Bringing a DSGE model into policy environment in Colombia

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Abstract

Central Banks build models for policy analysis and forecasting. Dynamic stochastic general equilibrium (DSGE) models have been useful for policy analysis. There is growing interest in evaluating their ability to forecast macroeconomic time series. We review the Colombian experience in designing and implementing a small open economy DSGE model for monetary policy analysis and forecasting. We describe the main elements of the model as well as issues related to its properties, empirical validation and forecasting ability. We build the model to take into account movements in productivity, terms of trade and oil prices. In addition we compare the forecasting performance of our current core model and the DSGE model, and show that although the MMT outperforms the DSGE in predicting inflation and output, the latter is not so far away from the former. We also find that under our specification of the model we cannot forecast the real exchange rate accurately. We argue that minimising out of sample forecasting errors is a desirable goal, but it should not be taken as a unique measure to evaluate a model for monetary policy decision making.

1 Introduction

In the second half of the nineties several emerging economies abandoned fixed (or fixed-like) exchange rate regimes and instead adopted inflation targeting as a monetary policy strategy. In September 1999, in the midst of a severe economic contraction, Colombia ditched its exchange rate crawling band and adopted inflation targeting. As an important part of its IT strategy, the Banco de la República developed a semi-structural model (Modelo de Mecanismos de Transmisión, MMT) to be used as a core model for monetary policy analysis and forecast.[1] The model has been useful to discipline the economic debate within the central bank and to anchor the communication strategy condensed in the Inflation Report. In 2003, the bank's technical staff decided to design and implement a DSGE model to be used as the main tool for monetary policy analysis and forecast.

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[1] See Gomez et al. (2002).

In this paper we provide a detailed description of how the Banco de la República has made progress in designing and implementing a DSGE model for monetary policy analysis and forecast. We start by describing the reasons that lead us to current design (or structure) of the model, the main problems that we have had to face and how we have approached them. We show that in designing the model we took into account several elements like: the stylized facts about emerging economies and Colombia, economic discussions between the technical staff and the Board of Governors, the language of the Governor and how he communicated to the public his views about the current stance of the economy and its likely path in the future. In implementing the model we had to face a different type of problems like: data availability, the frequency and the timeliness of information arrival, the resources and technical constraints within the bank among other things. We could safely argue that how we approached these design and implementation problems determined the main elements of the model.

We proceed as follows: in the next section we describe briefly the policy process at the Banco de la República. Then we characterize the set of stylized facts of the Colombian economy that our model should be able to capture. In the third section we describe the model and connect its elements to the facts that we described in the previous section. In the fourth section we describe how we built a model-consistent database. Next, we proceed to discuss the empirical validation of the model. We finalize the paper addressing the problem of how to use the model as a tool for an effective communication strategy.

2 The Policy Process

At the Banco de la República the policy process runs in a regular quarterly cycle, with monthly updates. The Board of Governors (Junta Directiva del Banco de la República, JDBR) meets 12 times per year. The bank has a primary model as well as other auxiliary models. The primary model is used to construct projections of alternative scenarios conditional on different assumptions about future exogenous events and/or on different assumptions about the current state of the economy. The current primary model at use is the "Modelo de Mecanismos de Transmisión". The model is a small linear dynamic rational expectations model with about 10 behavioral equations. The equations of the model are not derived from well defined microeconomic principles. This model has been refined since its introduction in 2000, but its basic structure remains essentially the same.[2] The auxiliary models support the forecast process at shorter horizons and the determination of the current state of the economy, in particular the determination of the value of the output gap at a given time.[3] The staff "owns" the models and is responsible for the projection and the forecasts. This is important because the Executive Summary of the Inflation Report is signed by the Board of Governors but the document is full responsibility of the technical staff. Nevertheless the Banco de la República is quite transparent. Every quarter the Governor makes public (TV broad casted) presentations sharing his views about the state of the economy, the economic outlook and potential risks. This presentations use the data, the analysis and the projections discussed during a quarterly policy round. At the end of the presentation

[2]A document in spanish describing details of the model (equations, solution method, calibration, etc) is available upon request.

[3]These models include time series models, VARs, SVARs, neural networks, principal components regressions and a Cobb-Douglas approach to the output gap.

TV viewers can ask live questions to the Governor.

Each quarterly policy round has a number of meetings within the staff and between the staff and the board. The idea is to arrive iteratively through discussion at a baseline or benchmark projection as well as to define the main sources of risk. The policy round starts with a startup staff-meeting in which the latest information and the story of the previous quarter is reviewed. In this meeting the staff studies the occurrence of events that might lead to changes in the story. The second staff-meeting defines the near term forecast (NTF) for the next two quarters of output growth, output gap and exchange rate. The external conditions to the economy are discussed in this meeting. After these two meetings, the staff presents the NTF to the Board. The third and fourth staff-meeting define the baseline scenario (based on the assessment of the external context and the material reviewed in the previous meetings) and the alternative scenarios to run the model. In the meantime, while model operators run the model, the staff meets the Board to present a well defined picture of what the staff thinks is the current state of the economy (external and internal context). Once the projections under alternative scenarios are available, the staff proceeds to define the Fan Chart to characterize the potential risks involved in the inflation forecast. All these elements are presented to the Board in a final meeting. The process closes with a written policy recommendation from the staff to the Board.

An important issue is how the NTF is integrated with the medium term forecast (MTF) provided by the model. The NTF is obtained from several econometric models as well additional information from economic indicators, news, telephone talks to key external private agents and meetings with firms managers. The NTF is fed through the MMT model to generate residuals for each of the variables for which an NTF is performed.[4] The NTF is made for two quarters. After two quarters the equilibrium conditions of the model produce the MTF. This mechanism of integrating the NTF and the MTF has similar effects as an unexpected shock to the model. We do this at the bank because experience shows that there is an advantage of subjective forecasts over model forecasts at short horizons (typically one year). For longer horizons the model tends to outperform the experts. Later we will discuss the challenges to incorporate such a procedure with DSGE models.

The reason to proceed in this way is that the economic models at hand are weak descriptions of the economy and expert judgement of well trained professional economists allows a more precise understanding of the inner workings and the structure of the economy. The fact that all models are false by definition, pushes us to rely more on key experts. However, our strategy in designing the elements of the model has been to take the rhetoric of these economists, their metal model, and put it into equations. We put special attention to the internal debates and exchange of ideas between senior economists at the bank about issues like: main shocks that hit the economy, structural relations between macro variables, stylized facts of the economy and other issues related to the way they perceive the economy. In the next section we summarize some of the stylized facts of the economy and show how the DSGE model was designed in order to capture some of them.

[4] At the bank we use NTF for inflation, exchange rate and output gap.

3 Stylized and Structural Facts of the Colombian Economy

Colombia is a small open economy in which capital flows and the real exchange rate play a fundamental role in the economy. The literature in international economics has identified several stylized facts related to the impact of capital flows in Latin America. According to this literature, capital inflows have been accompanied by:

- a significant nominal and real exchange rate appreciation combined with low sovereign spreads,
- a boom in total credit (to the private and/or the public sector) and domestic demand (consumption and investment),
- rapid growth in asset prices, not only stocks or financial assets, but also non-traded assets (like house prices) and
- increased economic activity and employment.

In contrast capital outflows have been periods of economic distress in which all these movements correct, usually in a sharp way. The evidence of the effects of capital flows on inflation is quite mixed. During the inflow period many countries experienced inflationary pressures, but in general, most of Latin American countries (LACs) were able to reduce inflation successfully. However, during the outflow period some countries experienced important inflationary pressures in the aftermath of a large devaluation, while in others (like Colombia) inflation actually dropped significantly because the domestic demand channel dominated the exchange rate channel.

3.1 Real variables

The first step was to verify the set of stylized facts of capital flows for the Colombian economy. We take a look at some indicators that we consider are informative about the developments in the economy. Many of these indicators are annual, but we think that they reveal a lot about the properties of our business cycle fluctuations. Many of the facts that have been identified for emerging economies are shared by the Colombian economy. For instance, figure 1 show the evolution of capital flows and the Colombian EMBI spread. Although no spread data are available before 1997, the inflow period was marked by favorable external financing conditions and low spreads. The outflow period moved spreads from 4% to 16%. Between 2000 and 2004 capital flows increased in nearly USD7.5 billions and the spread fell in 900 bp (from 1100 bp to 200 bp).

As in the case of LACs, capital inflows in Colombia during the first half of the nineties were associated with:

1. a large real appreciation (Figure 2),
2. increased investment and aggregate demand (Figure 3),
3. a rapid growth of asset prices (Figure 4) and
4. increased economic activity (Figure 5).

The previous set of facts lead us to think that understanding the dynamics of the real exchange rate and its relation to capital flows was a key element that our model should incorporate. The real exchange rate is a relative price that is determined endogenously as part of the macroeconomic equilibrium. The RER relates the price of tradable goods and services to the non tradables. So it is important in determining the dynamics of tradable and non-tradable inflation. Our model should reflect this dichotomy: some goods, mainly services and housing services, are non tradable while others are tradable, mainly imported goods. This issue is important because the dynamics of inflation in a standard one-good Keynesian model might be very different in a two-good model, depending on the source of the shocks. If this is the case, the policy recommendation might vary from model to model.

As with the RER, capital flows are also related to investment and credit. Periods of capital inflows are related to rapid growth in credit to the private sector to finance investment projects and, in general, to increase aggregate expenditure. When capital stopped flowing, so did credit and many investment projects were either abandoned or postponed. In the Colombian case the effects of the 98 crisis were protracted: it was only until 2004 that investment recovered its level observed in 1993.

So, the behavior of investment was also a key element in our model. The MMT was a small gap model that did not allow for the possibility of incorporating investment in the model. The way in which the staff incorporated investment information was the following logic: increased investment adds to the capital stock, which in turn increases potential output. So implicitly, and consistently with the RBC tradition, the MMT treated *all* investment as an inflation reliever.

The economic boom of the first half of the nineties lead to rapid growth in asset prices and to the development of financial markets. The price of capital, in association with investment, was another feature that we considered important. In particular, the price of non tradable assets, like houses or domestic government debt might play an important role affecting households savings and investment decisions. Variations in these prices might have substantial wealth effects that in turn affect consumption demand and inflation. This channel was also ignored in the previous model.

Figure 5 shows a general result: periods in which foreign capital entered the country were periods of increased employment and production. On the contrary , capital outflows (or lack of inflows) were associated with recession and unemployment. In the next section we show the relationship of these facts to inflation.

3.2 Inflation

The second step was to determine some stylized facts of the Colombian inflation and to study their connection to the behavior of the RER. There are two important considerations when studying inflation in Colombia. First, until the beginning of the nineties, inflation was high (25% annual average growth rate for 20 twenty years) and volatile (about 10% standard deviation). A long period of gradual disinflation started in 1991 when the central bank was made independent. The strategy started by announcing admissible targets and a long term objective of "reducing inflation to a single digit". Once inflation was reduced below 10%, the Board of Governors established a long run inflation target of 2-4%. By the first quarter of 2006 annual inflation was 4.1%.

