1}}{\pi_{t+1}} \right) \quad (24)$$

$$\frac{\eta}{1-h_t} = \lambda_t w_t x_t^h \quad (25)$$

$$\frac{\lambda_t}{R_t} = \beta E_t \left(\frac{\lambda_{t+1}}{\pi_{t+1}} \right) \quad (26)$$

where λ_t is the Lagrangian multiplier associated with the budget constraint and $m_t = M_t/p_t$, $w_t = W_t/p_t^h$, $\pi_{t+1} = p_{t+1}/p_t$ are real money balances, real wages, and the gross inflation rate respectively.

In addition, the optimality condition governing the choice of foreign bonds in conjunction with (26) yields the following uncovered interest parity condition (UIPC):

$$E_t \left\{ \frac{\lambda_{t+1}}{\pi_{t+1}} \left[R_t - \varphi_t R_t^* \frac{s_{t+1}}{s_t} \right] \right\} = 0 \quad (27)$$

2.2.2 Foreign Behavior

Following Gertler et al (2007), we distinguish between the wholesale (import) price of foreign goods and the retail price in the domestic market by allowing for imperfect competition and pricing-to-market in the local economy (see section 2.2.3). At the wholesale level, the law of one price holds:

$$p_{w,t}^f = s_t p_t^{f*} \quad (28)$$

where $p_{w,t}^f$ represents the wholesale price of foreign goods in domestic currency, and p_t^{f*} the foreign currency price of such goods. Both foreign nominal interest rate, R_t^* and the nominal price of the foreign good, p_t^{f*} are taken as exogenous. In addition, we assume that foreign demand for home tradable good, c_t^{h*} , is given by:

$$c_t^{h*} = \left[\left(\frac{p_t^{h*}}{p_t^*} \right)^{-\tau} y_t^* \right]^v (c_{t-1}^{h*})^{1-v} \quad 0 \leq v \leq 1, \quad (29)$$

where y_t^* is real foreign output, which is taken as exogenous². Inertia in foreign demand is represented by the term $(c_{t-1}^{h*})^{1-\nu}$

2.2.3 Retailers

We assume that entrepreneurs sell all their output to retailers. Retailers then sell differentiated output goods to households, capital producers, and the government sector. Given that their output is differentiated, retailers have the monopolistic power to set prices of these final output goods. Following Calvo (1983), we assume that only a fraction $(1 - \phi)$ of sellers are allowed to change their prices. In particular, If the firm cannot set an optimal price, then it evolves according to the non-optimal rule $p_{t+1}^h(j) = p_t^h(j) (1 + \pi_t^h)^{\gamma_{p^h}} (1 + \pi)^{1-\gamma_{p^h}}$ where $\gamma_{p^h} \in [0, 1]$ is the price indexation degree to past inflation and π is the CPI average inflation³, and $\pi_t^h = \frac{p_t^h}{p_{t-1}^h}$. This rule implies that if the firm is not allowed to reset prices during l periods, then $p_{t+l}^h(j) = p_t^h(j) \prod_{i=1}^l (1 + \pi_{t-1+i}^h)^{\gamma_{p^h}} (1 + \pi)^{l(1-\gamma_{p^h})}$.

The problem of the firm j is to pick $p_t^h(j)$ to maximize the discounted sum of expected profits when the firm adjust prices once:

$$\max_{p_{jt}^h} E_t \sum_{l=0}^{\infty} (\beta\phi)^l \frac{\lambda_{t+l} \Omega_{t+l}(j)}{p_{t+l}^h}$$

subject to the demand function for variety j ⁴

²the exogenous variables T_t^* , p_t^{f*} , R_t^* and y_t^* are also assumed to be AR(1) processes

³Non-optimizing firms adjust the price with a composite inflation: they assign a weight of γ_{p^h} to past-period inflation rate, and a weight of $1 - \gamma_{p^h}$ to the average (steady state) inflation rate. If $\gamma_{p^h} = 1$ there is full price indexation. If $\gamma_{p^h} = 0$ there is no indexation at all.

⁴In the monopolistic competition framework of Dixit and Stiglitz (1977) this demand function is derived as the composite of individual final output (retail) goods and the corresponding price index as follows

$$y_{t+l}^h = \left(\int_0^1 y_{t+l}^h(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}$$

$$y_t^h(j) = \left(\frac{p_t^h(j)}{p_t^h} \right)^{-\theta} y_t^h \quad (30)$$

where

$$\Omega_{t+l}(j) = \left(p_t^h(j) \prod_{i=1}^l (1 + \pi_{t-1+i}^h)^{\gamma_{p^h}} (1 + \pi)^{l(1-\gamma_{p^h})} - \xi_{t+l}^h \right) y_{t+l}^h(j)$$

The optimal price, \tilde{p}_t^h , is characterized by:

$$\frac{\tilde{p}_t^h}{p_t^h} = \frac{\theta}{\theta - 1} \frac{E_t \sum_{l=0}^{\infty} (\beta\phi)^l \lambda_{t+l} \xi_{t+l}^h \prod_{i=1}^l \left\{ (1 + \pi_{t+i}^h)^\theta (1 + \pi_{t-1+i}^h)^{-\theta\gamma_{p^h}} \right\} (1 + \pi)^{-\theta l(1-\gamma_{p^h})} y_{t+l}^h}{E_t \sum_{l=0}^{\infty} (\beta\phi)^l \lambda_{t+l} \prod_{i=1}^l \left\{ (1 + \pi_{t+i}^h)^{\theta-1} (1 + \pi_{t-1+i}^h)^{(1-\theta)\gamma_{p^h}} \right\} (1 + \pi)^{(1-\theta)l(1-\gamma_{p^h})} y_{t+l}^h}$$

