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No. 481
2008

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BANCO DE LA REPÚBLICA COLOMBIA

Financial Accelerator Mechanism: Evidence for Colombia*

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Abstract

Colombia experienced a deep recession in 1999-2003. Growth slowed by 4.2%, and investment by 34.6%. Was the severity of the recession due to a financial accelerator mechanism à la Bernanke, Gertler, and Gilchrist (1999)? To answer this question, this paper estimates a dynamic stochastic general equilibrium model with credit-market imperfections for the Colombian economy using Bayesian methods. The results show that balance-sheet effects played an important role in explaining recent Colombian recession; the financial accelerator mechanism turns out to be quantitatively significant accounting for about 50 percent of the total reduction in output after a monetary policy tightening.

Key Words: DSGE modelling, Financial Accelerator, Bayesian Estimation.
JEL Clasification: C11, C15, E32, E44, E52.

Resumen

Durante 1999-2003 Colombia experimentó una profunda recesión. El producto cayó un 4.2% y la inversión cayó aún más, 34.6%. La severidad de la recesión puede ser explicada por un mecanismo de acelerador financiero como el desarrollado por Bernanke, Gertler y Gilchrist (1999)? Para responder esta pregunta, en

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*We would like to thank Lavan Mahadeva, Andrés González, Javier Gómez, Eduardo Sarmiento Gómez and Munir Jalil for comments on earlier drafts. The opinions expressed herein do not involve the Banco de la República or its Board of Directors; theses are the authors exclusive responsibility.

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con imperfecciones en el mercado de crédito para la economía colombiana utilizando métodos Bayesianos. El principal resultado es que los efectos de hoja de balance juegan un papel importante en la explicación del ciclo económico en Colombia.

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

1 Introduction

The Colombian economy has experienced a series of large fluctuations since 1980. The recession at the end of the 1990s was particularly long and severe; output fell 4.2% in 1999 and it took about 4 years to recover to its average growth rate. One of the explanations that has been put forward to explain why the recession was so severe was the poor state of the financial balance sheets of households and firms during the years previous to the crisis; see Chang and Velasco (1998). The beginnings of the 1990s were characterized by a boom in investment, output, and credit. During the years previous to the build up of the crisis, Colombian debt increased fourfold reflecting a greater confidence about future profitability and an easier access to credit following a financial and commercial liberalization. Property and equity prices increased during the spending spiral. But when they reversed during the recession, the financial positions of households and firms were suddenly exposed.

Fixed investment was especially volatile during the 1990s. Many macroeconomic models explaining investment assume perfect capital markets. Therefore, that the Modigliani-Miller theorem holds: financing decisions have no impact on real economic activity, and investment is determined by expected future business profitability and the cost of capital. However, many empirical studies suggest that financial factors such as balance sheet conditions also influence investment expenditures to some extent (Hall, 2001). Balance sheets models emphasize how companies will often prefer to use internal funds rather than external borrowing to finance investment because external borrowing is more costly than internal finance. External borrowing incorporates an external finance premium because external lenders cannot perfectly observe and/or control the risk involved in supplying funds to borrowers, a costly state verification problem, and therefore require compensation for expected losses. According to this view, credit market imperfections can amplify initial shocks to that economy. Changes in credit market conditions such as asset prices and debt burdens are not simply passive reflections of the real activity but explain the amplitude and duration of the business cycle.

In this paper we develop and estimate a model that takes into account financial market imperfections in order to quantify the importance of this channel in the propagation of shocks in the Colombian economy during the period 1980-2005. The model is based on Bernanke, Gertler and Gilchrist (1999) (BGG hereafter) and Dib and Christensen (2006). A micro financial contracting problem between firms (borrowers) and financial intermediaries (lenders) is set into a macroeconomic Dynamic New Keynesian framework (DNK) with sticky prices. The model distinguishes households and entrepreneurs in order to explicitly motivate lending and borrowing. In addition, there are retailers who set the final price of output goods, capital producers who transform output goods into capital goods, and a government which conducts monetary policy. The only source of economic fluctuations comes from unanticipated shocks: technology shocks, demand shocks (to preferences, investment and money demand shocks), 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. As noted by Fukunaga (2002), 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". Dib and Christensen (2006), on the other hand, introduce money in the utility function of households and estimate the model using investment data. This is important in this context, since we are interested in the interaction of the price of capital, financing cost, and investment. Dib and Christensen (2006) estimate the model by maximum-likelihood for the United States economy during the period 1979-2004, and find that there is evidence of a financial accelerator mechanism. We estimated the model for the Colombian economy using Bayesian methods for the period 1980-2005. The results show that balance-sheet effects also play an important role in explaining recent Colombian business cycles.