A second issue, is the pass-through from the nominal exchange rate to prices. To model and quantify pass-through, we started collecting some studies about empirical evidence on the impact of nominal exchange rate changes to *total* inflation. These studies found little evidence of pass-through.[5] A natural explanation, consistent with the fact that a large fraction of the production is non tradable, was that a large fraction of the consumption basket was also non tradable, while a small fraction was tradable. We decided to split the CPI into tradable and non tradable. To measure the degree of passthrough we used a "natural" experiment provided by the events that took place during 2002. In that year, two exogenous shocks raised the Colombian spreads and the exchange rate: First, in 2002 uncertainty about the outcome of the Brazilian presidential election and second a crisis with Venezuela. These two exogenous events provided us with a natural experiment to evaluate the degree of passthrough.

We can summarize the following stylized facts about the Colombian inflation:

- A large fraction (70%) of the goods and services consumed by Colombians are non-tradables.
- The rest, 30% of the consumption basket, exhibit higher passthrough than the non tradable. Inside the bank these goods were labeled as "tradables".[6]
- Non tradable inflation is more persistent than tradable inflation.
- An unexpected depreciation that raises the nominal exchange rate annual growth from 0% to 30% in two quarters, caused by exogenous factors, generates an increase in annual tradable inflation from about 5% to about 8%, that is 300bps, with a delay of nearly two quarters. (see figure 6).
- The dynamics of tradable and non-tradable inflation is different and the combined dynamics is informative about the trend of the bilateral (with the US) real exchange rate. (see figure 7)

Having these simple facts in mind the technical staff at the bank decided to model total inflation as the result of two types of goods, tradable and non tradable. The relative price of tradable to non tradables would be driving the real exchange rate dynamics. To introduce stickiness in inflation and to be able to capture a more persistent non tradable inflation, we introduced sticky prices in the non tradable sector.

3.3 Economic structure

A third step was what features of the economic structure needed to be incorporated in the model in order to improve the type of stories that were being told to the Board of Governors. Forecasting economic activity, either using a sectoral or supply approach or a demand approach had been an important element of the meetings between the board and the staff. Sectoral projections are performed using a lot of judgement and a static CGE (computable general equilibrium model). The staff decided that the DSGE model should have some level of disaggregation without compromising the basic understanding of the model.

[5]See for example Rowland (2003) and an internal document of the central bank prepared by the Subgerencia de Estudios Económicos "Devaluación y passthrough: evidencia empírica y evolución reciente" written in 2003.

[6]In fact in public speeches the Governor of the central bank has referred to these goods as tradables.

Another element that is very important in the macroeconomic forecast of the central bank is the balance of payments (BOP) projections. The BOP model is basically and identity that adds some behavioral reduced form equations for export and import demands. Taking as given the rest of components of the BOP, the model is closed by solving for the exchange rate. The BOP use a lot of judgement, mainly about an exogenous path of export prices, export production, changes in the net foreign asset position of the government, reserve accumulation policy of the central bank and some aggregate macroeconomic variables. An important point is that private capital flows are taken as exogenous. The staff decided that the DSGE model could, in principle, provide a framework to "endogenize" several macroeconomic variables that were taken as "exogenous" in the BOP projection exercise, if the paths for the truly exogenous variables were the same.

We recognized that the model should incorporate the following elements:

1. External variables are an important, if not the most important, sources of fluctuations in the economy. Large external shocks can hit the Colombian economy. These shocks have nominal and real consequences:
    (a) terms of trade
    (b) external demand for Colombian exports
    (c) remittances
    (d) external interest rates
    (e) exogenous movements in the Colombian spread
2. The mining sector is an important source of exports (about 1/3 of total exports are oil, coal and other minerals).
3. Sectors that are mainly non tradables are: housing and construction and services. These sectors account for 57% of GDP.
4. The main sources of domestic shocks are:
    (a) Total factor productivity (TFP) in the tradable and non tradable sector
    (b) Government expenditure shocks

An important feature of the Colombian economy is that of remittances from abroad. In 1999 remittances accounted for 1.5% of GDP. In 2004, they increased to 3%. To have an idea of the magnitude of the shock, in 1999 the flow of remittances was similar to the flow of coffee exports. In 2004 remittances were approximately three times the amount of coffee exports. Figure 8 shows how this variable may be related to the behavior of the real exchange rate.

A structural issue, that is very important but we have not considered yet, is the relationship of the labor market and the macroeconomy. Issues like the informal job market and the real frictions in the formal market remain largely unexplored. These problems are left for a future research agenda.

4 The model

Having in mind the considerations presented in the previous section, we build a small open economy model with two main sectors: tradable and non tradable. The model is similar in spirit to that of Burstein et al. (2005) , Devereux et al. (2004), Kam and Lim (2001) and Zanna (2003, 2004). A minor difference is that the tradable sector is comprised of an endowment sector (mining hereafter) and a sector that produces an exportable good using capital and labor. The non tradable production also uses capital and labor. Labor moves freely between sectors, while capital is sector specific. Households consume the non tradable good and an importable good. The model exhibits two features: first, nominal rigidities in the form of Calvo pricing in the non tradable sector. Second, perfect pass-through of exchange rate movements into imported good prices "at the dock" and imperfect pass-through into imported good prices "at retailer".

Nominal rigidities are needed, not only to introduce a role for monetary policy, but to reproduce the stylized fact that non traded inflation is more persistent than traded inflation. There is some evidence in the international economics literature and in the Colombian economy that deviations from the PPP are an important factor in determining the RER.[7] Since there are significant differences across countries in the speed with which exchange rate pass-through to the CPI, we pay special attention in the calibration exercise to this feature. Furthermore, Devereux et al (2004) show that the degree of pass-through is very important for the model dynamics.

There are three domestic agents in the model: households, firms and a government comprised of a fiscal authority and a monetary authority. The fiscal authority is introduced to account for the impact of government expenditure shocks. The monetary authority sets the nominal interest rate using a simple Taylor rule to lead inflation to target. In addition there is a "rest of the world" sector where foreign interest rates and prices of exports and imports are set. Exportable firms produce whatever they can of the exportable good, given the technology available and the resources they decide to employ in order to maximize profits. Importing firms buy the foreign import good at the dock and demand non traded services to make the imported good available to consumers. The retail price of the imported good has two components a purely imported part and a non traded part than accounts for the fact that intermediation margins and transportation costs should influence the final price. Now we continue to describe the model.

4.1 Households

There is a continuum of households of measure one. The representative household has preferences given by:

$$E_0 \sum_{t=0}^{\infty} \beta^t \frac{c_t^{1-\sigma}}{1-\sigma} \tag{1}$$

where c_t is a composite consumption index, $0 < \beta < 1$ is a discount factor and $\sigma > 0$ is a parameter that drives the intertemporal elasticity of substitution. Composite consumption is a CES index of consumption of traded, c_t^M,

[7] See Engel (1999) and more recently Burstein et. al (2005).

and non traded goods, c_t^N:

$$c_t = \left[\gamma^{\frac{1}{\omega}} \left(c_t^N\right)^{\frac{\omega-1}{\omega}} + (1-\gamma)^{\frac{1}{\omega}} \left(c_t^M\right)^{\frac{\omega-1}{\omega}}\right]^{\frac{\omega}{\omega-1}} \tag{2}$$

where $\omega > 0$ determines the elasticity of substitution between traded and non traded goods, and $0 < \gamma < 1$ determines the share of non traded goods in the price index, which in turn is:

$$P_t = \left[\gamma \left(P_t^N\right)^{1-\omega} + (1-\gamma)\left(P_t^M\right)^{1-\omega}\right]^{\frac{1}{1-\omega}} \tag{3}$$

a composite index of the price of non traded and traded goods.

To introduce nominal rigidities in the non traded sector we need some form of price setting power. We assume that the non traded sector is monopolistically competitive. The consumption of the non traded good is differentiated :

$$c_t^N = \left[\int_0^1 c_t^N(z)^{\frac{\theta-1}{\theta}} dz\right]^{\frac{\theta-1}{\theta}} \tag{4}$$

with elasticity of substitution between every variety, z, equal to $\theta > 1$.

Households may borrow and lend in perfectly competitive international financial markets by writing a standard non-state contingent debt contract that are denominated in either domestic or foreign currency. They can borrow an amount F_t in foreign currency at a rate of i_t^e or can issue a bond in domestic currency, B_t, at a rate of i_t. The interest rate at which households borrow in international financial markets is increasing on the aggregate stock of external debt, $\widetilde{F}_t$. Households are the owners of all inputs and firms. Firms that operate in a competitive environment will generate zero profits, while non traded firms in monopolistic competition will generate non-zero profits. The flow of revenue of the representative household at a given period comes from the supply of hours of work at wage w_t, the supply of capital to the exporting and non traded sectors at rental rates r_t^X and r_t^N, profits from the non traded sector, Π_t, interest repayments on domestic bond holdings, $(1+i_t)B_t$, less foreign debt repayment from last period, $s_t(1+i_t^e)F_t$, at a nominal exchange rate of s_t. Households can issue new debt in international financial markets or can purchase domestic bonds in local currency to smooth consumption or to finance investment, x_t. We assume that it is costly to adjust investment so that the marginal return to investment in terms of capital goods is declining in the amount of investment undertaken relative to the capital stock available at the beginning of period t, k_t. Capital stock depreciates at rate δ. So, capital stocks in the exporting and non traded sectors evolve according to:

$$k_{t+1}^X = x_t^X - \frac{\Phi}{2}\left(\frac{x_t^X}{k_t^X} - \delta\right)^2 k_t^X + (1-\delta)\, k_t^X$$

and

$$k_{t+1}^N = x_t^N - \frac{\Phi}{2}\left(\frac{x_t^N}{k_t^N} - \delta\right)^2 k_t^N + (1-\delta)\, k_t^N.$$

Finally, households might receive uncertain unilateral transfers from abroad in an amount TR_t. These transfers follow a stochastic process to be described later. So, the household's budget constraint is:

$$P_t\left[c_t+x_t^N+x_t^X\right]+(B_{t+1}-B_t)+s_tF_ti_t^e\leq P_t\left[w_tl_t+r_t^Xk_t^X+r_t^Nk_t^N+\pi\right]+i_tB_t+s_t(F_{t+1}-F_t)+s_tTR_t \quad (5)$$

with $l_t=l_t^X+l_t^N$ that states that the household chooses freely the sector to work.