Because the probability of adjusting prices is independent across firms, a fraction $1 - \phi$ of all the firms adjust each period.

$$\text{Then } p_t^h = \left[(1 - \phi) (\tilde{p}_t^h)^{1-\theta} + \phi [p_{t-1}^h (1 + \pi_{t-1}^h)^{\gamma_{p^h}} (1 + \pi)^{1-\gamma_{p^h}}]^{1-\theta} \right]^{\frac{1}{1-\theta}}.$$

After some algebra we arrive to the neo-keynesian hybrid Phillips curve

$$\hat{\pi}_t^h = \frac{\beta}{1 + \beta\gamma_{p^h}} \hat{\pi}_{t+1}^h + \frac{\gamma_{p^h}}{1 + \beta\gamma_{p^h}} \hat{\pi}_{t-1}^h + \frac{(1 - \beta\phi)(1 - \phi)}{\phi(1 + \beta\gamma_{p^h})} \hat{\xi}_t^h \quad (31)$$

where variables with hats are log deviations from steady-state values.

Owing to imperfect competition, foreign goods sold in the local economy are subject to an analogous mark-up over the wholesale price. According with equation (28) retailers of foreign goods face the marginal cost $p_{w,t}^f$ and set prices according to a Calvo-style price setting equation. The inflation rate for foreign goods then satisfies

$$p_{t+l}^h = \left(\int_0^1 p_{t+l}^h(j)^{1-\theta} dj \right)^{\frac{1}{1-\theta}}$$

where $y_{t+l}^h(j)$ and $p_{t+l}^h(j)$ are the demand and price faced by each individual retailer j , respectively.

$$\hat{\pi}_t^f = \frac{\beta}{1 + \beta\gamma_{pf}} \hat{\pi}_{t+1}^f + \frac{\gamma_{pf}}{1 + \beta\gamma_{pf}} \hat{\pi}_{t-1}^f + \frac{(1 - \beta\phi^f)(1 - \phi^f)}{\phi(1 + \beta\gamma_{pf})} \hat{\xi}_t^f \quad (32)$$

where $\pi_t^f = \frac{p_t^f}{p_{t-1}^f}$, the corresponding real marginal cost is $\xi_t^f = \frac{s_t p_t^{f*}}{p_t^f}$ and $(1 - \phi^f)$ denotes the probability that a retailer of foreign goods resets its price in any given period. We assume that retailers of domestic and foreign goods face the same degree of price rigidity, so that $\phi^f = \phi$

Finally, CPI inflation may be expressed as

$$\hat{\pi}_t = (\hat{\pi}_t^h)^\nu (\hat{\pi}_t^f)^{1-\nu} \quad (33)$$

2.2.4 Monetary policy rule

To close the model we assume, following Ireland (2003), that the central bank conducts monetary policy by adjusting a linear combination of the short-term nominal interest rate, R_t^n , and the money growth rate, $\mu_t = M_t/M_{t-1}$, in response to deviations of output, y_t , and inflation, π_t , from their steady-state values. Thus reaction function of the monetary authority is

$$\frac{R_t^n}{R^n} = \left(\frac{\pi_t}{\pi}\right)^{\rho_\pi} \left(\frac{y_t}{y}\right)^{\rho_y} \left(\frac{\mu_t}{\mu}\right)^{\rho_\mu} \exp(\varepsilon_{R_t^n}) \quad (34)$$

where ε_{R_t} is the monetary policy shock.

3 Bayesian Estimation

In order to test for of a financial accelerator mechanism in Colombia, we estimate and compare two versions of the model. The first model is estimated assuming that there

exists a financial accelerator mechanism (FA model). The second, is a constrained version of the model without financial rigidities, $\psi = 0$, that collapses to a standard DNK model. In addition, for Colombia, only about 35% of debt during the sample period was in units of foreign currency. For this reason, in our baseline exercises we have assumed that entrepreneur's debt was in domestic currency units⁵

The log-linearized version of the model form a linear rational expectation system. The solution takes the form of a state-space model, driven by the ten exogenous shocks $e_t, b_t, x_t, A_t, \varepsilon_{Rt}, R_t^*, p_t^{f*}, y_t^*, T_t^*$ and φ_t . The structural parameters can be estimated by a Bayesian procedure using data on six variables: Consumption, investment, money real balances, the short-term nominal interest rate, inflation and net exports.