The rest of the paper is organized as follows. Section 2 briefly reviews what happened to real economic activity and financial conditions during recent recession in Colombia. Section 3 describes the model. Section 4 reports on our implementation of Bayesian inference methods. Section 5 presents the results on estimates. Section 6 concludes.

2 Investment and financial conditions during the Colombian business cycle

The depth and duration of Colombian recession of the late 1990s was not predicted by most economic analysts. In the search for explanations, the great weakness in financial conditions of households and firms was often identified as a likely exacerbating factor.

This is particularly true in the case of the behavior of investment. In this section we explore this hypothesis by reviewing historical evidence on real activity and financial conditions in recent recessions.

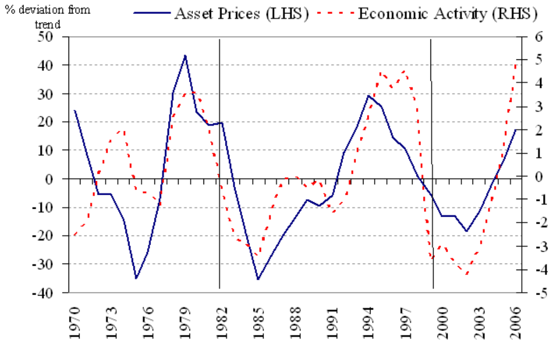
Figure 1 describes the behavior of real GDP during the last three decades. There has been two severe recessions, the first in 1982 and the second in 1999. These business cycles were accompanied by similar cycles in asset prices[1] which help to determine households and firm's financial conditions.

Interestingly, the performance of investment is somehow different in years previous to the two recessions. During the economic recession at the end of the 1990s, private investment fell unusually sharply in relation to previous recessions and to its standard explanatory factors (user cost and firm's profits). In the years before 1982, investment did not grow as much as it did during the 1990s, and also did not fall as much during the downturn, see Figure 2. The traditional explanation for this behavior of investment would be that the sharp fall in investment in the late 1990s reflected a particularly weak output growth or a high cost of capital. However as noted above, the variations in GDP were quite similar during the two recessions. It is not easy to measure the real cost of finance for Colombia but we can obtain some approximation based on the ratio of gross operating surplus relative to net financial liabilities which we plot in Figure 3. This measure suggests that during the years previous to the 1999 crisis, the cost of finance was lower than in the early 1980s. Therefore, the cost of finance was not the main explanation for weaker investment in the late 1990s.

[1] Asset prices correspond to a weighted average of equity prices and real estate prices