The household chooses non traded and imported goods to minimise expenditure taking as given the total composite demand, so demands for these goods are:

$$c_t^N=(1-\gamma)\left(\frac{P_t^N}{P_t}\right)^{-\omega}c_t \quad (6)$$

and

$$c_t^M=\gamma\left(\frac{P_t^M}{P_t}\right)^{-\omega}c_t. \quad (7)$$

The households maximize (1) subject to (5) and performing the usual algebra, the household's intertemporal optimum can be characterized by:

$$\beta E_t\left[\frac{c_t^{-\sigma}}{c_{t+1}^{-\sigma}}\frac{P_t}{P_{t+1}}\frac{s_{t+1}}{s_t}\right]=\frac{1}{1+i_t^e} \quad (8)$$

$$\beta E_t\left[\frac{c_t^{-\sigma}}{c_{t+1}^{-\sigma}}\frac{P_t}{P_{t+1}}\right]=\frac{1}{1+i_t} \quad (9)$$

$$\beta E_t\left[\frac{c_t^{-\sigma}}{c_{t+1}^{-\sigma}}\left(r_{t+1}^X+\frac{\Phi\left(\frac{x_{t+1}^X}{k_{t+1}^X}-\delta\right)\frac{x_{t+1}^X}{k_{t+1}^X}-\frac{\Phi}{2}\left(\frac{x_{t+1}^X}{k_{t+1}^X}-\delta\right)^2+(1-\delta)}{\left(1-\Phi\left(\frac{x_{t+1}^X}{k_{t+1}^X}-\delta\right)\right)}\right)\right]=\frac{1}{\left(1-\Phi\left(\frac{x_t^X}{k_t^X}-\delta\right)\right)} \quad (10)$$

$$\beta E_t\left[\frac{c_t^{-\sigma}}{c_{t+1}^{-\sigma}}\left(r_{t+1}^N+\frac{\Phi\left(\frac{x_{t+1}^N}{k_{t+1}^N}-\delta\right)\frac{x_{t+1}^N}{k_{t+1}^N}-\frac{\Phi}{2}\left(\frac{x_{t+1}^N}{k_{t+1}^N}-\delta\right)^2+(1-\delta)}{\left(1-\Phi\left(\frac{x_{t+1}^N}{k_{t+1}^N}-\delta\right)\right)}\right)\right]=\frac{1}{\left(1-\Phi\left(\frac{x_t^N}{k_t^N}-\delta\right)\right)}. \quad (11)$$

Equations (8) and (9) are the first order conditions with respect to foreign debt and domestic bonds, while equations (10) and (11) are the first order conditions with respect to capital in the exporting and non traded sectors.

4.2 Firms

There are three sector in the model: an exporting sector, an importing sector and a non traded sector. All domestically produced traded goods are exported.

4.2.1 Exporting sector

Exports in the model are composed of two types of goods. Every period the economy is exogenously endowed with a non storable final good. This good is shipped abroad to be consumed in the rest of the world. Its foreign price,

P_t^e, and quantity, y_t^e, are determined in the rest of the world. We can think of this good as being the production of oil and coal.

The second exportable good is a final good that is produced using capital, labor and a Cobb-Douglas technology, $y_t^X = A_t^X \left(k_t^X\right)^{\alpha^X} \left(l_t^X\right)^{1-\alpha^X}$. Firms in this sector compete with foreign firms in a competitive foreign market. An exporting firm takes this price as given. She chooses capital and labor to maximize profits and so:

$$r_t^X = \left(\alpha^X\right) \frac{P_t^X}{P_t} A_t^X \left(k_t^X\right)^{\alpha^X - 1} \left(l_t^X\right)^{1-\alpha^X}$$

$$w_t = \left(1 - \alpha^X\right) \frac{P_t^X}{P_t} A_t^X \left(k_t^X\right)^{\alpha^X} \left(l_t^X\right)^{-\alpha^X}$$

where P_t^X is the price of exports which is defined as $P_t^X = s_t P_t^{X^\star}$ with $P_t^{X^\star}$ defined as the foreign price of exports in dollars, A_t^X is the level of productivity in the sector, and $0 < \alpha^X < 1$ is a production function parameter.

4.2.2 Importing distribution sector

To model the importing distribution we follow Burstein et al (2005). In this sector the tradable consumption good is imported. The dollar price of this good, P_t^{M*}, is set in the foreign markets. We assume that the price of imports at the dock is $s_t P_t^{M*}$and that selling a unit of the tradable consumption good requires η units of the non traded final good. This sector is perfectly competitive so:

$$P_t^M = s_t P_t^{M*} + \eta P_t^N.$$

The domestic distribution margin, defined as the fraction of the final price accounted for by distribution costs is equal to $\eta P_t^N / P_t^M$. This implies that imported inflation is:

$$\Pi_t^M = \frac{RER_{t-1}}{RER_{t-1} + \eta} \tilde{\Pi_t^M} + \frac{\eta}{RER_{t-1} + \eta} \Pi_t^N$$

where $RER_{t-1} = \frac{s_t P_t^{M*}}{P_t^N}$ and $\tilde{\Pi_t^M}$ is the imported inflation at the dock, this one is composed by the nominal devaluation times external inflation .

4.2.3 The non traded sector

The non tradable goods are produced using capital, labor and a Cobb Douglas technology, $y_t^N = A_t^N \left(k_t^N\right)^{\alpha^N} \left(l_t^N\right)^{1-\alpha^N}$. Cost minimizing behavior implies that:

$$w_t^N = \left(1 - \alpha^N\right) \psi_t^N \frac{P_t^N}{P_t} A_t^N \left(k_t^N\right)^{\alpha^N} \left(l_t^N\right)^{-\alpha^N}$$

$$r_t^N = \left(\alpha^N\right) \psi_t^N \frac{P_t^N}{P_t} A_t^N \left(k_t^N\right)^{\alpha^N - 1} \left(l_t^N\right)^{1-\alpha^N}$$

where ψ_t^N is the marginal cost in the non tradable sector.

Firms in this sector set prices as monopolistic competitors. A firm will maximize its expected profit stream discounted at the factor:

$$\beta_{t+1} = \beta \frac{P_t c_t^{\sigma}}{P_{t+1} c_{t+1}^{\sigma}}.$$

So, the objective function of the non tradable firm z is to choose prices to maximize:

$$E_0 \sum_{t=0}^{\infty} \beta_t \left[\frac{P_t^N(z)}{P_t^N} c_t^N(z) - \psi_t^N(z) c_t^N(z) \right] \tag{12}$$

where

$$c_t^N(z) = \left[\frac{P_t^N(z)}{P_t^N} \right]^{-\theta} c_t^N$$

represents the total demand for firm z's non tradable output and $\beta_0 = 1$.

To introduce stickiness in the model we follow Calvo (1983). Each period, some firms cannot adjust prices optimally with some constant probability, ε . These firms follow a backward indexation rule:[8]

$$P_t^{rule}(z) = P_{t-1}^N(z) \left(1 + \pi_{t-1}^N\right) \tag{13}$$

where $P_{t-1}^N(z)$ is the price of the non traded variety z in the previous period and π_{t-1}^N is the inflation rate of non traded goods.

Firm z will optimize with probability $(1-\varepsilon)$ and choose $\tilde{P}_t^N$ so, the problem becomes to maximize:

$$v_t^{opt} = \max_{P_t^N(z)} \left\{ \frac{\Pi_t^N(z)}{P_t^N} + \beta E_t(\varepsilon) v_{t+1} + \beta E_t(1-\varepsilon) v_{t+1}^{opt} \right\} \tag{14}$$

where $\frac{\Pi_t^N(z)}{P_t^N}$ are the real profits at time t. It can be shown, after tedious algebra, that the solution to this problem is:

$$\frac{\tilde{P}_t^N}{P_t^N} = \frac{\theta}{\theta-1} E_t \frac{\sum_{k=0}^{\infty} (\beta\varepsilon)^k \left(\varphi_{t+k}^N(z) \left(\frac{(1+\pi_{t+k}^N)}{(1+\pi_t^N)} \right)^{\theta} c_{t+k}^N \right)}{\sum_{k=0}^{\infty} (\beta\varepsilon)^k \left(\left(\frac{(1+\pi_{t+k}^N)}{(1+\pi_t^N)} \right)^{\theta-1} c_{t+k}^N \right)} \tag{15}$$

[8] This practice has been documented by the academic and central banking literature in Colombia.

or equivalently

$$\frac{\tilde{P}_t^N}{P_t^N} = \frac{\theta}{\theta - 1} E_t \left(\frac{\Theta_t}{\Psi_t} \right)$$

where

$$\Theta_t \quad = \quad c_t^N \varphi_t^N (z) + \beta \varepsilon E_t \left(\frac{\left(1 + \pi_{t+1}^N\right)}{\left(1 + \pi_t^N\right)} \right)^{\theta} \Theta_{t+1} \tag{16}$$

and

$$\Psi_t \quad = \quad c_t^N + \beta \varepsilon E_t \left(\frac{\left(1 + \pi_{t+1}^N\right)}{\left(1 + \pi_t^N\right)} \right)^{\theta - 1} \Psi_{t+1} \tag{17}$$

with $\tilde{P}_t^N$ as the optimal price of good $c_t^N(z)$ chosen by firm z. Since demand of non tradable goods $c_t^N(z)$ implies that the price aggregator is also CES, it can also be shown that the price index P_t^N is given by:

$$P_t^N = \left[(\varepsilon) \, (P_t^{rule})^{1-\theta} + (1 - \varepsilon)(\tilde{P}_t^N)^{1-\theta} \right]^{\frac{1}{1-\theta}} . \tag{18}$$

Finally, inflation of non traded goods is:

$$(1 + \pi_t^N) = \left((\varepsilon) \, (1 + \pi_{t-1}^N)^{(1-\theta)} + (1 - \varepsilon) \left(\frac{\tilde{P}_t^N}{P_t^N} \right)^{(1-\theta)} (1 + \pi_t^N)^{(1-\theta)} \right)^{\frac{1}{1-\theta}} \tag{19}$$

that shows that non tradable inflation has a backward and forward looking component.

4.3 Economic policy

The monetary authority sets the nominal interest rate in order to drive prices to target and to smooth fluctuations in the nominal interest rate:

$$i_t = \lambda_s i_{t-1} + (1 - \lambda_s) \left[i_t^n + \lambda_\pi (\pi_t - \overline{\pi}) + \lambda_y \left(\frac{y_t}{y_{t-1}} \right) \right] .$$

The parameter $0 < \lambda_s < 1$ controls the degree of interest rate smoothing while λ_π and λ_y determine the degree of responsiveness of the monetary authority to deviations of inflation from the long run steady state inflation and output growth. We focus on policies that deliver a determinate equilibrium.

4.4 Closing the model

We close the model as in Schmitt-Grohe and Uribe (2002) using a debt elastic interest rate:

$$i_t^e = i^\star + \epsilon_t^\star \psi \left(\exp^{\left(\widetilde{F}_t - \overline{F}\right)} - 1 \right) \tag{20}$$

where ϵ_t is a shock to the spread and i^* is the nominal external interest rate. It is well known from the literature in international economics that this device is needed for the small open economy model to have a well defined steady state around the long run level of debt $\overline{F}$. We motivate equation (20) based on the argument that the cost of borrowing in international financial markets is increasing in the aggregate stock of foreign debt.

