Development of MEGA-D: A DSGE Model for Policy Analysis*

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(preliminary)

Abstract

This paper summarizes the development of a DSGE model for policy analysis at the Central Reserve Bank of Peru. The first sections describe the importance of the model, a small review of the project and describe linear version of the model. The fourth and fifth sections describe some parameter-estimation results and some policy exercises. The last section describes the forecasting process and exercises with the model.

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1. The MEGA-D Project

1.1 ¿Why a general equilibrium model?

In recent decades, academic research has emphasized the development of Dynamic Stochastic General Equilibrium (DSGE) models, whose key feature is the use of microeconomic foundations for modeling the behavior of the aggregate economy. This type of models offers several advantages. First, microfundations prevent equations arising from these models to be subject to the Lucas' critique (1976). Also, this feature allows to analyze the macroeconomic effects of microeconomic phenomena, such as changes in the degree of competition between firms, and analyze the effects of economic policy measures from economic agents´ welfare point of view. Second, the individual rationality behind the aggregate behavior is useful to analyze the impact of monetary policy on private agents expectations. Moreover, rational expectations differentiate effects between permanent and transitory shocks and between anticipated and unanticipated shocks. Third, the general equilibrium structure maintain in the model the consistency between flow and stock variables, such as investment with respect to capital and the current account balance with respect to the net foreign assets position. Last but not least, there is recent empirical evidence showing that DSGE models can have a better forecasting performance than purely statistical models[1].

The flexibility of these models allows to solve a wide range of questions relevant to the central bank, such as the role of financial frictions in the transmission mechanisms (for example, *what are the effects on the risk premium for increasing debt?, what are the effects of limiting the access to credit?*), the role of frictions in the labor market (for example, *what are the effects of low of labor mobility?, what are the effects of the slow adjustment in nominal wages?*), effects of changes in relative prices (for example, *what happens when the terms of trade or the real exchange rate change*?), implications of aggregate shocks to a specific sector (for example, *what are the differences between an increase in productivity in the tradable sector respect to the non-tradable sector?*), among others. Additionally, the larger structure helps to disentangle the sources of macroeconomic fluctuations (eg, *inflation of recent years has been generated by supply or demand shocks?*).

1.2 Objetives

The DSGE model that is being developed at the Central Reserve Bank of Peru (BCRP) has received the name of MEGA-D, whose initials in English mean Aggregate General Equilibrium Model with dollarization. The MEGA-D has been designed to include the main features of the Peruvian economy –including partial dollarization-, in a medium-scale model that can be easily extended to explain different stylized facts or economic episodes.

[1] See Del Negro and others.

The main objective of this model is to conduct policy analysis, namely forecast and simulations conditional on the behavior of monetary (and / or fiscal) policy. Also, the model structure can be used to decompose macroeconomic variables on the factors that explain their fluctuations (shocks), both in history and forecast.

Because of its design features, such as micro-foundations, dynamics, uncertainty and rational expectations, a potential use of the model is the evaluation of monetary policy measures using a welfare criterion. For example, we can assess the effects of a lower reaction to the exchange rate or a stronger reaction to inflation.

Other potential uses of the model are the estimation of non-observable variables such as the natural interest rate[2], the potential output, the real exchange rate equilibrium and the natural unemployment rate for the Peruvian economy. The main advantage of the model in the estimation of these variables is the ability to estimate all of them simultaneously. In this way, the forecast of the natural interest rate in the model would be consistent with the forecast of the potential output and the real exchange rate equilibrium.

Finally, the model can also be used to assess the impact of economic policy measures in the long term using the steady state equilibrium. Thus, from the steady state of the model we can analyze the implications of policies such as tariff reductions, changes in tax levels, greater financial market development, increased competition in the goods markets, among others.

1.3 Brief review of the project

Because of the advantages previously mentioned, DSGE models are gradually being incorporated as tools for policy analysis in central banks. Thus, most of central banks that operate under the MEI are implementing such models in their projection systems, for example, the Central Bank of Sweden - Riskbank (Ramses), Bank of Canada (TOTEM), USA (SIGMA), Central Bank of Norway (TOTEM), UK (BEQM), Chile (MAS), Switzerland (DSGE-CH) [3].