Figure 1

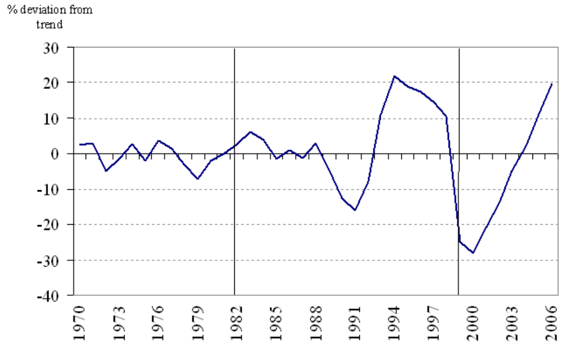
Asset prices and economic activity



Source: Banco de la República and DANE

Figure 2

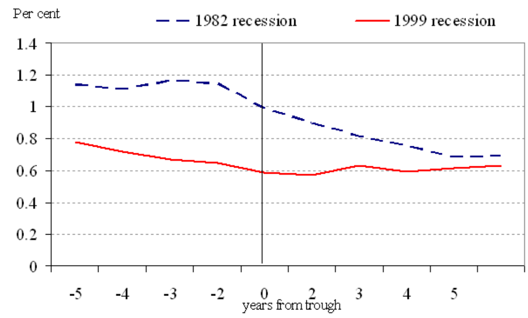
Investment



Source: DANE

Figure 3

Cost of finance

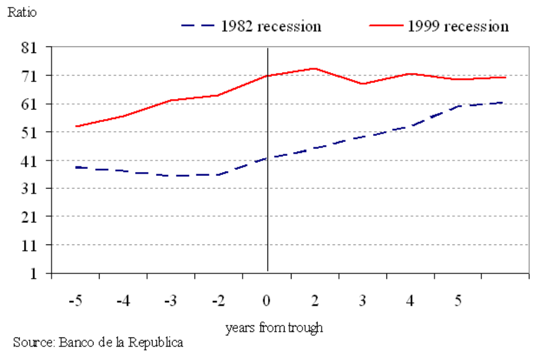


(a) Defined as gross operating surplus divided by financial liabilities

Source : Banco de la Republica

Figure 4

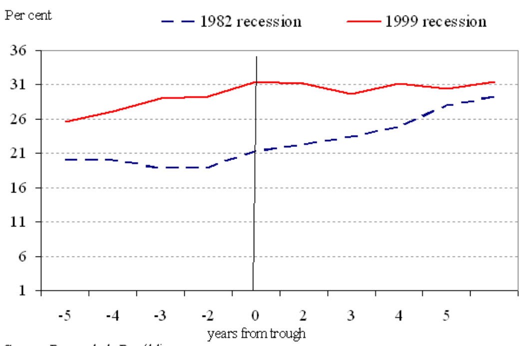
Debt to GDP ratio



Source: Banco de la Republica

Figure 5

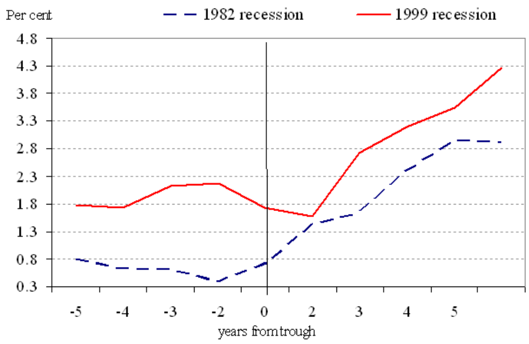
Debt to physical asset ratio



Source: Banco de la República

Figure 6

Income Gearing



Source: Banco de la Republica

Given that standard explanations of investment cannot fully explain the patterns over this period, could financial imperfections account for the unusual weakness of investment in the late 1990s compared with the early 1980s? Figure 4 reports the high level of debt that the economy was facing in the years previous to the 1999 recession. Credit was much higher during the 1990s than during the 1980s leaving the Colombian economy in a vulnerable position before the second recession. Confidence about future profitability and greater credit availability due to financial liberalization contributed to an increasing level of debt of households and firms, which made them the more vulnerable to interest rate changes. Another indicator of financial conditions that is worth noting is capital gearing, as measured by debt relative to physical capital. This also shows that balance sheet positions were less favorable in the years previous to the 1999 recession than in the years preceding 1982, see Figure 5. Similarly, interest payments were a greater burden on Colombian income entering the 1999 recession. Income gearing (interest payments as a share of income) was almost twice as high in the years previous to the 1999 recession than in the previous downturn (see Figure 6), reflecting both weaker income and greater indebtedness. The behavior of asset prices was not favorable either. Since 1996 they started to decline and that weakness persisted until 2003. This was true for both property and equity prices. These asset price reductions lowered the collateral available to back household and corporate borrowing.

In summary, the sharp slowdown in investment went hand in hand with a deterioration in the financial conditions of households and firms, higher interest payments on debts and abrupt falls in asset prices, specially when we compare the second recession to the first.

3 The Model

The model we estimate to quantify this hypothesis is based on BGG and Dib and Christensen (2006). A micro financial contracting problem between firms (borrowers) and financial intermediaries (lenders) is set into a macroeconomic dynamic New Keynesian framework with sticky prices. In a first stage we describe the financial accelerator mechanism developed by BGG.

3.1 Financial Accelerator Mechanism

The financial accelerator 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 and financial intermediaries providing external funds. 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.

3.1.1 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

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

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

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

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

$$r_{kt} = \alpha \xi_t \frac{y_t}{k_t} \tag{3}$$

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

where ξ_t is real marginal cost; w_t is the real wage; and r_{kt} is the real rental rate on capital. 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

$$E_t f_{t+1} = E_t \left[\frac{r_{kt+1} + (1-\delta) q_{t+1}}{q_t} \right] \tag{5}$$

where q_t is the relative price of a unit of capital which varies depending on the capital production technology. 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.

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 default. 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

$$E_t f_{t+1} = R_{t+1} S\left(\frac{n_t}{q_t k_t}\right) \qquad \text{with} \qquad S(1) = 1 \qquad S'(\cdot) < 0 \tag{6}$$

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

$$f_{t+1} - R_{t+1} = -\psi n_{t+1} + \psi k_{t+1} + \psi q_t \tag{7}$$

where ψ represents the elasticity of the external finance premium with respect to a change in the leverage position of entrepreneurs, $-\frac{S'(\cdot)}{S(\cdot)}(\frac{n_t}{q_t k_t})$. 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

$$n_{t+1} = f_t q_{t-1} k_t - R_t S\left(\frac{n_t}{q_{t-1}k_t}\right)(q_{t-1}k_t - n_t) \tag{8}$$

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. That 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).