4.5 Aggregate Equilibrium Conditions

Since the production of the non traded good can be consumed, invested or used to supply distribution services, we have that in equilibrium:

$$y_t^N = c_t^N + \frac{P_t}{P_t^N} x_t^N + \eta c_t^M$$

The aggregate balance of payments condition can be obtained from equation (5) and when aggregating across households we recognize that in equilibrium $B_t = 0$, so:

$$y_t + \frac{s_t}{P_t}(F_{t+1} - F_t) + \frac{s_t}{P_t} TR_t = c_t + x_t^N + x_t^X + \frac{s_t F_t i_t^e}{P_t} \tag{21}$$

with:

$$P_t y_t = P_t^X y_t^X + P_t^e y_t^e + P_t^N y_t^N.$$

The left hand side of equation (21) shows the sources of income of the economy: production, issuing of new debt and transfers from abroad. The right hand side shows the expenditures: consumption, investment and interest payments.[9]

4.6 Model Solution

In order to solve the model, we first state the first order nonlinear dynamic system that characterizes the competitive equilibrium. In order to calculate the steady state we transform the system equations into their deterministic steady state representation and solve using numerical methods. Then we log-linearize around the deterministic steady state. At this stage the system is expressed in terms of relative deviations from the steady state. After solving the model using the method of Klein (2000) (or any other method to solve the log-linear approximation to the rational expectations solution) we obtain matrices **M** and **H** which generate the dynamic solution by iterating on

[9] We have implicitly assumed that the government collects adjustment costs and rebates them to the households as lump sum transfers.

the following two equations:

$$\begin{aligned} \mathbf{Y}_t &= \mathbf{H}\mathbf{x}_t \\ \mathbf{x}_{t+1} &= \mathbf{M}\mathbf{x}_t + \mathbf{R}\eta_{t+1} \end{aligned} \tag{22}$$

where $\mathbf{Y}$ is a vector composed by control, co-state and flow variables, $\mathbf{x}$ is a vector of endogenous and exogenous states, $\mathbf{H}$ characterizes the policy function and $\mathbf{M}$ the state transition matrix. η_{t+1} is an innovation vector and $\mathbf{R}$ is a matrix composed of zeros, ones or a parameter instead of a one. This matrix determines which variables are hit by the shock and in what magnitude. Given a set of values of the parameters of the model, this state space representation will help us to compute the relevant statistics of the model such as the spectrum of the data, the likelihood function, among others.

5 Building a model-consistent database

We begin this section pointing which is the data that is used in the model, later we show which are the transformations made to the data in order to make it model consistent.

Since this is a multi sectoral model, the first step is to construct multi sectoral data. The data that we use is the areas of economic activity from the system of national accounts (SNA), the household national survey (HNS) and the balance of payment (BOP).[10]

The SNA classifies the GDP by areas of economic activity (or economic sectors). Each economic sector includes an additional disaggregation by goods; in order to classify each of these goods between non tradable, exportable/importable or endowment, we use two criteria: first, we classify goods by its nature, i.e. a good that it is extremely costly to move across borders is classified as non traded, otherwise is classified as tradable. Goods and services related to construction and services sectors are classified as non tradable goods. Obviously this is not a clear cut division. Some goods are difficult to classify, so we introduce a second criterion: if the volume of trade with respect to the production for each good is below 10 percent the good is classified as non traded. This classification gives bundles of goods that are used to construct the series for output, consumption, government expenditure, labor, consumption index prices, capital and investment for each sector.[11]

Time series of consumption of non tradable goods and services, consumption of importable sectors, output of non tradable, exportable and endowment sectors are constructed the same way as described above. The government consumption was classified as non traded as all the government expenditure is on non tradable goods and services.

Labor is included in the model as a share of worked hours devote to production between the non tradable and exportable sectors; therefore we need to construct a series of total worked hours for each sector. To construct total worked hours series we use the HNS. The survey includes an economic sectors classification that allows to construct

[10] In spanish these are: Sistema de Cuentas Nacionales, Encuesta Nacional de Hogares and Balanza de Pagos. The first two are released by the Department of National Statistics (DANE) and the last one by the Banco de la República.

[11] Non traded goods account, on average between 1994 and 2005, for 57.1% of GDP. Traded sector accounts for 42.9% of GDP distributed as 38.8% in exporting sectors and 4.1% in mining (oil and coal mainly).

the series for non tradable and exportable sectors. The real wage is also taken from the HNS.

Investment series for non tradable and exportable sector are constructed from the share of gross operation surplus[12] for each sector out of total gross operation surplus. These shares are applied to the economy gross capital formation from national accounts to obtain a proxy for investment in the non tradable and exportable sectors. To build time series of the capital stock of non tradable and exportable sectors we use the share of investment in each sector out of total economy investment. This shares are applied to an estimated initial value of total capital stock and then we use the capital accumulation equation to construct the time series.

We also need series for prices. The series for non tradable CPI and importable CPI are constructed using a classification of goods similar to the one use to construct the series for consumption and output. Other price series like total CPI, importable PPI, nominal exchange rate, real exchange rate, domestic interest rate, external debt, are available directly without any transformation. The external debt series are taken from the BOP accounts.

The model also includes several exogenous shocks for which we need time series; there are two technology shocks one for non tradable sector and other for exportable sector, there are external transfer shocks, endowment shocks, spread shocks, government expenditure shocks, and external prices shocks. The technology shocks for non tradable goods and exportable goods are constructed as a standard Solow's residuals for each sector.

We relate the endowment sector with the oil and coal exports in Colombia, therefore we use the values of exports for these two goods as a series of exogenous endowment sector. The external transferences series are taken from the BOP account "net foreign transfers". The spread shocks are constructed as deviations of the domestic 90 day certificates of deposits from the 90 day certificates of deposits in the US.

There are two external price shocks in the model, the first one is the price of importable goods, here we use the importable components of the US economy's CPI and construct and index of prices. The second one is the exportable good price, here we construct a price index of the international prices of Colombian exports.

Given that all macroeconomic aggregates in the model are expressed in terms of effective units of labor, we need to transform the database accordingly. We follow Prescott So we divide all variables which represent quantities (such as consumptions, investments, exports, imports, etc) by working-age population (WAP) multiplied by an exogenous path of technological progress. This latter is a linear trend with a slope equal to the average growth rate of the GDP per WAP of last twenty years and an intercept equal to the value of steady state of the TFP.

Other variables as CPI of non tradable and importable goods, total CPI, producer price index (PPI) were seasonally adjusted. Level of variables as worked hours and real external debt expressed in domestic currency are normalized. This normalization let that all these variables have an average of last twenty years equal to their steady state value implied by the model.

6 Parameterization

Model validation along with model design is an ongoing process at the central bank. There are a number of formal and informal econometric techniques to parameterize and evaluate DSGE models: calibration, generalized

[12]In spanish these correspond to the "Excedente Bruto de Explotación" in the system of national accounts.

method of moments (GMM) estimation, minimum distance estimation based on discrepancies between either impulse response functions or the spectrum of a VAR and the linearized solution of the DSGE model, full information maximum likelihood (FIML) estimation and Bayesian estimation. We review three approaches that we have followed: calibration, minimum distance based spectral analysis and more recently, the Bayesian perspective.[13]

6.1 Calibration

The word "calibration" has had different meanings at the Banco de la República. Initially, it was used to refer to a practice of setting the parameters of a model in such a way that the model exhibit some features that were consistent with either "the data" and/or particular events. For instance, instead of estimating the complete set of equations of the MMT, some parameters were set to reproduce certain degree of persistence, or pass-through observed in the time series. Later on, with the arrival of DSGE models, the word calibration was used in the Kydland-Prescott sense: setting parameters so that they are consistent with the long run restrictions implied by the model and the data.

The calibration practice has been useful at the bank in the model development phase. It has helped us to gain a lot of knowledge about key properties of the models that we have developed. It has been helpful to train staff members that are less familiar with modern macroeconomics. To calibrate our models we have employed standard techniques used in the Real Business Cycle literature.

The model calibration approach posed several difficulties for practical application at our central bank. First, setting parameters through calibration left us with little room to deal with parameter uncertainty. An important aspect of policy decisions is that the decisions are made under model uncertainty. In decision making under uncertainty every aspect of a model is subject to probability calculations and that includes parameters, model, shocks, to mention a few. So, we needed an approach that allow us to deal with parameter uncertainty.

Second, there has been a tradition at the Banco de la República in favor of econometric estimation. For econometricians the calibration practice is not seen as a scientific practice. In part, because there is no formal set of procedures that describes what exactly calibration is. The existence of some degree of informality in the procedure is a clear disadvantage over other methods.

6.2 Minimum Distance Spectral Analysis

In order to formalize the calibration procedure, we moved to more formal techniques of model validation. We found that the approach proposed by Ohanian and Berkowitz (1998) was a first step in that direction. Using simulated data from a single good small open economy model Hamann et al. (2004) study the ability of the model to capture the spectra, the phase and the coherence of observed output and inflation. This methodology allowed us to identify, at the relevant frequencies, what were the strong and weak features of the model in a formal and systematic way.

[13] Each of these approaches has reflected a process of discussions and exchange of ideas (either explicitly or implicitly) within the staff and or between staff and the academic community about what constitutes "best practice" in policy decision making.

The methodology consists of five steps. The first is to take the seasonally adjusted component of the log of GDP and inflation time series[14] and to filter them using Hodrick and Prescott, in order to eliminate frequencies beyond eight years. Second, estimate the sample data spectrum and compute its uncertainty using bootstrap techniques. Third, from the estimated spectrum and its uncertainly the researchers determine the salient and/or interesting features that they expect the theoretical model should be able to replicate. Fourth, compute the model's theoretical spectrum. Finally, compare the theoretical and observed estimated spectrums at the required frequencies and use an spectral maximum likelihood estimation technique to calibrate the model parameters by minimizing the disagreement between sample and theoretical spectrums at previously defined frequencies. Details of the results can be found in Hamann et al (2004).

Although this methodology is a formalization of the calibration procedure, it falls short of recognizing the possibility of parameter uncertainty. This is one of the reasons why the Bayesian perspective is attractive for applied work at the bank.

6.3 Bayesian Estimation

One of the advantages of estimating economic models using a Bayesian approach is that we can incorporate additional information on parameters through the use of priors. To perform the Bayesian estimation of our model we follow Schorfheide (2000) and proceed in five steps. First, for a given set of parameters we find the state transition equation. This equation describes the dynamics of the system around the deterministic steady state. Then, we add a measurement equation to the model dynamics to get its state-space representation. Next, we use the Kalman filter to derive the likelihood function of the model. The fourth step is to combine the likelihood function with the prior distribution of the parameters to compute the posterior density. Using numerical optimization we compute the mean of the posterior density and use a Metropolis-Hastings algorithm to get the posterior distribution of the parameters.[15]

6.3.1 Data

To estimate some of the parameters of the model we use our model-consistent database. We seek to explain the behavior of inflation, nominal interest rate, real output and real exchange rate for the period 1987:1 to 2005:4. As a proxy of the nominal interest rate we use the interest rate on 90-day certificates of deposits; our inflation measure is the quarterly (annualized) growth rate of the CPI; output is measured as the real GDP; and the real exchange rate is computed as the ratio of non tradable CPI to importable CPI. Let $d_t = (\pi_t, y_t, i_t, q_t)$ denote the observed data and $\Theta = (\omega, \theta, \sigma, \lambda_s, \lambda_\pi, \lambda_y, \Sigma, \Gamma)$ the vector of parameters to be estimated, where Σ denotes a vector containing the standard deviations of the shocks and Γ the autocorrelation coefficients of the exogenous states. We

[14]The series for the GDP was constructed as follows: For the period 1994-2003, the quarterly data was taken from the national accounts statistics reported by the Colombian national department of statistics (DANE). For the period 1977-2003, this series was backward-chained using the quarterly growth rate reported for this period by the national department of planning (DNP). The inflation series is from the Central Bank.

[15]The algorithm that we use is a Random Walk Metropolis (RWM). The RWM algorithm was first used by Schorfheide (2000) where it is described in detail. We use DYNARE, a Matlab Toolbox to estimate our model.

use Klein's method to solve the linear rational expectations model and the Kalman filter to evaluate the likelihood of the observable variables contained in d_t.