3.1 Methodology

We apply Bayesian techniques for several reasons. First, from a practical point of view, the use of prior distributions over the structural parameters makes the highly non-linear optimization algorithm more stable. This is particularly valuable when only relatively small samples of data are available, as is the case with Colombian time series. Second, the Bayesian approach has the advantage of facilitating comparison of models that are non-nested and taking explicit account of all uncertainty surrounding parameter estimates. Third, the Bayesian approach allows us to formalize prior information coming from previous studies, and, in this way, creates a link with the previous calibration-based

⁵If debt is denominated in foreign currency, the entrepreneurial net wealth and the external finance premium equations are modified as follows:

$$n_{t+1} = f_t q_{t-1} k_t - \left[R_t S(\cdot) \varphi_{t-1} R_{t-1}^* \frac{s_t}{s_{t-1}} \frac{p_{t-1}}{p_t} \right] \frac{s_{t-1} B_t^*}{p_{t-1}} \quad (35)$$

and

$$E_t f_{t+1} = S(\cdot) E_t \left[\varphi_t R_t^* \frac{s_{t+1}}{s_t} \frac{p_t}{p_{t+1}} \right] \quad (36)$$

literature. Finally, the potential under-identification problems, which could emerge in DSGE models, can be reduced by the use of informative priors using a Bayesian strategy, as in Canova (2007)

This empirical approach involves obtaining the posterior distribution of the model's parameters based on its log-linear state-space representation. The posterior distribution is obtained by the combination of the likelihood function for the observed data (obtained from the help of a Kalman filter) with the selected prior distributions for each of the parameters of the model. If conjugacy is obtained by this combination, then the posterior can then be analytically optimized with respect to the model parameters directly, otherwise, computational tools, like Monte-Carlo Markov-Chain (MCMC) sampling, should be used.

Formally, defining Θ as the parameter space, we wish to estimate the model parameters, denoted by $\theta \in \Theta$. Given a prior $p(\theta)$, the posterior density of the model parameters, θ , is given by

$$p(\theta | Y^T) = \frac{L(\theta|Y^T)p(\theta)}{\int L(\theta|Y^T)p(\theta)d\theta} \quad (37)$$

where $L(\theta|Y^T)$ is the likelihood conditional on observed data, Y^T . The likelihood function is computed under the assumption of Gaussian distributed disturbances by combining the state-space representation implied by the solution of the linear rational expectations model and the Kalman filter.

The posterior distribution is typically characterized by measures of central location, such as the mode or the mean, and measures of dispersion, such as the standard deviation, or as the highest posterior density (HPD).

Having applied this procedure to both models, the DSGE models are compared in their ability to fit the data. Suppose we have two competing models, A and B, whose

prior distribution are $p(A)$ and $p(B)$, respectively. Model comparisons are based on the ratio of the posterior model densities, known as the Posterior Odds ratio:

$$\frac{p(A|Y^T)}{p(B|Y^T)} = \frac{p(A)p(Y^T|A)}{p(B)p(Y^T|B)} \quad (38)$$

where $p(Y^T|A)$ and $p(Y^T|B)$ are the marginal densities of the data conditional on the model A or B , respectively. When competing models are assigned equal prior probabilities, so that $p(A) = p(B)$, posterior odds are equivalent to the ratio of the marginal likelihoods. In this paper, we estimate these marginal densities using the Laplace approximation ⁶. As the value of the Posterior Odds ratio is higher than 1, the data information alters the prior odds in favor of A, or against A when it is lower than 1.

3.2 Data

We estimate the models using quarterly data on consumption, inflation, interest rates, real money balances, investment and net exports for the period 1980:1-2005:4. All of these variables are measured as deviations from trend obtained using a Hodrick-Prescott filter with a smoothing parameter of 1600. Data on both consumption and investment are used, rather than data on output alone, as this help to identify the capital adjustment cost and capital share parameters. Consumption is measured by real personal consumption expenditures, while investment is measured by real gross private investment. We calculate real money balances by dividing the M1 money stock by the GDP deflator and inflation is measured as changes in the GDP deflator. Finally, the short-term nominal interest rate is measured by the 90-day deposit rate. Consumption,

⁶Laplace approximation is the logarithm of the posterior density. Second order approximations are used to obtain posterior moments, instead of modal or first order approximation, see Carlin and Louis (1998)

investment, net exports and real money balances are all expressed in per-capita terms.

3.3 Calibration and Priors

Before estimating the models it is necessary to calibrate several parameters in the model that remain unidentified even with data on six variables. Some are set to match key steady-state ratios. The parameter, η , that measures the weight of leisure in the representative household's utility function, cannot be estimated without data on employment, Ireland (2003). The calibrating value $\eta = 1.315$ implies that in steady-state households spend about one third of their time working. The parameter, θ , determining the steady-state markup of price over marginal cost, cannot be estimated without data on wages; the calibrating of $\theta = 6$ implies a steady-state markup of 20 percent, a common value used in the literature. The constant associated with money demand, b , is set to 0.052 to ensure that the steady-state ratio of real balances to consumption is close to its historical value. We set the steady-state leverage ratio equal to 0.26, according to its empirical counterpart over our estimation sample. The discount factor, β , is set equal to 0.99 and the depreciation rate, δ , is set at 0.025. The parameter ρ that measures consumption intra-temporal elasticity of substitution is set equal to 1. The elasticity of exports demand, τ was calibrated in 0.75. The weight of inertia in export demand $(1 - \nu)$ is set equal to 0.75. The elasticity of country risk premium with respect to net foreign debt, ϱ , is set equal to 0.003. Finally, the price indexation degree parameters, γ_{ph} and γ_{pf} are set equal to 0.5.