3.1.2 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:

$$\max_{i_t} \left[q_t x_t i_t - i_t - \frac{\chi}{2} \left(\frac{i_t}{k_t} - \delta \right)^2 k_t \right] \tag{9}$$

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

$$q_t x_t - 1 - \chi \left(\frac{i_t}{k_t} - \delta \right) = 0 \tag{10}$$

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

$$k_{t+1} = x_t i_t + (1 - \delta) k_t \tag{11}$$

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

$$log(x_t) = \rho_x log(x_{t-1}) + \varepsilon_{x_t} \tag{12}$$

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.

3.2 The complete model

We now present a conventional dynamic New Keynesian framework that completes the economic model, adding both households and retailers. 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 goods. Retailers are introduced to motivate sticky prices and we follow Calvo (1983) in introducing price inertia.

3.2.1 Households

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

$$U\left(c_t, M_t/p_t, h_t\right) = \frac{\gamma e_t}{\gamma - 1} log \left\{ c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} \left(\frac{M_t}{p_t}\right)^{\frac{\gamma-1}{\gamma}} \right\} + \eta log(1 - h_t) \tag{13}$$

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

$$log(e_t) = \rho_e log(e_{t-1}) + \varepsilon_{e_t} \tag{14}$$

and

$$log(b_t) = (1 - \rho_b) log(b) + \rho_b log(b_{t-1}) + \varepsilon_{b_t} \tag{15}$$

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:

$$E_t\left(\sum_{k=0}^{\infty}\beta^k U\left(c_t, M_t/p_t, h_t\right)\right) \tag{16}$$

subject to budget constraint:

$$c_t + \frac{M_t}{p_t} + \frac{D_t}{p_t} \leq \frac{W_t h_t + R_{t-1}D_{t-1} + M_{t-1} + T_t + \Omega_t}{p_t} \tag{17}$$

where D_t represents the household's nominal deposits in a financial intermediary and W_t the nominal wage. The household receive a lump-sum transfer,T_t, from monetary authority, as well as dividend payments, Ω_t, from retailers.

Solving the household 's problem yields the first-order conditions

$$\frac{e_t c_t^{-\frac{1}{\gamma}}}{c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} m_t^{\frac{\gamma-1}{\gamma}}} = \lambda_t \tag{18}$$

$$\frac{e_t b_t^{\frac{1}{\gamma}} m_t^{-\frac{1}{\gamma}}}{c_t^{\frac{\gamma-1}{\gamma}} + b_t^{1/\gamma} m_t^{\frac{\gamma-1}{\gamma}}} = \lambda_t - \beta E_t\left(\frac{\lambda_{t+1}}{\pi_{t+1}}\right) \tag{19}$$

$$\frac{\eta}{1-h_t} = \lambda_t w_t \tag{20}$$

$$\frac{\lambda_t}{R_t} = \beta E_t\left(\frac{\lambda_{t+1}}{\pi_{t+1}}\right) \tag{21}$$

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

3.2.2 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 does not adjust its price between t and $t+l$ then the price it charges in $t+l$ is given by the price that was in effect in the preceding period indexed by steady-state gross rate of inflation, π. If the firm receives a signal to optimally adjust its price it will chooses prices $\tilde{p}_t(j)$ in order to maximizes its discounted expected real total profit over the intervals during which its price remains fixed:

$$\max_{\{\hat{p}_t(j)\}} E_0 \left[\sum_{l=0}^{\infty} (\beta\phi)^l \frac{\lambda_{t+l}\Omega_{t+l}(j)}{p_{t+l}} \right] \tag{22}$$

subject to the demand function for variety j [2]

$$y_t(j) = \left(\frac{\tilde{p}_t(j)}{p_t} \right)^{-\theta} y_t \tag{23}$$

where the retailer's nominal profit function is

$$\Omega_{t+l}(j) = \left(\pi\tilde{p}_t(j) - p_{t+l}\xi_{t+l} \right) y_{t+l}(j) \tag{24}$$

where ξ_t is the real marginal cost.

The first-order condition for $\tilde{p}_t(j)$ is

$$\tilde{p}_t(j) = \frac{\theta}{\theta-1} \frac{E_t \sum_{l=0}^{\infty} (\beta\phi)^l \lambda_{t+l} y_{t+l}(j) \xi_{t+l}}{E_t \sum_{l=0}^{\infty} (\beta\phi)^l \lambda_{t+l} y_{t+l}(j) \pi^l / p_{t+i}} \tag{25}$$

The aggregate price is

$$p_t^{1-\theta} = \phi(\pi p_{t-1})^{1-\theta} + (1-\phi)\tilde{p}_t^{1-\theta} \tag{26}$$

These equations lead to the New Keynesian Phillips curve:

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1-\beta\phi)(1-\phi)}{\phi} \hat{\xi}_t \tag{27}$$

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

[2] In 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

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

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

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

3.2.3 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

$$\frac{R_t^n}{R^n} = \left(\frac{\pi_t}{\pi}\right)^{\rho_\pi} \left(\frac{y_t}{y}\right)^{\rho_y} \left(\frac{\mu_t}{\mu}\right)^{\rho_\mu} exp(\varepsilon_{R_t^n}) \tag{28}$$

where ε_{R_t} is the monetary policy shock.