6.3.2 Priors

We impose dogmatic priors on the following parameters: β, γ, α_N, α_X, δ, ψ, Φ, ε and η. We choose $\beta = 0.98$ to give a real annual return close to 4%, which corresponds to the long run real return to capital in the US. To fix γ we compute the share of non traded goods in the CPI, which corresponds to 36%. We fix $\alpha_N = 0.38$ and $\alpha_X = 0.25$ to replicate the capital share in real GDP for each sector. For the depreciation rate we use 0.025. As for the ε, we set its value equal to 0.75, which is a standard value in the literature and implies that price contracts are updated once a year. The adjustment cost parameters are $\Phi = 15$ for investment and $\psi = 3$ for foreign debt. These calibrated values were set to match the volatility of investment and the current account. We put a very strong prior on both parameters because in estimating the model we do not use investment nor current account data. We also set $\eta = 0$, which corresponds to the perfect pass-through case.[16]

The prior distributions for the rest of the parameters are reported in the first four columns of Table 1. The inverse of the intertemporal elasticity of substitution follows a gamma distribution with mean 5 and standard deviation 2.5. We use these prior because evidence for the US shows that its value is higher than 1 but not much larger than 2. Evidence for emerging markets shows that it should be between 2 and 5, but some estimates get numbers close to 10.

For the Taylor rule coefficients we use the priors that are commonly used in the literature: $\lambda_\pi = 1.5$ and $\lambda_y = 0.125$. We use a normal distribution for both with standard deviations of 0.25 and 0.125. For the smoothing coefficient we have no previous information, so we choose a uniform distribution between 0 and 1.

For all autoregressive parameters we use a uniform prior between [0,1). We do not have strong priors about these values, since to our knowledge this is the first joint estimation of a micro-founded neokeynesian model. For all standard deviations of shocks we use an inverse gamma distribution with mean 0.1 and the largest possible variance.

6.3.3 Estimation Results

The last three columns of Table 1 summarize the estimation results. The parameter $\sigma = 0.2124$, which implies an intertemporal elasticity of substitution of 4.71, a bit lower than our prior of 5. We can say, with 90% confidence, that the elasticity lies between 3.45 and 7.47. This result is in line with the range of estimates in the literature for emerging markets: between 2 and 10. We find that the elasticity of substitution between varieties of non traded goods is $\theta = 3.8275$, different from our prior of 6. With 90% confidence its value lies between 2.63 and 5.64. This result implies markups in the range of 60% to 20%. The values are extremely high if we compare them to those found for developed countries. In studying the markups in the Colombian industry, Arango et al. (1998) find that the average markup is 25%. This value is consistent with our lower range.

[16] At the time of writing this paper we are having convergence problems with this parameter for values other than zero in the Metropolis Hastings algorithm.

As for the policy rule parameters, we find that a response to inflation of $\lambda_\pi = 1.68$, to output growth of $\lambda_y = -0.04$ and a smoothing desire of $\lambda_s = 0.43$. The response to inflation and real growth differ from our priors, that were set accordingly to the Taylor principle. In fact, what our results show, is that the monetary authority has been active when responding to deviations from long run inflation and passive when responding to output. This result is in line with recent theoretical developments of Schmitt-Grohe and Uribe (2004). They find that social welfare increases when the central bank only responds to inflation. Bernal (2002), using a frequentist approach to estimate Taylor rules in a partial equilibrium model for Colombia, finds that $\lambda_\pi = 1.34$, $\lambda_y = 0.19$ and $\lambda_s = 0.10$. Notice that our rule does not respond to the output gap but to output growth. As we will see later, our results support the idea of the Colombian business cycle being mainly driven by productivity and foreign shocks. In this case, the central bank can lower interest rates during economic expansions.

The rest of parameters are those associated with the dynamics of the shocks. We observe that terms of trade and productivity shocks are volatile and persistent. Foreign and policy interest rate shocks are less volatile. Later, we will study the contribution of these shocks to the variance of the observed time series.

7 Quantitative Analysis

We use the posterior mean estimates of the parameters to perform some quantitative exercises. We evaluate the response of the model to several shocks: an oil shock, a terms of trade shock and a monetary policy shock. We compute the percentage of the variance of inflation, output, interest rates and real exchange rate that is explained by each of these shocks. In a final exercise we explore the quarterly forecasting performance of the model at a horizon of two years.

7.1 Effect and importance of shocks

Figures 9-11 show the response of the main variables to a positive shock in: the mining sector, the price of exports shock and the monetary policy rate. All three shocks cause a real exchange rate appreciation but operate through different channels. A positive mining shock increase disposable income of households, so they can increase consumption and investment of all goods. Traded goods can be imported, but non traded goods have to be supplied by domestic firms. So there is a trade balance deficit and the real exchange rate falls initially, but must increase in the future. There is a nominal appreciation that passes through inflation and so the monetary authority reduces the policy rate.

The price of exports shock has a similar effect. An unexpected increase in the price of exports induces a reallocation of resources from the non traded to the traded sector causing an initial real appreciation a depreciation later. Inflation falls because of the pass-through and the central bank reduces the policy rate. The difference here is the effect on the trade balance: here we have a trade surplus, while in the case of the mining shock we have a standard Dutch disease effect.

An unexpected monetary policy shock causes output and inflation to fall but consumption to increase. This is an unconventional result in the closed-economy-sticky-price models, but a feasible one in a small open economy model. As household can smooth consumption by borrowing or lending in foreign financial markets, an increase in the domestic policy rate, makes it cheaper for household to borrow abroad than at home. So, by running a trade balance deficit consumption can increase, despite the negative effects of higher interest rates production and investment.

A related finding is that monetary policy shocks account for a small fraction of fluctuations of the main macroeconomic variables. We present the results in Table 2. The variance decomposition exercise shows that policy shocks explain 3.7% of the variation of inflation, 2.2% of the real exchange rate and 0.1% of output. The largest source of variation comes from shocks in the Total Factor Productivity of the non traded sector. Non traded TFP shocks explain 52% of variation in output, 54% of inflation and 57% of the interest rate. This shock explains only 13% of real exchange rate variation. Terms of trade shocks account for 62% of the variance of the real exchange rate and explain a significant portion of fluctuations in output (32%), interest rates (29%) and inflation (28%).

7.2 Forecasting Performance

In this section we compare the forecasting performance of our current core model, the MMT, and our general equilibrium model, the MTYNO. We compare the out-of-sample forecasting performance of both models. We compute a two year forecast and compare their accuracy at different horizons (quarters). As our measure of the forecasting accuracy we use the Root Mean Square Error (RMSE) for the forecasted inflation and for the forecasted output gap. We use the Root Mean Square Percentage Error (RMSPE) for the output level.

To compute the RMSE for the MMT we take the official central bank's projection and compare it to the observed inflation and output gap ex-post.[17] This projection includes the short term forecast made by the bank's expert. We refer to this projection as the "MMT's forecast". For the MTYNO we compute the statistics using a rolling of the out of sample forecast, for the period 2003:1 to 2005:4, then we take the first nine quarters forecast for each period and compute the statistic. We assume that the endogenous states of the model start from steady state, while the observable exogenous states start from their trend deviations. This is some form of systematic adjustment to the model's forecast to recognize first, that there is no short term forecast for the MTYNO and second that the model does not have enough persistence.

Table 3 summarizes our results. The first two columns compare the RSME of annual inflation for both models; in the first 8 quarters, the MMT outperforms the MTYNO: it has lower RSME than the MMT.[18] However, at the first quarter horizon both models generate similar forecast errors. There is only a 6 bps difference on average between the inflation RMSEs. As the horizon increases these differences grow. The MMT produces more accurate forecasts of inflation after the fourth quarter. For instance, at 8 quarters the MTYNO has an inflation RMSE of 140 bps while the MMT has an error of 64 basis points.

The last two columns present the results for output. In forecasting the output gap, the MMT outperforms the

[17] To compute the ex-post output gap we take all sample information available and use an HP filter (adjusted by priors).

[18] Unfortunately it was not possible to recollect all the information to compute the RMSEs for more than 9 quarters. This is so because the published bank's forecast is performed at a two year horizon.

MTYNO at the first eight quarters. At the first quarter horizon the RMSE of the MMT model is 1.06, while the RMSE of the MTYNO is 1.14. In this case the difference also grows as the forecasting horizon becomes larger, but on the ninth quarter the MTYNO delivers its best fit.

In the table 4 we present the results of the tradable and non tradable for the real exchange rate and for the output growth. The results for the real exchange rate represent deviations of the index of real exchange rate with respect to the observed index in percentage. The results for the output growth represents deviations of the growth rate of output forecasted against the observed growth rate. The model forecasts output growth quite well at short and longer horizons. However, at the horizon that is relevant for monetary policy, 5 to 8 quarters, produces large forecasting errors.

It is evident that the model is not able to forecast the real exchange rate at any horizon and that forecasting errors are very large. We suspect that this is because the persistence in the observed real exchange rate is higher than the one in the model. As labor can move freely between sectors, the implied RER will also adjust at a similar speed. This may induce a gap between the observed RER and the model's RER. We are currently working on this topic.

8 Final Remarks

In this paper we presented a description of the progress made in designing and implementing MTYNO, a DSGE model for monetary policy analysis and forecast in Colombia. We explained the reasons that lead us to the current structure of the model, the main problems that we have had to face and how we have approached them. In designing the model we took into account several elements like: the Colombian economy stylized facts, the economic discussions between the technical staff and the Board of Governors, the Governor's language to communicate decisions to the public, among other factors. Our DSGE model includes two main productive sectors; the non traded sector and the traded sector. The first one produces differentiated goods that are consumed domestically and used for investment. The second is divided in two categories, the exportable sector that use labor and capital as inputs for production and the mining sector that is modeled as an exogenous endowment. All the production of the traded goods is exported abroad. In addition there is an importing sector of consumption goods. We assume complete markets for domestic assets, but incomplete markets for foreign assets. Households consume imported and non traded goods, so the inflation rate is determined by the weighted behavior of imported and non traded prices. The model allows us to study the impact of several shocks commonly ignored in standard models like: oil prices, terms of trade, productivity (in the exporting and non traded sectors) and net foreign transfers.

To find the values of the parameters of the model we described three approaches: calibration, spectral analysis and a Bayesian approach. Using the estimated parameters we compute impulse responses and decompose the variance of the main macro variables into the contributions of different shocks: mining, the price of exports and the monetary policy. We illustrate that the structure of the economy is important in understanding how these shocks propagate through the economy. Furthermore, when we simulate the model we find that monetary policy shocks account for a small fraction of fluctuations of the main macroeconomic variables. Policy shocks explain only 3.7%

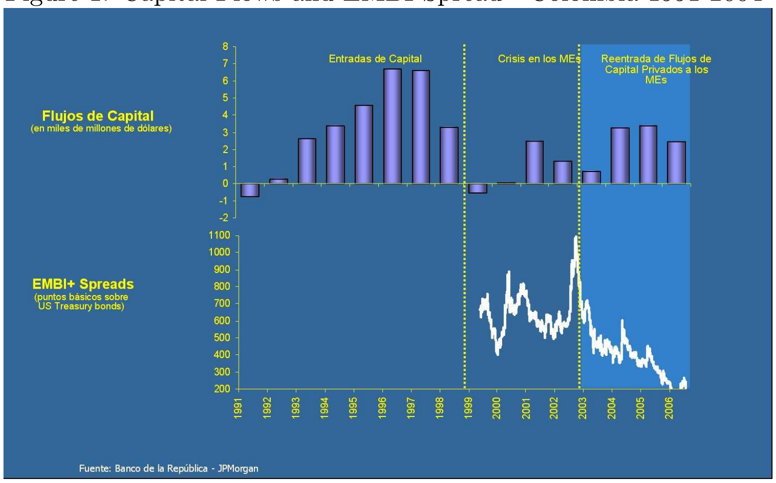
of the variation of inflation, 2.2% of the real exchange rate and 0.1% of output. The largest source of variation comes from shocks in the TFP of the non traded sector. Non traded TFP shocks explain more than half of the variation in output, inflation and the interest rate. Foreign shocks are also important. For instance, terms of trade shocks account for 62% of the variance of the real exchange rate and explain nearly a third of fluctuations in output, interest rates and inflation.