Currently, the BCRP is integrating the MEGA-D in its process of forecast and analysis of monetary policy. This project began in 2006 at the Research Division of the Economic Studies Department. The first phase of the project was to write a document that recounts the main empirical regularities of the Peruvian economy (Castillo, Montoro and Tuesta 2007a). Also, a previous version of the model was estimated with Bayesian econometrics (Castillo, Montoro and Tuesta 2006a) and used to estimate non-observable variables. Currently the project is implementing the forecast of macroeconomic variables using the latest version of the model (Castillo, Montoro and Tuesta 2009).

[2] Following Wicksell´s definition (1898), the natural interest rate is the real interest rate consistent with price stability.
[3] See Tovar (2007) for a review on the current situation and challenges of these models in the conduct of monetary policy.

2. Key Elements and Assumptions of the Model

2.1 Overview

The model has several features to replicate the main stylized facts of the Peruvian economy, which are linked to the structure of the economy in question. For example, the model allows households and businesses to use two currencies, the dollar and the Sol, to conduct transactions, pricing and issue debt. In this way, we are taking into account the high degree of dollarization in the Peruvian economy. We also consider that firms when borrowing pay a risk premium on top of the interest rate set by the central bank, a typical feature of little developed financial markets as in Peru. Similarly, we allow real wages to deviate from their competitive equilibrium, taking into account the presence of unemployment and the low response of real wages to fluctuations in aggregate demand, as observed in the Peruvian economy.

Besides the features mentioned above, the model allows for flows of goods, services and financial assets between domestic and foreign agents, typical of open economies. These flows explain the dynamics of balance of payments and foreign debt in the model. It also assumes that the internal conditions of the Peruvian economy had no effect on the global economy, consistent with the relative size of the Peruvian economy to the rest of the world. All these characteristics within the model have implications for the design of monetary policy and its transmission mechanism, which is summarized below.

2.2 The transmission mechanism of monetary policy in the MEGA-D

Following the recent advances in the development of models for monetary policy analysis, the role for monetary policy in this model is based on: a) money b) monopolistic competition in the market for final goods, and c) price stickyness. The presence of money in the model is crucial because it allows prices to be set in terms of monetary units. However, unlike other general equilibrium models, in this model there are two forms of fiat money: the Sol and the dollar. In this way, we consider the fact that in the Peruvian economy part of the pricing, trading and financial intermediation is performed using U.S. dollars. Moreover, the monopolistic competition assumption in the model allows firms to set prices. The optimal price of firms is proportional to their marginal costs, which in turn depend on wages, productivity, cost of capital, the terms of trade and the real interest rate, among other factors. The third element, price rigidities, imply that firms cannot change prices every period without incurring costs. Therefore, when setting prices they must consider not only the current marginal costs but also those expected for future periods.

The combination of monopolistic competition and price rigidities determines in the model the aggregate supply curve (also called Phillips curve) to domestic prices, which relates the dynamics of domestic inflation to three factors: a) expectations inflation, b) marginal costs and c) cost shocks not related to demand pressures (also known as cost-push shocks). In the model, there are four main transmission mechanisms of monetary policy to inflation and economic activity: the interest rate, expectations, the financial accelerator and the crowding out in spending.

Monetary policy in the model affects directly both consumption and investment by controlling the rate of interest, and control inflation through these effects on aggregate demand. Monetary policy is implemented via an interest rate rule, which summarizes the preferences of the central bank to avoid the costs associated with inflation and fluctuations in the economic activity and interest rates. This rule evolves according to a) deviations in inflation expectations respect to the inflation target, b) demand pressures, as measured by the level of economic activity and c) variations in the exchange rate. It is also considered that the interest rate rule is highly persistent, consistent with the behavior observed in most central banks.