We estimate the remaining 27 parameters in the model. Table 1 summarizes our assumptions regarding the prior distributions. Those structural parameters that are only bounded from below are modeled using a gamma distribution. In particular, for the elasticity of money demand with respect to interest rate, γ , we assume a gamma

distribution with mean 0.14. The adjustment cost parameter, χ , also follows a gamma distribution with mean 0.5 with standard deviation of 1. Therefore this coefficient can vary in a 90% confidence interval between 0.089 and 3.841. This is a wide range that intends to account for the uncertainty that we have about this parameter. The prior for the elasticity of the external finance premium with respect to firm leverage, ψ , follows a gamma distribution with mean 0.14 and standard deviation of 1.

The probability that prices remain unchanged for the next period, ϕ , follows a beta distribution with a mean of 0.5, a common value in the literature. The capital share, α , also follows a beta distribution with mean 0.5. In this case α can vary in a range that contains the value of 0.4 from previous evidence presented by GRECO (1999).

The prior distribution for the parameters in the interest rate rule are modeled as normal distributions in order to allow for a more general policy rule as in Ireland (2003). The prior mean for the inflation feedback coefficient in the policy rule, ρ_π , is set to 1.4 based on previous work by Bernal (2002). For the other two parameters in the policy rule, ρ_y and ρ_μ , the prior mean was set to 0.6, with standard deviation of 0.1 and 0.3, respectively. The autoregressive parameters of the stochastic shocks should lie in the (0,1) interval range, and therefore are modeled using beta distributions. Finally, the prior distribution for the standard deviation of the structural shocks follow an inverse gamma distributions.

4 Estimation Results

The posterior means and the 5 and 95 percentiles of the posterior distribution of the parameters are calculated from the output of the Metropolis algorithm and summarized

Table 1: Prior distribution for the parameters of the models

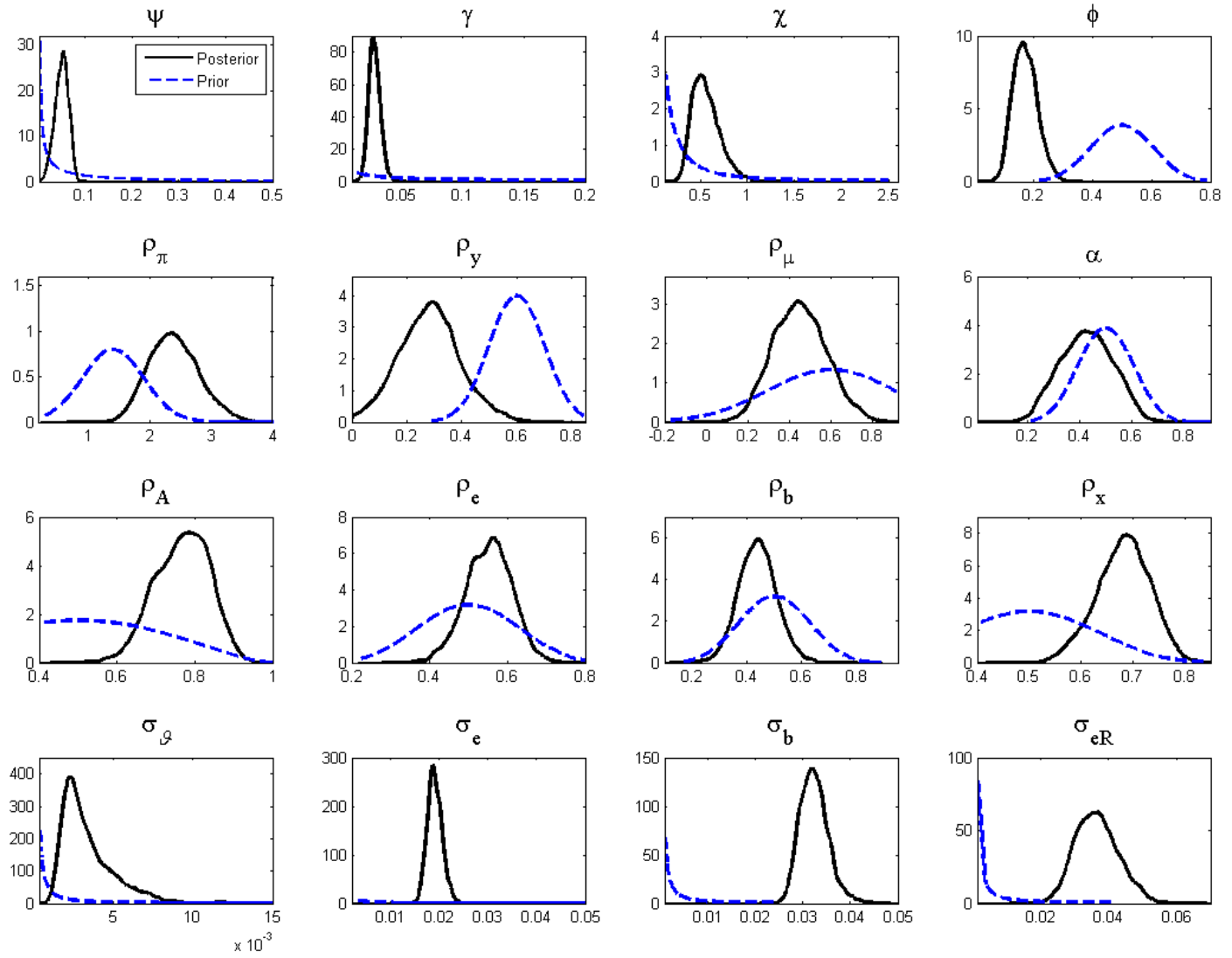
Name	Range	Density	Mean/Mode	Std/df	90% Interval	
ψ	$[0, \infty)$	Gamma	0.100	0.500	0.023	0.221
γ	$[0, \infty)$	Gamma	0.140	1.000	0.066	0.236
χ	$[0, \infty)$	Gamma	0.500	1.000	0.335	0.665
ϕ	$[0, 1]$	Beta	0.500	0.100	0.335	0.665
ρ_π	\mathbb{R}	Gaussian	1.400	0.500	0.804	1.996
ρ_y	\mathbb{R}	Gaussian	0.600	0.100	0.424	0.776
ρ_μ	\mathbb{R}	Gaussian	0.600	0.300	0.447	0.753
α	$[0, 1)$	Beta	0.500	0.100	0.335	0.665
ρ_a	$[0, 1]$	Beta	0.500	0.200	0.172	0.828
ρ_b	$[0, 1]$	Beta	0.500	0.120	0.302	0.698
ρ_e	$[0, 1]$	Beta	0.500	0.120	0.302	0.698
ρ_x	$[0, 1]$	Beta	0.500	0.120	0.302	0.698
ρ_{y^*}	$[0, 1]$	Beta	0.500	0.250	0.097	0.903
ρ_{pf^*}	$[0, 1]$	Beta	0.500	0.250	0.097	0.903
ρ_{T^*}	$[0, 1]$	Beta	0.500	0.250	0.097	0.903
σ_A	$[0, \infty)$	Inv. Gamma	0.003	2.000	0.001	0.017
σ_e	$[0, \infty)$	Inv. Gamma	0.018	2.000	0.001	0.017
σ_b	$[0, \infty)$	Inv. Gamma	0.030	2.000	0.002	0.028
σ_x	$[0, \infty)$	Inv. Gamma	0.033	2.000	0.013	0.169
σ_{e_R}	$[0, \infty)$	Inv. Gamma	0.027	2.000	0.003	0.042
σ_{pf^*}	$[0, \infty)$	Inv. Gamma	0.067	2.000	0.001	0.017
σ_φ	$[0, \infty)$	Inv. Gamma	0.003	2.000	0.001	0.017
σ_{y^*}	$[0, \infty)$	Inv. Gamma	0.089	2.000	0.001	0.017
σ_{T^*}	$[0, \infty)$	Inv. Gamma	0.003	2.000	0.001	0.017