Using DSGE models at central banks helps to illustrate the importance of understanding how different shocks propagate through the economy. They help also to have an idea of the quantitative importance of these shocks. One lesson of our model is that, in an economy in which tradable competitive sectors are important the relevance of monetary policy shocks can be greatly diminished (at a given degree of nominal rigidities). This result contrasts with the one derived from the single good neokeynesian model in which monetary policy has a great deal of power in affecting real activity.

We conclude by evaluating the ability of the model to forecast inflation, output and the real exchange rate. We also contrast these results against our best macroeconomic projection available at the time the forecast is made with the current core model, the MMT, and the staff's assessment. We find that the latter beats the former at most horizons, but the difference is not so large. In general, the MTYNO is able to forecast accurately inflation, output and output growth. The results are better at shorter horizons than at longer ones. Unfortunately, in forecasting the real exchange rate the model performs poorly at any horizon. This is a serious problem, given that the aim of our model was precisely to explain open economy variables. Solving this problem sets the agenda for future model developments. Although forecasting accuracy is important for any central bank, this should not be the only criterion taken to evaluate a model. First, besides the statistical error, there are other sources of errors in policy models. An important comes from the fact that the monetary authority can deviate from the model's policy recommendation. Some times this discrepancy lasts for long periods of time. So, if we look at the forecasting performance it may be difficult to assess, in a general equilibrium framework, how much of the error is due to the policymaker deviating from the model's policy recommendation and how much is due to purely forecasting ability. Second, having a structural model can help to develop the logic of other models that are more flexible and that might have better forecasting ability. Third, not only quantitative assessments are important for central bank economists. The logic of general equilibrium may help to support monetary policy decisions or to explain puzzling economic outcomes. This puzzling events may arise as a natural outcome in general equilibrium models. These are some reasons why, we should continue to use DSGE models, even though their forecasting ability is not so great. Our MTYNO is a first step in that direction.

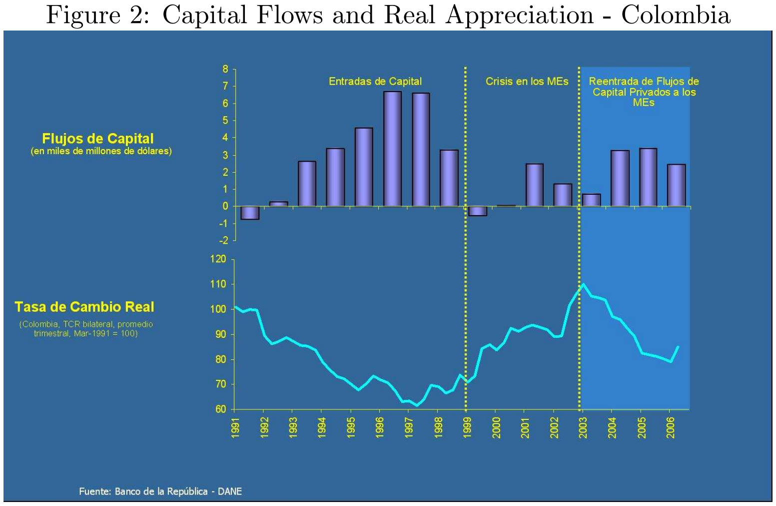
Appendix 1: Figures

Figure 1: Capital Flows and EMBI Spread - Colombia 1991-2004



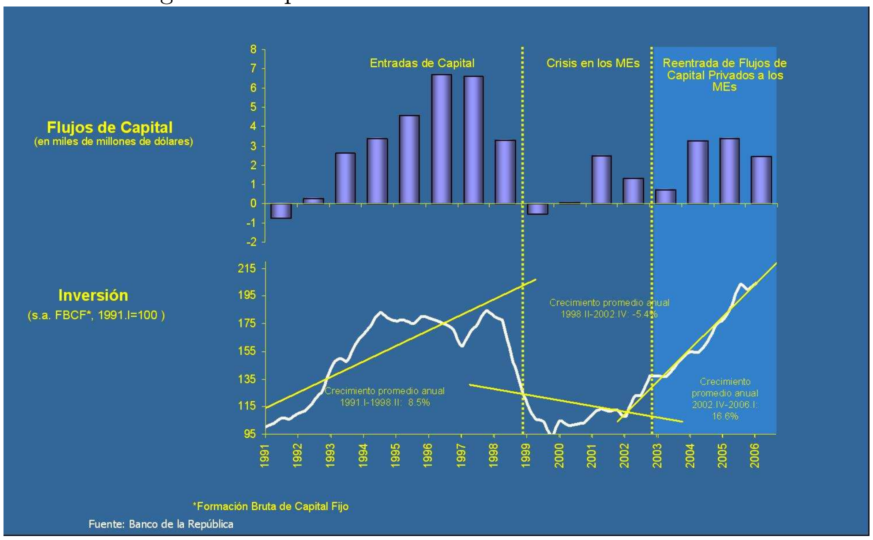
Source: S&P and Banco de la República - DMM calculations

Figure 2: Capital Flows and Real Appreciation - Colombia



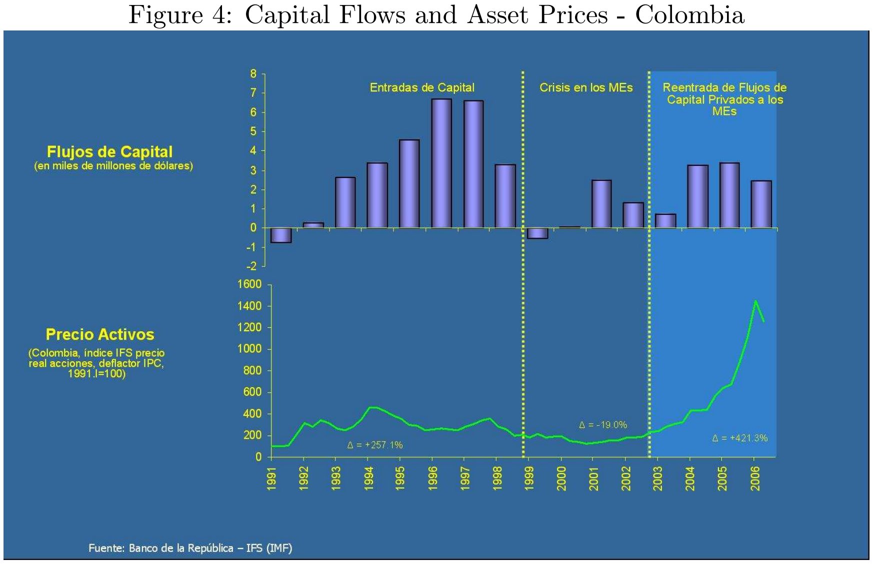
Source: Banco de la República - DMM calculations

Figure 3: Capital Flows and Investment - Colombia



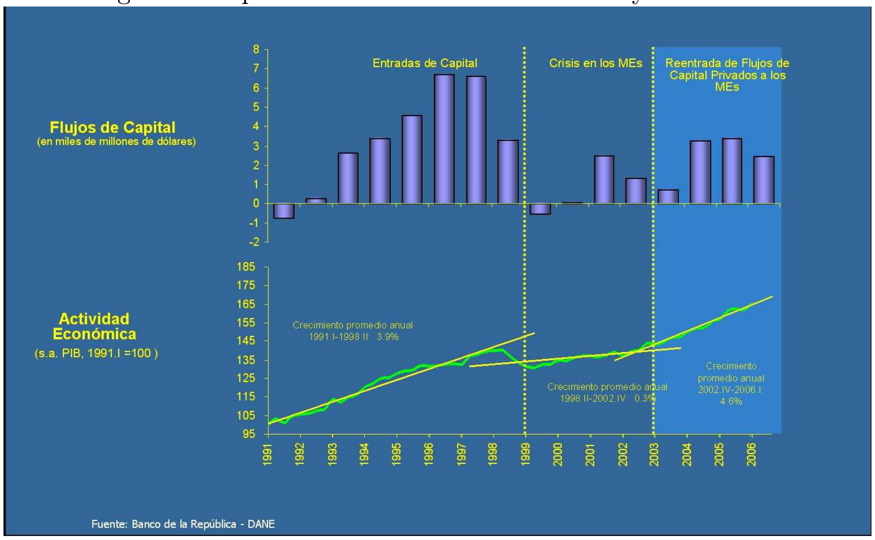
Source: DANE and Banco de la República - DMM calculations

Figure 4: Capital Flows and Asset Prices - Colombia



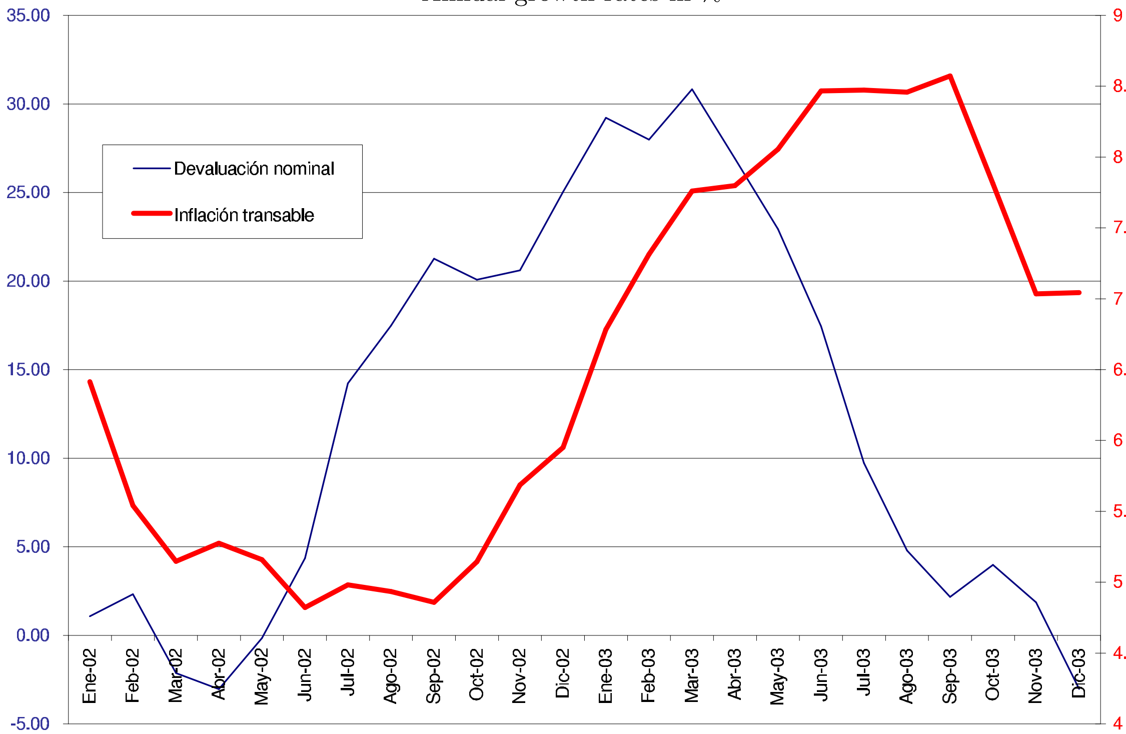
Source: Banco de la República - DMM calculations