4 Bayesian Estimation

In order to 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.

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 five exogenous shocks e_t, b_t, x_t, A_t, and, ε_{Rt}. Therefore, the structural parameters can be estimated by a Bayesian procedure using data on as many as five variables[3]: consumption, investment, money real balances, the short-term nominal interest rate, and inflation.

4.1 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

[3]We use five observable variables for five exogenous shocks in order to avoid singularity problems, see Canova (2007)

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 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

$$p(\theta \mid Y^T) = \frac{L(\theta|Y^T)p(\theta)}{\int L(\theta|Y^T)p(\theta)d\theta} \tag{29}$$

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 of 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:

$$\frac{p(A|Y^T)}{p(B|Y^T)} = \frac{p(A)p(Y^T|A)}{p(B)p(Y^T|B)} \tag{30}$$

where $p(Y^T|A)$ and $p(Y^T|B)$ are the marginal density 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 [4]. 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.

4.2 Data

We estimate the models using quarterly data on consumption, inflation, interest rates, real money balances and investment 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, investment, and real money balances are all expressed in per-capita terms.

4.3 Calibration and Priors

Before estimating the models it is necessary to calibrate several parameters in the model that remain unidentified even with data on five 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

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

consumption is closed to its historical value. We set the steady-state leverage ratio equal to 0.26, according to its empirical counterpart over our estimation sample. Finally, the discount factor, β, is set equal to 0.99 and the depreciation rate, δ, is set at 0.025.

We estimate the remaining 17 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 an inverse gamma distribution. In particular, for the elasticity of money demand with respect to interest rate, γ, we assume an inverse gamma distribution with mode 0.032 and two degrees of freedom. The adjustment cost parameter, χ, also follows an inverse gamma distribution with mode 0.46 and four degrees of freedom. Therefore this coefficient can vary in a 90% confidence interval between 0.11 and 1.39. This is a wide range that intends to account for the uncertainty that we have about this parameter. For the capital share, α, the mode is set to 0.172 with two degrees of freedom. In this case α can vary in a range that contains the value of 0.4 from previous evidence presented by GRECO (1999).

The probability that prices remain unchanged for the next period, ϕ, follows an uniform distribution which implies a mean of 0.5, a common value in the literature. The prior for the elasticity of the external finance premium with respect to firm leverage, ψ, follows a normal distribution with mean 0.1 and standard deviation of 0.15. The prior mean for this parameter is set higher than the parameter estimate found by Dib and Christensen (2006) for the United States because balance sheet effects might be higher in emerging economies.

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, ρ_a, ρ_b, ρ_e, ρ_x 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 inverse gamma distributions.

Table 1: Prior distribution for the parameters of the models

Name	Range	Density	Mean/Mode	Std/df	90% Interval	
ψ	$\mathbb{R}$	Gaussian	0.100	0.150	-0.147	0.347
γ	$[0,\infty)$	Inv. Gamma	0.032	2.000	0.030	0.394
χ	$[0, \infty)$	Inv. Gamma	0.466	4.300	0.110	1.395
ϕ	$[0, 1]$	Uniform	0.500	0.063	0.050	0.950
ρ_π	$\mathcal{R}$	Gaussian	1.400	0.500	0.578	2.222
ρ_y	$\mathcal{R}$	Gaussian	0.600	0.100	0.436	0.764
ρ_μ	$\mathcal{R}$	Gaussian	0.600	0.300	0.107	1.093
α	$[0, \infty)$	Inv. Gamma	0.172	2.200	0.093	1.101
ρ_a	$(0, 1)$	Beta	0.500	0.120	0.302	0.698
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
σ_A	$[0, \infty)$	Inv. Gamma	0.013	2.000	0.001	0.017
σ_e	$[0, \infty)$	Inv. Gamma	0.020	2.000	0.001	0.017
σ_b	$[0, \infty)$	Inv. Gamma	0.033	2.000	0.002	0.028
σ_x	$[0, \infty)$	Inv. Gamma	0.032	2.000	0.013	0.169
σ_{e_R}	$[0, \infty)$	Inv. Gamma	0.031	2.000	0.003	0.042