The mode and the degrees of freedom for the inverse gamma are presented.

in table 2.⁷ The plots of the prior and posterior densities are presented in Figure 1 which give an indication of how informative the observed data are about the structural parameters. Overall, it appears that the data are quite informative on the behavioral parameters, as indicated by the lower variance of the posterior distribution relative to the prior distribution. Two exceptions are the output response in the interest-rate rule and the capital's share in the production function.

⁷The results are based on a total of 100000 draws and four independent chains. Brooks and Gelman (1998) convergence criteria are achieved.

Figure 1: Priors and Posteriors densities



The central question of interest for the empirical analysis is whether the financial accelerator mechanism helps in fitting the data. First we present the parameter estimates and the Posterior Odds test to compare the models with (FA) and without (NoFA) financial accelerator mechanism. Next, we present some impulse response implied by the models in order to illustrate the different model dynamics implied by the financial accelerator.

4.1 Estimates and Test

The main result is that the posterior mean of the elasticity of the external finance premium with respect to leverage, ψ , is statistically higher than zero and equal to 0.050, see Table 2. This estimate turns out to be similar to the value calibrated by Bernanke and Gertler (2000).

Other estimates are plausible, for both models the posterior mean of the constant elasticity of substitution between consumption and real balances, γ , is about 0.02 which is similar to the value estimated for the US by Ireland (2003). On the other hand, conditional on the FA model the posterior mean of the capital adjustment cost parameter, χ , is 0.56 while under the NoFA model the posterior mean estimate is 0.23. These estimates are similar to the 0.25 value used by BGG. Capital adjustment costs have an important interaction with the financial accelerator mechanism. If capital adjustment cost are high, the price of capital will respond to shocks to a greater extent. The price of capital has a direct effect on the net worth of firms and the cost of external financing, as in Dib and Christensen (2006). The higher capital adjustment cost in the FA model suggest that the FA mechanism may be helping to generate investment volatility.

The estimates of the Calvo probability of not resetting optimally prices are 0.17 in the FA model and 0.19 in the NoFA model. This implies an expected price duration

of about 1.2 quarters, a result that is in line with Julio and Zárate (2007). For both models the posterior mean of the capital share parameter, α , is about 0.4, somewhat higher than the value that is often used in calibration exercises.

In both models the estimates for the policy rule coefficients, ρ_π , ρ_y , and ρ_μ , indicate that the central bank of Colombia has responded much more strongly to inflation deviations than to output or to money-growth fluctuations.