Figure 5: Capital Flows and Economic Activity - Colombia



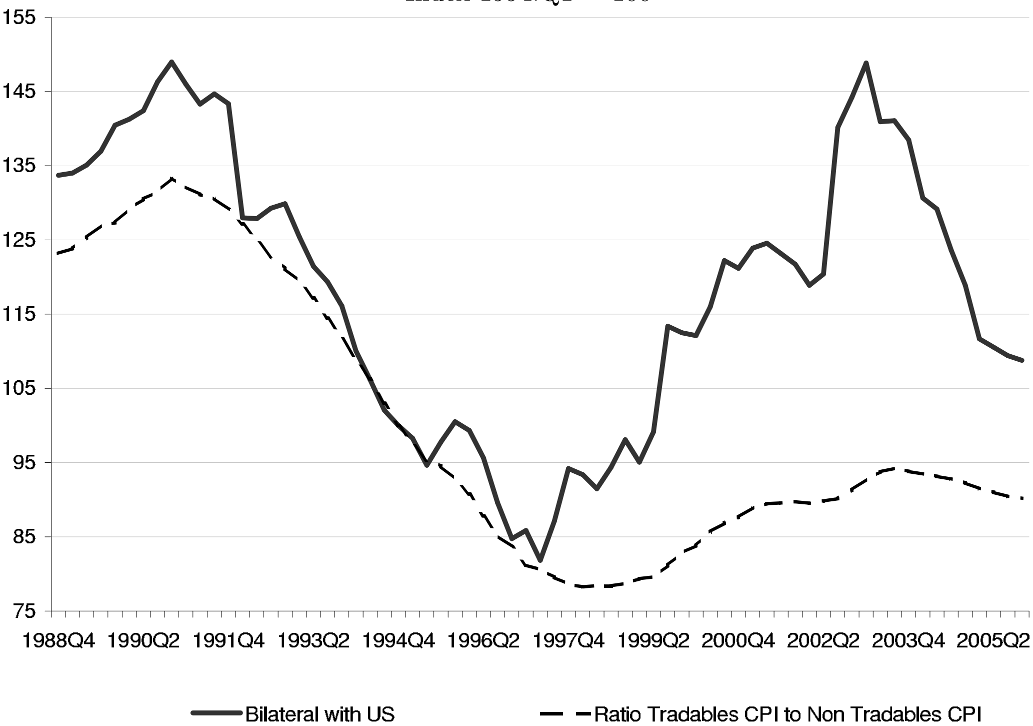
Source: DANE and Banco de la República - DMM calculations

Figure 6: Nominal depreciation and tradable inflation
Annual growth rates in %



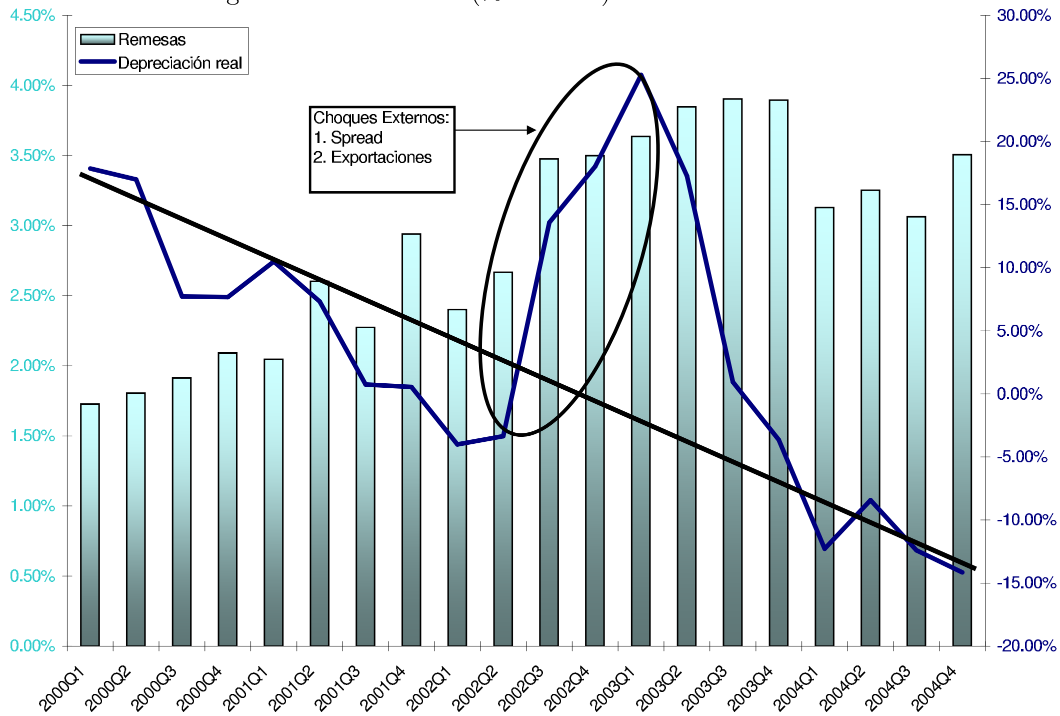
Source: DANE and Banco de la República - DMM calculations

Figure 7: Bilateral RER with US and tradable and nontradable inflation
Index 1994:Q1 = 100