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

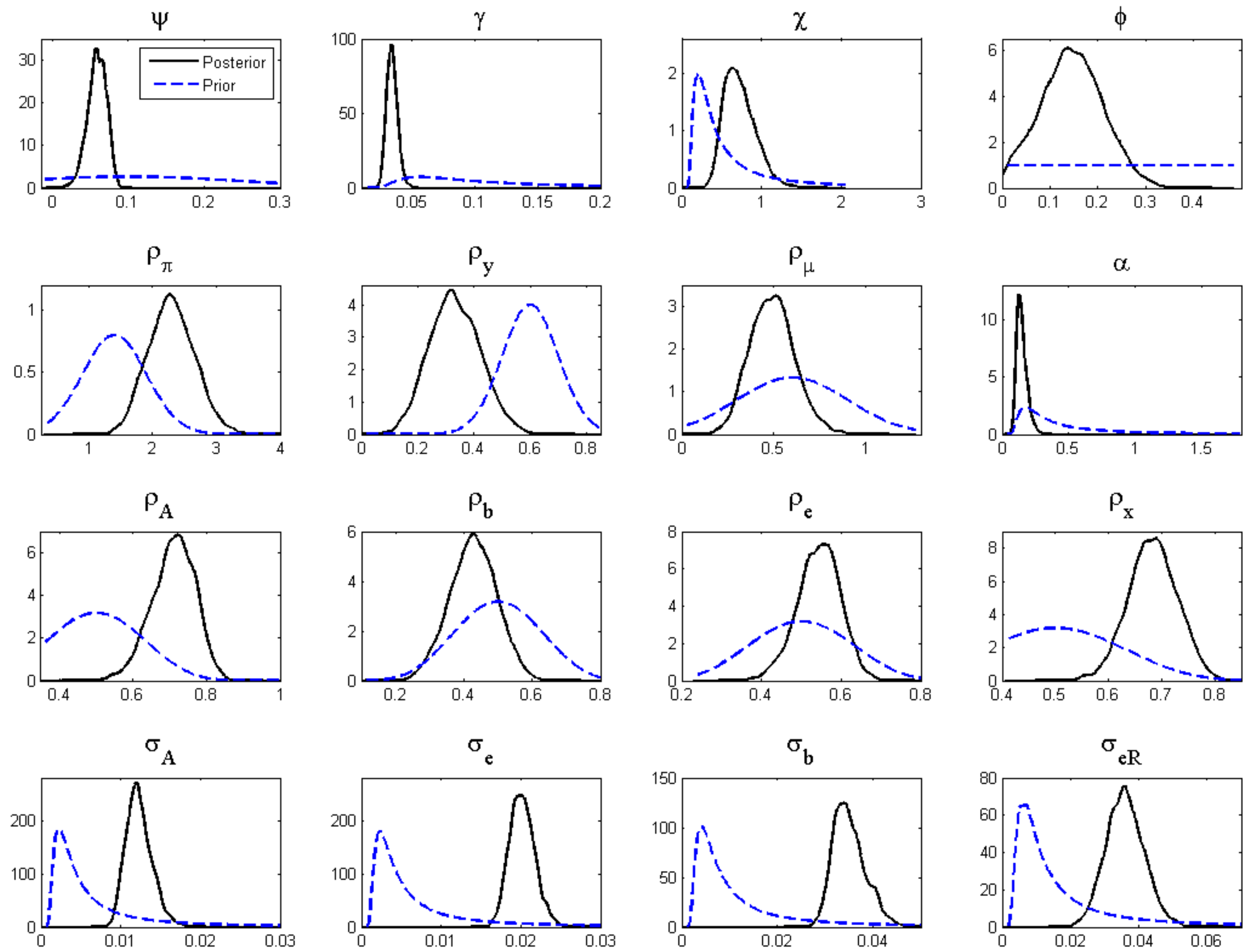
5 Estimation Results

The posterior means and standard errors are calculated from the output of the Metropolis algorithm and summarized in table 2.[5] The plots of the prior and posterior densities are presented in Figure 7 which give an indication of how informative the observed data are about the structural parameters. Figure 7 suggest that the observed data provide additional information for all parameters.

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.

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

Figure 7: Priors and Posteriors densities



5.1 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 0.059, 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 0.035 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 0.73 while under the NoFA model the posterior mean estimate is 0.54. These estimates are higher than 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 0.15 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 0.2, somewhat lower 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 30) 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 518 and thus strongly favors the FA model[6].

[6] The posterior odds ratio (518) is obtained as the exponential of the difference of the Laplace approximations.