Finally, we use the Bayesian Posterior Odds ratio (equation(38)) to compare the models in their ability to fit the data. The prior probabilities for each model are assumed equal to 1/2. Therefore the odds ratio test is the ratio of the marginal density of the data. The approximations of the log data densities of each model is presented in the last row of Table 2. The posterior odds of FA model versus NoFA model are roughly 1 to 34 and thus strongly favors the FA model⁸.

4.2 Variance decompositions

Table 3 shows the forecast-error decomposition of the detrended output, consumption, investment, money growth, inflation, and the nominal interest rate attributed to each of the ten shocks (external shocks are aggregated). In both models productivity shocks account for a high percentage of the variance of all of the variables except inflation. In the FA model, both investment efficiency shocks and monetary policy shocks account for a large part of investment fluctuations, together they account for more than 50 percent of the forecast error variance of investment. On the other hand, in the FA model, the percentage of the variance of output explained by the policy shock is 17.8 percent. This means that monetary policy shocks have played an important role in driving business cycles in Colombia. The FA model increases the role of this shock

⁸The posterior odds ratio is obtained as the exponential of the difference of the Laplace approximations.

Table 2: Posterior distribution for the structural parameters

Parameter	FA model			NoFA model		
	Mean	5%	95%	Mean	5%	95%
ψ	0.050	0.027	0.073			
γ	0.028	0.021	0.036	0.020	0.011	0.034
χ	0.5647	0.328	0.767	0.234	0.172	0.281
ϕ	0.169	0.104	0.235	0.194	0.111	0.271
ρ_π	2.408	1.738	3.060	1.159	0.905	1.213
ρ_y	0.292	0.093	0.462	-0.051	-0.079	-0.028
ρ_μ	0.448	0.242	0.655	0.075	0.002	0.174
α	0.438	0.258	0.580	0.654	0.533	0.768
ρ_a	0.763	0.655	0.877	0.838	0.767	0.889
ρ_b	0.432	0.318	0.551	0.455	0.327	0.564
ρ_e	0.546	0.459	0.648	0.610	0.510	0.726
ρ_x	0.677	0.596	0.766	0.693	0.597	0.803
ρ_{y^*}	0.485	0.112	0.892	0.488	0.086	0.857
$\rho_{p^f^*}$	0.572	0.123	0.923	0.510	0.141	0.928
ρ_{T^*}	0.497	0.088	0.895	0.510	0.087	0.891
σ_A	0.026	0.016	0.036	0.052	0.031	0.072
σ_e	0.019	0.017	0.021	0.014	0.012	0.016
σ_b	0.032	0.027	0.037	0.030	0.027	0.035
σ_x	0.046	0.023	0.067	0.013	0.010	0.015
σ_{e_R}	0.037	0.026	0.047	0.018	0.015	0.020
$\sigma_{p^f^*}$	0.009	0.001	0.006	0.005	0.002	0.009
σ_φ^*	0.004	0.001	0.006	0.004	0.001	0.007
σ_{y^*}	0.005	0.002	0.010	0.004	0.002	0.009
σ_{T^*}	0.004	0.001	0.007	0.004	0.002	0.007
Laplace Approx.	1302.329			1298.8		
Posterior Odds(FA/NoFA)				34.090		

because it introduces a direct transmission mechanism from monetary policy that is missing in the NoFA model.

The variance decomposition also show that in the FA model the preference shocks, productivity shocks and the foreign shocks are the main driver of consumption while in the NoFA model the main driver force are the productivity shocks and foreign shocks. It is quite clear that in both models monetary policy shocks are the most important drivers of inflation.

Table 3: Variance decompositions
With Financial Accelerator

Variable	Preference Shock e_t	Money Demand Shock b_t	Investment Efficiency Shock x_t	Productivity Shock A_t	Monetary Policy Shock eR_t	Foreign Shocks
Output	3.0	0.7	6.5	70.9	17.8	1.2
Consumption	29.5	0.2	10.3	31.2	6.0	22.8
Investment	3.0	0.9	47.5	20.9	27.0	0.7
Money	1.4	21.8	12.6	51.3	6.3	6.6
Inflation	0.4	4.5	3.4	20.4	70.9	0.4
Interest rate	17.9	10.0	13.2	52.5	5.0	1.4

Without Financial Accelerator

Variable	Preference Shock e_t	Money Demand Shock b_t	Investment Efficiency Shock x_t	Productivity Shock A_t	Monetary Policy Shock eR_t	Foreign Shocks
Output	0.5	0.0	3.2	95.7	0.3	0.3
Consumption	14.2	0.0	4.2	52.3	0.3	29.0
Investment	3.3	0.0	17.3	76.8	0.7	1.9
Money	0.1	41.5	28.0	25.2	1.8	3.4
Inflation	4.7	1.2	14.8	10.3	61.5	7.5
Interest rate	14.4	4.3	36.6	20.4	1.4	23.0