Source: DANE and Banco de la República - DMM calculations

Figure 8: Remittances (% of GDP) and RER - Colombia



Source: DANE and Banco de la República - DMM calculations

Figure 9: Response to an oil shock

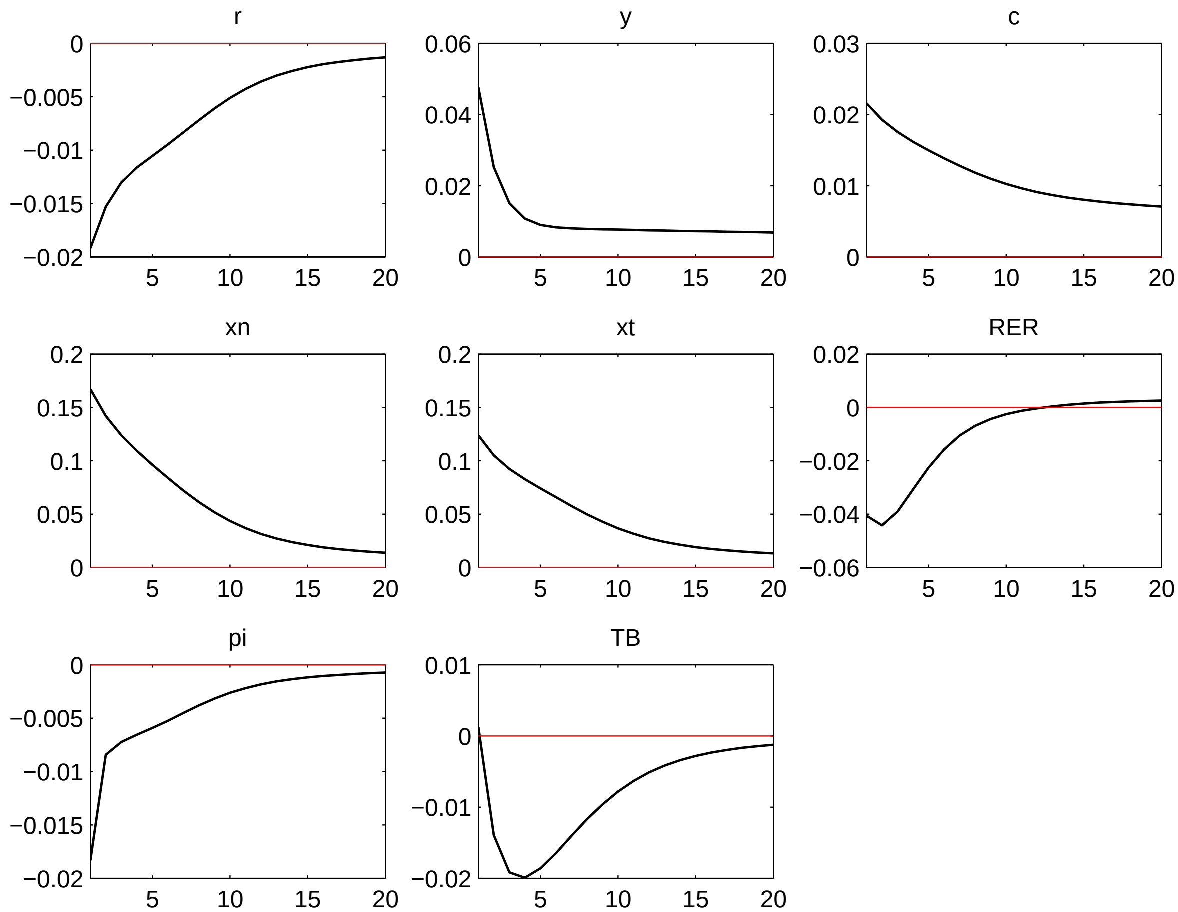


Figure 10: Response to a terms of trade shock

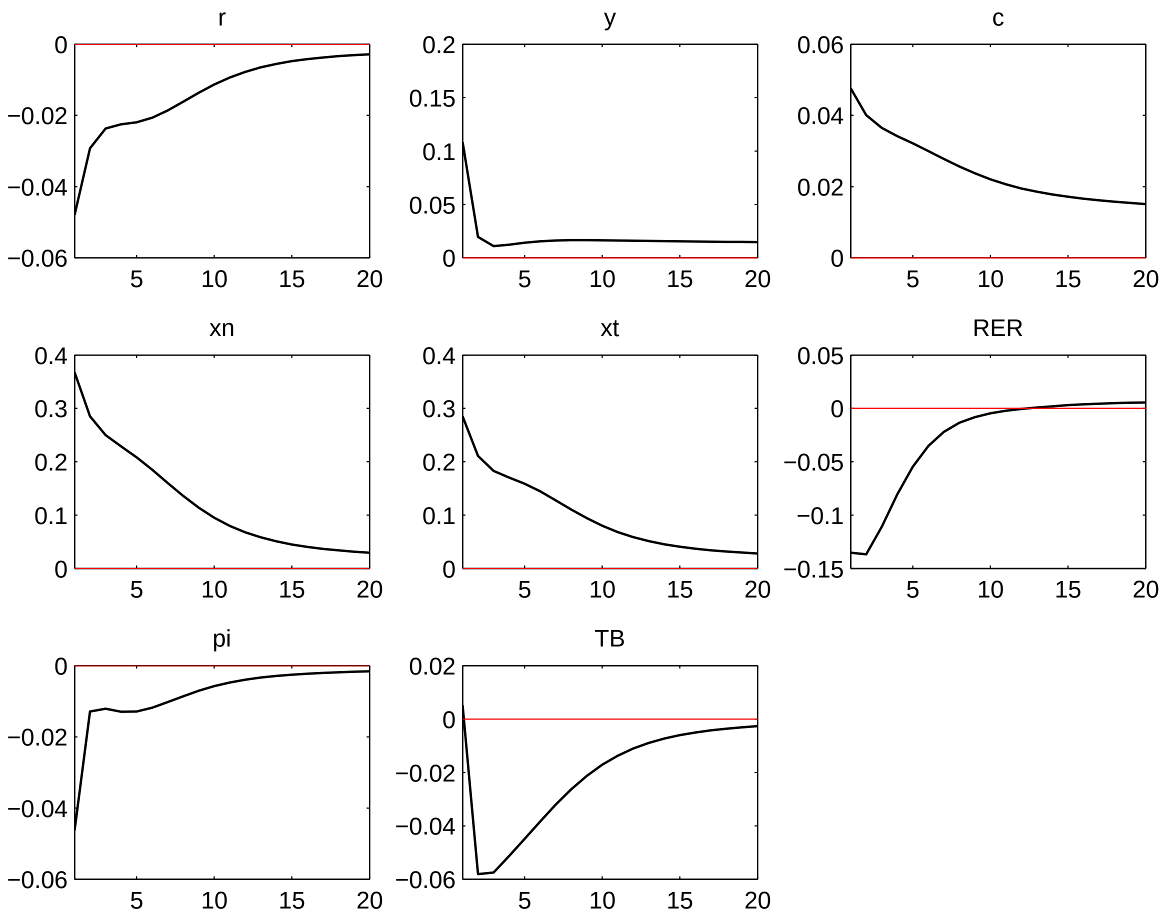
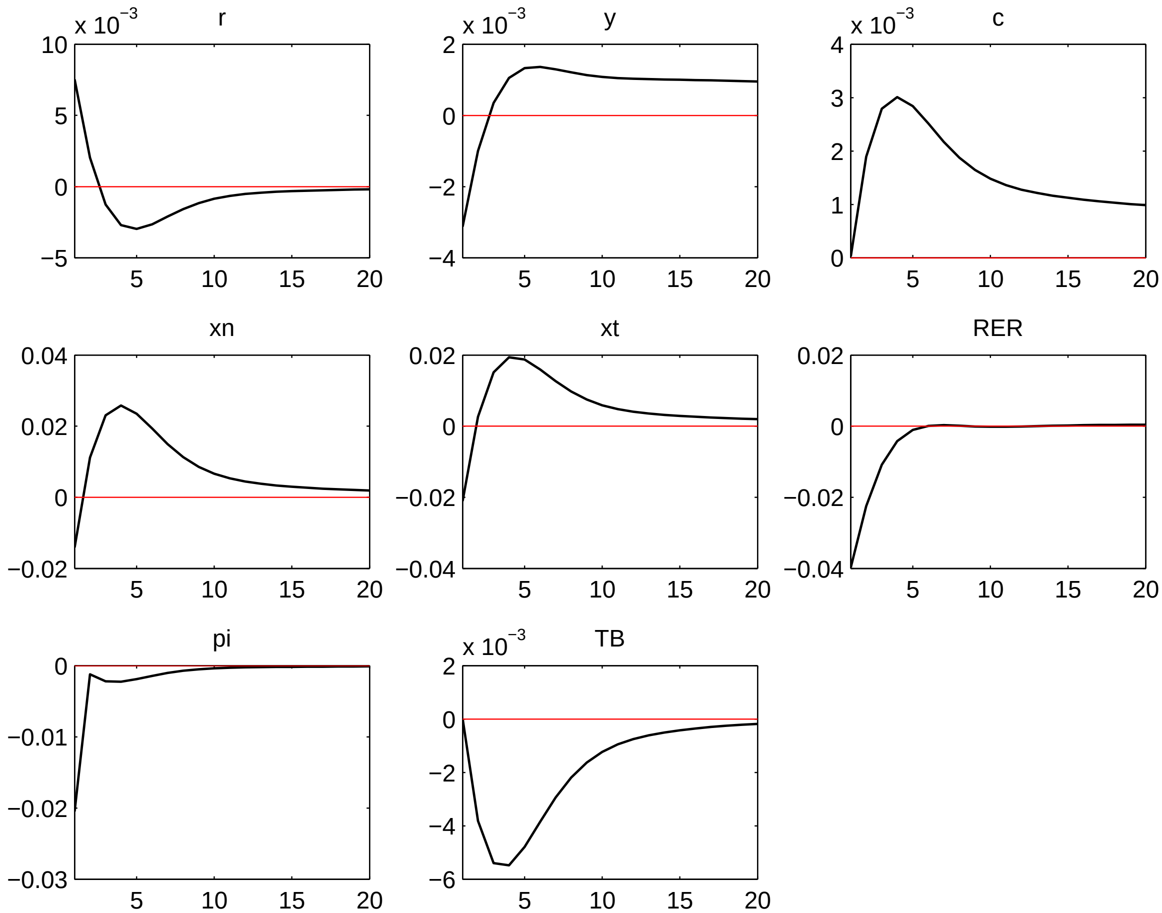


Figure 11: Response to a monetary policy shock



Appendix 2: Tables

Table 1: Prior and Posterior Distributions

Parameter	Prior Distribution	Prior mean	Prior Std Dev	Posterior Mean	Posterior Conf. Interval	
σ	Normal	0.2	0.1	0.2124	0.1338	0.2901
λ_s	Uniform [0,1)	0.5	0.2887	0.4341	0.3296	0.5472
λ_π	Normal	1.5	0.25	1.6753	1.3261	1.9504
λ_y	Normal	0.125	0.125	-0.0423	-0.2055	0.2171
ρ_{A^T}	Uniform [0,1)	0.5	0.2887	0.0188	0.0002	0.0466
ρ_{A^N}	Uniform [0,1)	0.5	0.2887	0.2242	0.0487	0.4254
ρ_{R^*}	Uniform [0,1)	0.5	0.2887	0.5251	0.1309	0.9878
ρ_{P^X}	Uniform [0,1)	0.5	0.2887	0.1177	0.0000	0.1112
ρ_{y^e}	Uniform [0,1)	0.5	0.2887	0.4740	0.0747	0.9708
θ	Gamma	6	1.42	3.8275	2.6328	5.6365
σ_{A^T}	Inv. Gamma	0.1	∞	0.1374	0.0243	0.2023
$\sigma_{A^{NT}}$	Inv. Gamma	0.1	∞	0.2640	0.2162	0.3186
σ_{R^*}	Inv. Gamma	0.1	∞	0.0911	0.0274	0.1277
σ_{P^X}	Inv. Gamma	0.5	∞	0.2691	0.1954	0.4098
σ_{y^e}	Inv. Gamma	0.1	∞	0.0392	0.0230	0.561
σ_μ	Inv. Gamma	0.05	∞	0.0271	0.0220	0.0315

Table 2: Variance Decomposition (in percent)

	Traded TFP	Non traded TFP	Foreign Int. Rate	Export Prices	Mining	Monetary Policy
Interest Rate	7.36	56.53	0.90	28.66	6.13	0.42
Output	8.02	51.88	0.34	31.95	7.73	0.09
Consumption	8.81	47.22	0.71	35.39	7.72	0.15
Invest.Non traded	8.17	51.15	0.76	32.54	7.19	0.19
Invest.Traded	7.94	52.63	0.79	31.56	6.87	0.22
RER	14.88	13.13	1.15	61.40	7.25	2.19
Inflation	7.35	54.13	1.10	28.21	5.49	3.71

Table 3: Forecasting errors in percent

Quarters Ahead	Annual Inflation	Annual Inflation	real GDP	gap GDP
	MTYNO	MMT	MTYNO	MMT
1	0.33	0.27	1.14	1.06
2	0.46	0.38	1.60	1.06
3	0.59	0.50	1.75	1.16
4	0.81	0.61	1.91	1.14
5	0.95	0.73	2.03	1.19
6	1.16	0.58	2.41	1.21
7	1.28	0.60	2.66	1.33
8	1.28	0.59	2.09	1.44
9	1.40	0.64	0.67	1.04

Table 4: Forecasting errors in percent

Quarters Ahead	Real Exchange Rate	GDP growth
	MTYNO	MTYNO
1	10.11	0.31
2	11.74	0.67
3	13.30	1.07
4	14.52	1.48
5	14.95	1.58
6	19.51	1.49
7	24.11	1.51
8	27.55	1.46
9	24.15	1.11

References

Arango, Juan Pablo, Orlando Gracia, Gustavo Hernández and Juan Mauricio Ramírez (1998), 'Reformas comerciales, márgenes de beneficio y productividad en la industria colombiana', *Planeación '&' Desarrollo* **XXIX**, 59–78.

Bernal, Raquel (2002), Monetary policy rules in colombia, Working paper, CEDE Universidad de los Andes.

Calvo, Guillermo A. (1983), 'Staggered prices in a utility-maximizing framework', *Journal of Monetary Economics* **12**(3), 383–398.

Devereux, Michael B., Philip R. Lane and Juanyi Xu (2004), Exhange rates and monetary policy in emerging market economies. University of British Columbia.

Engel, Charles (1999), 'Accounting for us real exchange rate changes', *jpe* **107**.

Gomez, Javier, J.D. Uribe and Hernando Vargas (2002), The implementation of inflation targeting in colombia, Working paper 202, banrep.

Hamann, Franz, Juan Manuel Julio, Paulina Restrepo and Alvaro Riascos (2004), Inflation targeting in a small open economy: the colombian case. Banco de la República.

Kam, T.C.Y. and G.C. Lim (2001), Interest rate smoothing and inflation-output variability in a small open economy. University of Melbourne.

Klein, Paul (2000), 'Using the generalized schur form to solve a multivariate linear rational expectations model', *Journal of Economic Dynamics and Control* **24**, 1405–1423.

Ohanian, Francis X. Diebold-Lee E. and Jeremy Berkowitz (1998), 'Dynamic equilibrium economies: A framework for comparing models and data', *Review of Economic Studies* **65**(3), 433–451.

Rowland, Peter (2003), Exchange rate pass-through to domestic prices: The case of colombia, Borradores de Economía 254, Banco de la República.

Schmitt-Grohe, Stephanie and Martin Uribe (2002), Closing small open economy models, Working paper 9270, National Bureau of Economic Research.

Schmitt-Grohe, Stephanie and Martin Uribe (2004), Optimal simple and implementable monetary and fiscal rules, Working paper 10253, National Bureau of Economic Research.

Schorfheide, Frank (2000), 'Loss function-based evaluation of DSGE models', *Journal of Applied Econometrics* **15**, 645–670.

Zanna, Luis-Felipe (2003), Taylor rules and multiple equilibria in the small open economy: The role of non-traded goods. Department of Economics, University of Pennsylvania.

Zanna, Luis-Felipe (2004), PPP rules, macroeconomic (in)stability and learning, International Finance Discussion Papers 814, Board of Governours of the Federal Reserve System.