Table 2: Posterior means and standard deviations for the structural parameters

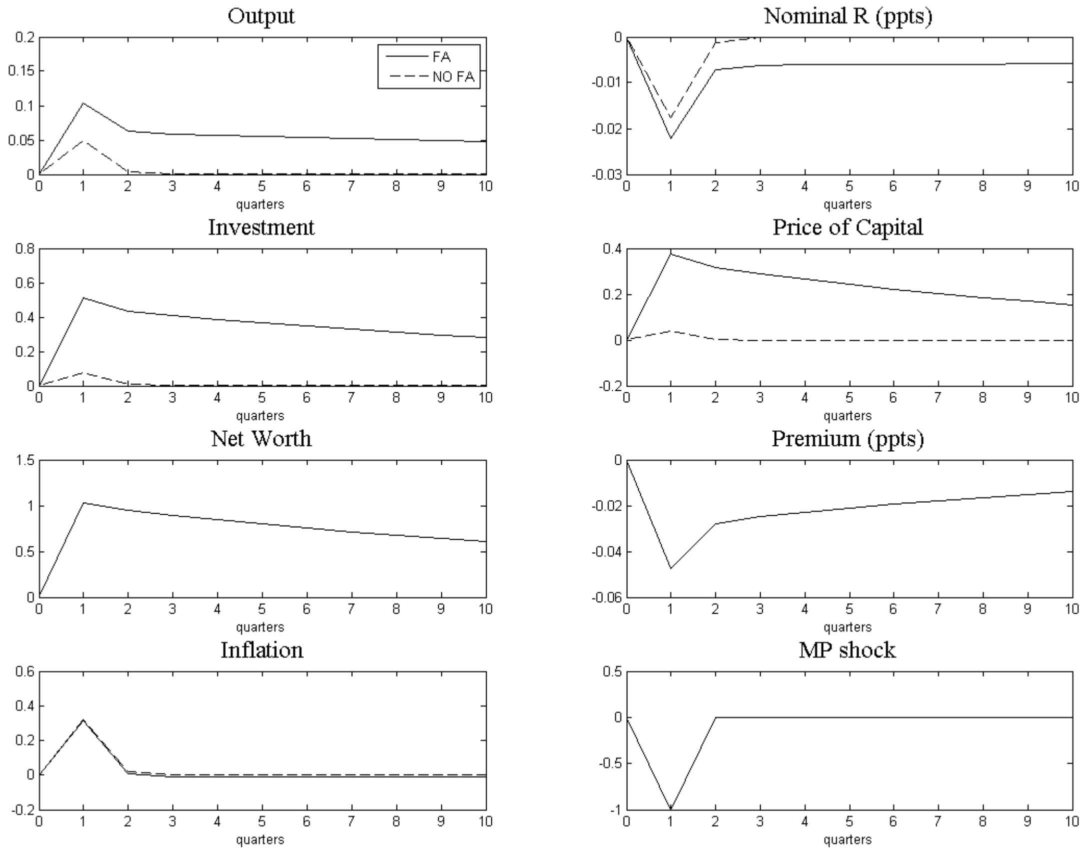
	FA model.		NoFA model.	
Name	**Mean**	**Std**	**Mean**	**Std**
ψ	0.059	0.012		
γ	0.035	0.004	0.034	0.004
χ	0.730	0.170	0.545	0.112
ϕ	0.150	0.065	0.190	0.063
ρ_π	2.291	0.382	2.355	0.411
ρ_y	0.332	0.094	0.252	0.100
ρ_μ	0.496	0.114	0.495	0.125
α	0.148	0.032	0.207	0.050
ρ_a	0.702	0.057	0.724	0.052
ρ_b	0.428	0.068	0.437	0.068
ρ_e	0.544	0.053	0.548	0.054
ρ_x	0.686	0.047	0.689	0.049
σ_A	0.012	0.001	0.015	0.002
σ_e	0.020	0.001	0.021	0.002
σ_b	0.035	0.003	0.035	0.003
σ_x	0.063	0.015	0.037	0.006
σ_{e_R}	0.036	0.006	0.036	0.006
Laplace approx.	1318		1309	

5.2 Impulse responses

5.2.1 With and without financial accelerator

In the previous section we 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 8 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

Figure 8: Responses to a monetary policy shock: with and without Financial Accelerator