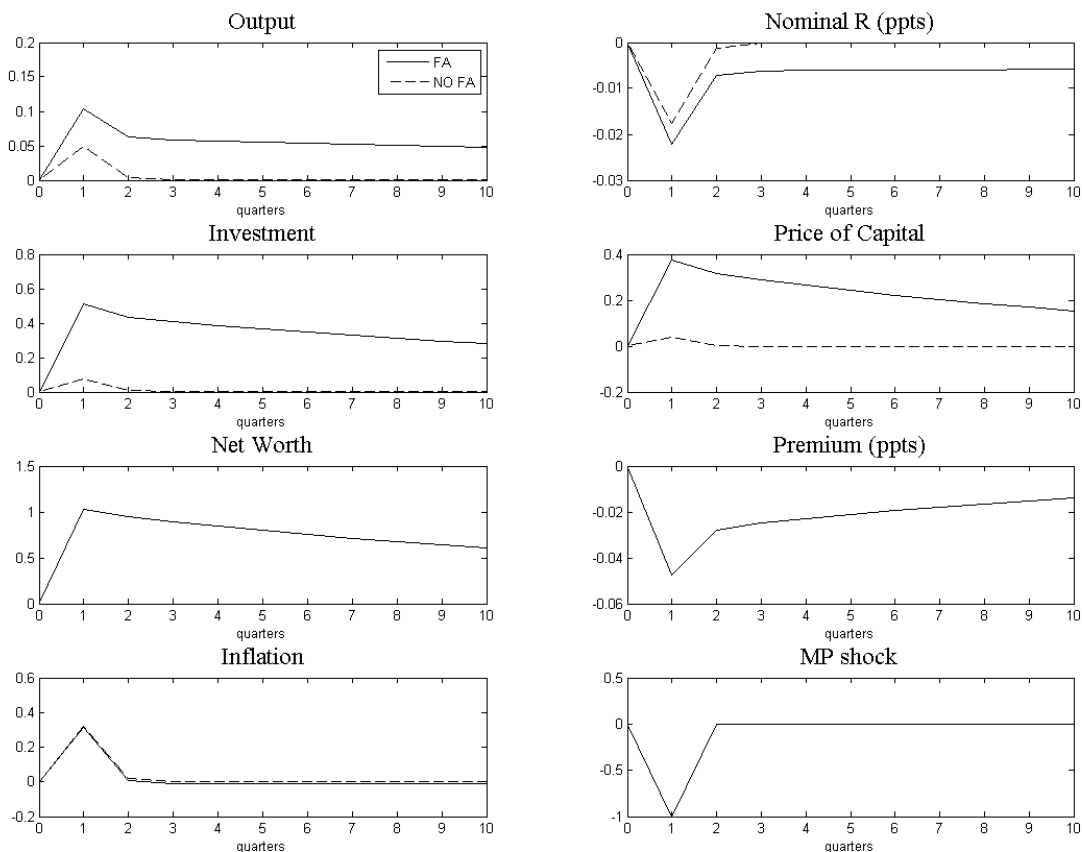
4.3 Impulse responses

4.3.1 With and without financial accelerator

Previously we have established that the parameter capturing the financial accelerator mechanism had a positive posterior mean. How important could that be? We now examine the responses of the whole model to the effects of an expansionary monetary policy shock. Figure 2 shows the impulse responses with and without the financial accelerator. In each figure the dashed line designates the "baseline" impulse response which are from a model with the same steady state as the complete model with imperfect credit markets, but in which the additional dynamics associated with the financial accelerator have been "turned off". The solid line correspond to the model that includes the financial accelerator mechanism. In response to a monetary policy shock of a 100 basis points, the addition of credit-market frictions does not substantially affect the behavior of the nominal interest rate. But its impact is important in real variables. In particular, the response of real output is twice as strong with the financial accelerator included than without it and the response of investment is increased fivefold.

The mechanism is as in BGG: The unanticipated decline in the policy rate stimulates the demand for capital, which in turn raises investment and the price of capital. The increase in asset prices raises net worth, forcing down the finance premium, which further stimulates investment. This mechanism introduces output persistence and amplifies the response of macroeconomic variables to the monetary policy shock given that it takes into account the evolution of net worth. Entrepreneurial net worth reverts to trend as firms leave the market, but the effect is slow enough to make the external finance premium persist below trend.

Figure 2: Responses to a monetary policy shock: with and without Financial Accelerator



4.3.2 Exchange Rate Regimes

Here we consider the model's response to a country risk premium shock under two scenarios: (i) a pure fixed exchange rate regime and (ii) a floating exchange rate regime, where the monetary authority follows a Taylor rule like the one presented in equation (34). Countries in the position of having to defend an exchange rate peg were more likely to have suffered severe financial distress, Gertler et al. (2007). Then, we evaluate whether the model is able to replicate a financial crisis like the one occurred in Colombia

in 1998-1999.