Expectations about the future conduct of the monetary authority and the macroeconomic variables are important in the transmission mechanism of monetary policy. In the model, the interest rate relevant to the decisions of consumption and investment is the long-term interest rate, which is determined by expected increases in short-term interest rates. So if it is expected that the increase in the short-term interest rate is persistent, the impact on aggregate demand will be higher. Similarly, consumption and investment depend on the level of expected future aggregate demand and the future productivity of capital, variables that are also related to the future behavior of the central bank. This feature of the model makes it a useful tool to analyze the macroeconomic implications of improvements in central bank credibility. The predictability of monetary policy in the model is crucial. If the central bank does not react in a predictable way to the state of the economy, it is possible to anchor inflation expectations to target of the central bank.

In addition to interest rate and the expectations channels, the model consider other transmission channels of monetary policy, as the financial accelerator. This block closely follows the work by Gertler, Natalucci and Gilchrist (2007) and Deveraux, Lane and Xu (2006). In these models, firms borrow in the financial system to finance investment by paying a risk premium that depends on their degree of leverage. Those who firms that are highly leveraged must pay a premium for higher risk than those who are not. In this case, the impact of monetary policy is amplified because the central bank also affects the risk premium. Thus, an increase in interest rates reduces the value of corporate assets and its cash flow deteriorates, both factors increase the risk premium amplifying and making more persistent the impact of monetary shocks in the economy.

In the model, the financial accelerator channel has an additional feature, financial dollarization. The model considers that part of firms' debt is denominated in U.S. dollars, therefore, this mechanism is triggered also by fluctuations in the exchange rate. In this case, an increase in the exchange rate increases the real value of company debt and consequently their risk levels. This leads banks to charge a premium for higher risk, increasing the cost of investment. In the model, the existence of financial dollarization weakens the transmission channel of interest rates for monetary policy, but amplifies the role of external shocks and the exchange rate. This result is consistent with the empirical evidence shows that economies with financial dollarization are more vulnerable to financial shocks[4].

The other channel of transmission of monetary policy in the model is the crowding out

[4] For example, Levy Yeyati (2005) found that depreciations make a crisis more likely as the financial dollarization increases. Moreover, Domac and Martinez Peria (2004) show that the liability dollarization, the ratio of foreign liabilities with respect to local assets, is positively correlated with the probability of a systemic crisis.

in spending, through which the interest rate affects the real exchange rate. The real exchange rate, in turn, determines the composition of aggregate demand between domestically produced goods and imported goods. When the real exchange rate lowers (consistent with a contractionary monetary policy), domestic goods become more expensive and thus imports rise and exports are reduced.

3. The linear version of the Model

In this section we present the log-linear version of the system of equations of the model. Those interested in the non-linear version of the model can find useful reading Castillo, Montoro and Tuesta (2009), however this paper is only available in a Spanish version. This system of equations is obtained by taking a first order approximation to the efficiency conditions of the consumer and firms' problems around the steady state. The resulting linear system is a set of stochastic difference equations, whose solution is a system of linear equations linking the variables of the model with endogenous state variables. State variables may be shocks such as productivity or international interest rates, or lagged endogenous variables such as the level of capital from the previous period.

There are several features of the model that distinguish it sharply from the Keynesian models of the 70s. First, in the model all the parameters of the equations are combinations of structural parameters related to preferences, technology and the behavior of the central bank and government. In this sense, the model is not subject to the Lucas' critique. Second, expectations in the model are rational and do not follow any *ad hoc* rule as in models from the previous generation. Finally, the behavior of the central bank is defined by an interest rate rule, as in most central banks in the world, and not by a rule of the growth rate of the amount of money as in the previous generation of models.

To make the presentation of the model easier, the system of equations that describe the model have been grouped into four blocks. The block of aggregate demand, including consumption, investment, exports and imports. The aggregate supply block, which is determined by the equations for inflation, the labor market and the capital market. The third block, the external sector, summarizes the interaction of this economy with the rest of the world. Finally, the fourth block is determined by the policy rule of the central bank.