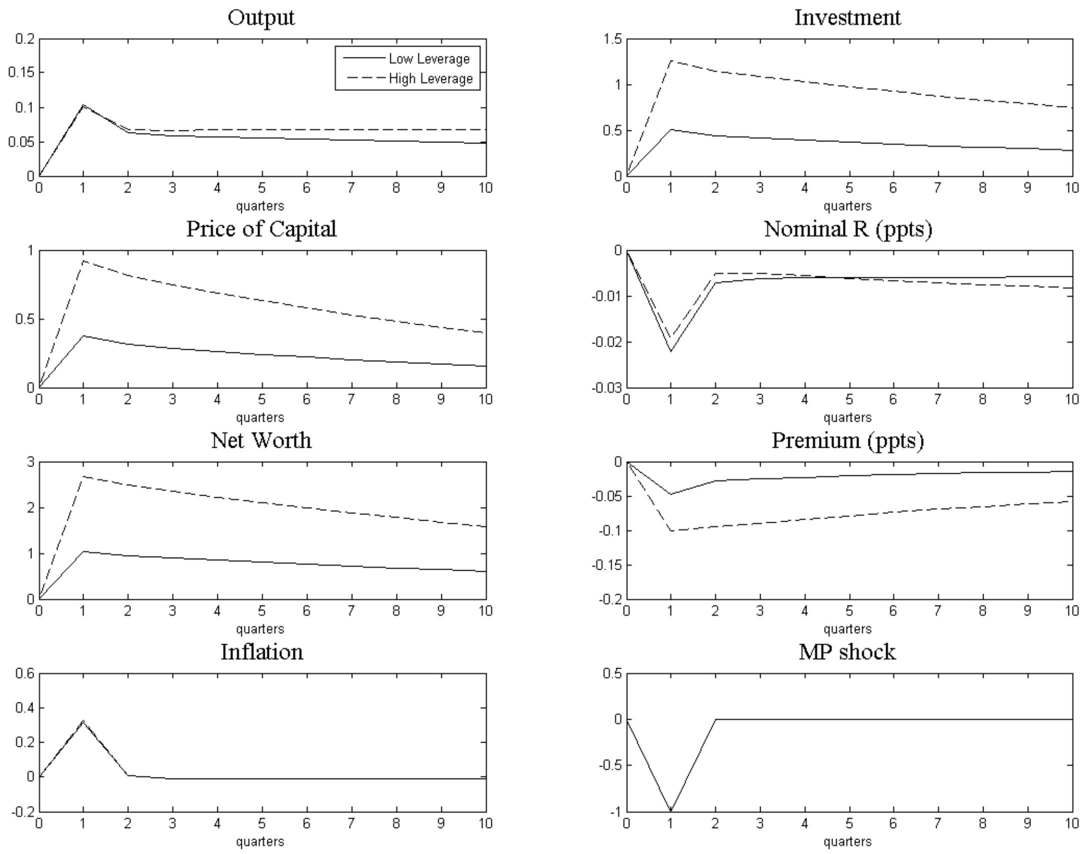
included than without it and the response of investment is increased fivefold.

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.

5.2.2 Implications of increased leverage

In a model with a financial accelerator, the impact of shocks on real activity also depends on initial financial conditions. As we show in the second section of this paper,

Figure 9: The Effect Leverage on responses to a monetary policy shock



financial conditions previous to the 1999 downturn in the Colombian economy were less favorable than previous to the 1982 recession. Part of this phenomena is explained by the increased credit availability due to the financial liberalization that began in the early 1990. As a result, the steady-state leverage ratio rose over that decade leaving the Colombian economy in a more vulnerable position. Figure 9 explores the impact of a higher steady-state leverage ratio, 60 percent instead of 50 percent in the baseline scenario. The figure shows that an increase in leverage significantly amplifies the investment cycle. These simulations suggest a rationale for a regulatory policy that discourages excessive leverage.

6 Final Remarks

This paper estimates a dynamic general equilibrium model incorporating credit-market imperfections using Colombian data. 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. An advantage of this approach is not only that financial effects are given explicit micro-foundations and respond endogenously to developments elsewhere in the economy, but also that the econometric estimates allow us to test the relevance of financial frictions in the explanation of Colombian business cycle and particularly of the behavior of investment.

Using a Bayesian procedure, we estimate 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.

This paper does not claim that financial accelerator effects were the single determinant of investment in the 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 1999 recession due to increases in interest rates: a large drop in output, investment, asset prices and net worth. The financial accelerator mechanism turns out to be quantitatively significant accounting for about 50 percent of the total reduction in output. Furthermore, initial financial conditions of households and firms were also relevant in the explanation of the depth and severity of the recession at the end of the 1990s. In this sense, monetary authorities should be aware that monetary policy might have stronger effects in the business cycle depending on the level of leverage of the economy.

In this paper we have considered responses to monetary shocks and the effects of different steady-state leverage ratios on the responses to monetary shocks only, but the model can also be used to analyze a range of other shocks, such as to productivity.

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