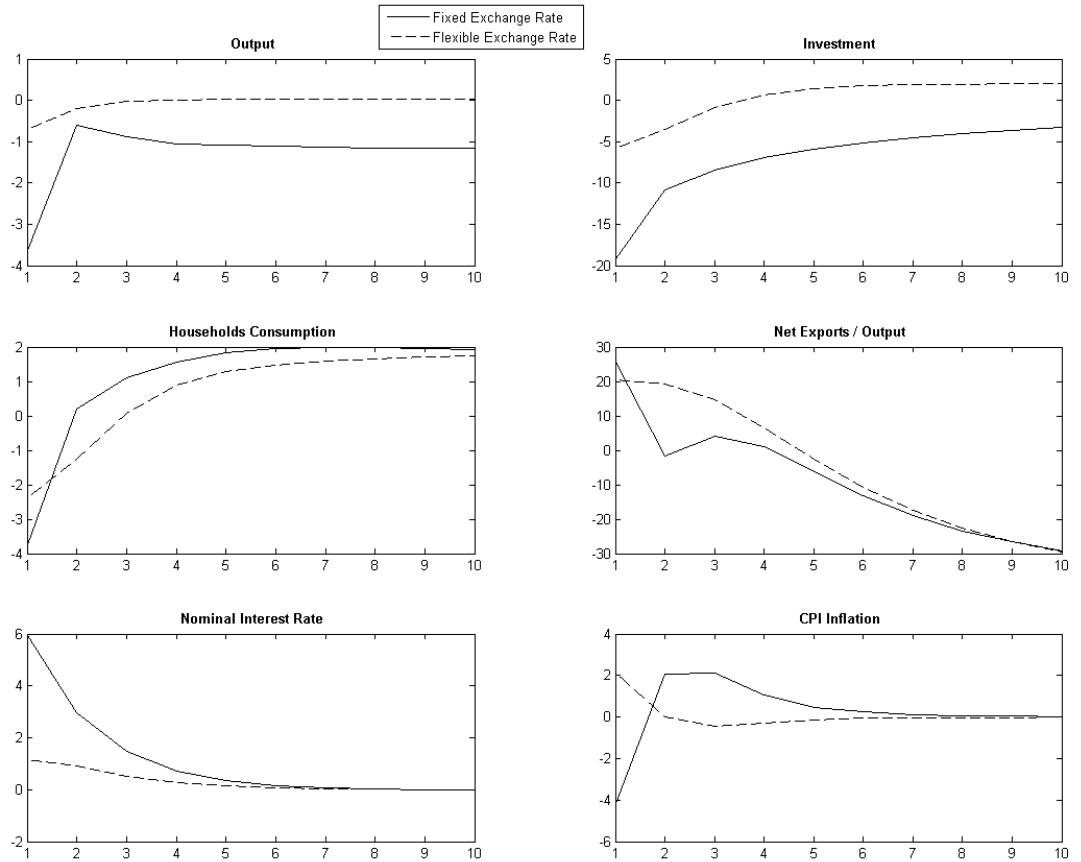
We consider a 600 basis point increase in the country borrowing premium, φ , similar to the increase observed in the EMBI Latin America in Colombia during the financial crisis. We assume a first-order autoregressive process with a 0.5 coefficient. The results are presented in figure 3.

Before 1998, Colombia was in a managed float with a band 7% wide. When the episode started, the monetary authority tried to fix the exchange rate. Under such regime, after the increase in the country borrowing premium, the domestic nominal interest rate rises sharply. Real interest rates also rise which, in turn, induces a contraction in output. The financial accelerator mechanism exacerbates the fall in output - the rise in the interest rates causes a contraction in asset prices which induces a fall in net worth and an increase in leverage ratios that increases the external finance premium. As a result of the latter, investment and output fall even further. Monetary authorities abandoned the peg as the crisis unfolded.

Overall, the model captures the key outcomes of the Colombian experience. The decrease in output is 4.2% while the model predicts a fall of 3.7%. Consumption dropped in about 5.5% compared with nearly 4.0% in the model. In the Colombian data, the drop in real investment is 34% and in the model is 20%. The data and the model imply a large reduction in imports which drives the expansion in net exports.

As figure 3 illustrates, the crises might have been less severe under a credible flexible exchange rate regime. Because the nominal interest rate is no longer tied to the foreign interest rate but follows the Taylor's rule, the increase in the country risk premium produces a depreciation of domestic currency which acts as a shock absorber. The depreciation of currency produces an increase in exports and CPI inflation. The nominal interest rate raises to fight inflation but its increase is lower than in the case of a fixed exchange rate regime. The fall in investment and output is moderate.

Figure 3: Responses to a country risk premium shock



5 Final Remarks

This paper estimates a small open economy dynamic general equilibrium model with credit-market imperfections for the Colombian economy. The estimation results support the existence of a financial accelerator mechanism that was essential in creating the strong and persistent downturn in investment during the late 1990s.

We use a Bayesian procedure to compare two versions of the model: one with and one without the financial accelerator. The estimated value of the key parameter in the

accelerator mechanism, the elasticity of the external finance premium with respect to firm leverage, is statistically significant. A posterior-odds test finds an improvement in the model's fit with the data when the financial accelerator is present. According to the variance decompositions, a monetary policy shock is able to explain about 18% of the business cycle in Colombia.

This paper does not claim that financial accelerator effects were the single determinant of investment in the 1998-1999 recession, but rather that financial frictions helped to magnify the effect of other shocks. Impulse responses from the model are able to match the main facts faced by the Colombian economy during the 1998-1999 recession due to increases in interest rates: a large drop in output, investment, asset prices and net worth. Furthermore, it is likely that having to defend an exchange rate peg in the face of a strong increase in the foreign country premium, as the one observed during the 1998-1999 crisis, had exacerbated the crisis.

Of course, the estimated model remains stylized and should be further developed. In particular, some other nominal and real rigidities might be included in order capture more of the sources of the business cycle in Colombia.

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