The model has 50 principal equations plus 8 autoregressive processes that determine the evolution of exogenous shocks[5]. Variables defined in lowercase correspond to the difference in neperian logarithms of the variable in levels with respect to its steady state. That is: $x_t = \ln X_t - \ln X$.

[5] For the forecast exercises, we have used a version of the model that also includes a commodity sector and households facing borrowing constraints. Those characteristics where important to capture in dynamics of exports and consumption in the forecasting exercises. Considering these new mechanisms, the number of principal equations becomes 78.

3.1 Aggregate demand

The aggregate demand is determined by the following equation:

$$y_t = \phi_{ABS} abs_t + \phi_X y_t^X - \phi_M y_t^M \quad (1)$$

where y_t represents the gross domestic product (GDP), abs_t, the domestic demand or absorption, y_t^X the exports and y_t^M the imports, respectively. Moreover, ϕ_{ABS}, ϕ_X and ϕ_M correspond to the value in steady state of the ratios of absorption, exports and imports on GDP. Associated to the GDP is the deflator, t_t^{def}, which is defined in relative terms with respect to the consumer price index (CPI):

$$t_t^{def} = \phi_X \left(rer_t + t_t^X \right) - \phi_M t_t^M \quad (2)$$

where t_t^X is the index of export prices relative to the external CPI and t_t^M is the import price index relative to the domestic CPI. rer_t is the real exchange rate defined as the value of the external CPI in terms of domestic currency in relation with the domestic CPI, which has the following dynamic:

$$rer_t = rer_{t-1} + \Delta s_t + \pi_t^* - \pi_t \quad (3)$$

where Δs_t is the percentage variation of the nominal exchange rate, defined as the price of foreign currency in terms of domestic currency, π_t^* is external inflation y π_t is inflation of domestic CPI.

All these equations of the MEGA-D summarize the rational behavior of a type of agent. For example, consumption reflects the decisions of household savings, the investment behavior of firms, and so on. The first component of aggregate demand, the domestic absorption is determined by the sum of consumption, investment and government spending:

$$\phi_{ABS} abs_t = \phi_C c_t + \phi_{INV} inv_t + \phi_G g_t \quad (4)$$

where ϕ_C, ϕ_{INV} and ϕ_G are values in steady state of the ratio of consumption, investment and public expenditure on the GDP. For simplicity, this version of the model has assumed that goods for consumption, investment and public expenditure are identical, consequently have the same price index[6].

[6] For this reason, equation (4) doesn't include relative prices.

3.1.1 Consumption

Aggregate consumption, c_t, is determined by the sum of the consumption decisions of all the agents in the economy: households, c_t^{fam} and entrepreneurs, c_t^{emp}

$$c_t = \phi_{fam} c_t^{fam} + \left(1 - \phi_{fam}\right) c_t^{emp} \tag{5}$$

where ϕ_{fam} is the participation in steady state of household consumption on total consumption. The fundamental difference between families and entrepreneurs is their ability to access the financial market. It is assumed that families have access to an efficient credit market, and consequently do not face restrictions to smooth their consumption, while employers have no access to this market. To borrow, the latter agents have to offer guarantees. Those that offer better guarantees receive a lower interest rate.

This difference in the access to credit market affects the consumption choices of each of these agents. Household consumption doesn't depend on current income, but on permanent income and the real interest rate. If the real interest rate increases, families will choose to consume less in the current period, and more in the future (saving). This rational behavior of households is reflected in the following Euler equation:

$$u_{ct} = i_t - E_t \pi_{t+1} + E_t u_{ct+1} \tag{6}$$

This equation equals the return of savings to its cost. The cost of savings is determined by the marginal utility, u_{ct}, that households give away when postponing consumption, while the profit or return on savings is determined by the real interest rate, $i_t - E_t \pi_{t+1}$, valued according to future marginal utility, $E_t u_{ct+1}$. Also, the marginal utility of consumption is defined by:

$$u_{ct} = -\left(\frac{1}{1-h} c_t^{fam} - \frac{h}{1-h} c_{t-1}^{fam} \right) + vm_t + \xi_t \tag{7}$$

where $0 \leq h < 1$ is the degree of habits, vm_t is the effect of money on the marginal utility and ξ_t is a preference shock. The marginal utility of consumption in the model depends not only on the present level of consumption, as in traditional models, but also on lagged consumption and the nominal interest rates in soles and dollars. The marginal value of consumption depends on their habits, which are a proportion of consumption in the previous period. The existence of habits is important because it generates a dynamic response of aggregate consumption to changes in real interest rate more realistic from an empirical approach. When there are habits, consumption does not react instantaneously to changes in the real interest rate, but the reaction is gradually reaching the maximum impact after a few periods.

Furthermore, the effect of money on the marginal utility has the following form:

$$vm = -\Omega\left[\left(1 - \delta^{DT}\right) i_t + \delta^{DT} i_t^*\right] \tag{8}$$

where $\Omega \equiv \beta(1-\omega)\left[\frac{(1-b)^{\omega}(1-\beta)^{1-\omega}}{b^{\omega}+(1-b)^{\omega}(1-\beta)^{1-\omega}}\right]$, β is the intertemporal discount factor, ω is the elasticity of substitution between consumption and money and $0 < b \leq 1$ determines the relative weight of consumption with respect to money in the utility function. δ^{DT} is the ratio of transaction dollarization, determined by the relative weight of demand for money in dollars with respect to the one in soles in the utility function. i_t and i_t^* are the nominal interest rates in domestic and foreign currency, respectively.

As shown in equation (8), nominal interest rates in domestic and foreign currency also affect household's consumption through demand for money and the dollarization of transactions. In the model, households need to maintain cash, whether in soles or dollars, to consume. Households choose optimally the composition of their money balances in soles and dollars, by comparing the opportunity cost in each currency with the reduction in transaction costs generated by money holdings. The more money households keep, the more the transaction costs associated with consumption will be reduced. If nominal interest rates are reduced, it is cheaper to maintain cash, and therefore the level of household consumption increases because transactions are cheaper[7]. If households keep both soles and dollars, then also movements in the foreign interest rate will adversely affect household consumption.

On the other hand, entrepreneurs' consumption have a different dynamic. Entrepreneurs consume just a fraction of their wealth, which is determined by the value of the net worth of the enterprises they own. Therefore, the consumption of the entrepreneurs is proportional to changes in its net worth, n_t :

$$c_t^{emp} = n_t \tag{9}$$

The entrepreneurs´ net worth is a key variable in the model because it affects entrepreneurs' consumption and influences the dynamics of capital investment. When the net worth of entrepreneurs is high (low), the risk premium paid by enterprises' debt is lower (higher), and therefore it is optimal to invest more (less).

3.1.2 Investment

The other component of domestic absorption is investment in physical capital. Investment is determined from the first order condition of firms producing capital. Condition known as "Tobin's Q," which in its log-linear form is given by the following equation:

$$q_t = \psi_I \left[(inv_t - inv_{t-1}) - \beta (E_t inv_{t+1} - inv_t) \right] \tag{10}$$

where $\psi_I = \Psi''(1)/\Psi'(1)$ is the elasticity of the adjustment costs in steady state. According to the above equation, investment depends positively on the price of capital, q_t, the expected level of investment, $E_t inv_{t+1}$, and the past level of investment, inv_{t-1}. This dynamic of investment reflects the existence of adjustment costs, a factor that induces firms to change more gradually investment. Moreover, the more elastic are the adjustment costs, investment adjusts more slowly to changes in the price of capital.

[7] This is true under the assumption that money and consumption are complementary goods, which implies that the rate of intertemporal substitution between these goods is less than one ($\omega < 1$).

It is important to mention that the interpretation of the "Tobin’s Q" in this model with imperfections in the capital market is different from a model with complete capital market. When capital markets are complete, the price of capital reflects the net present value of future marginal productivity of capital. However, when markets are incomplete, the price of capital also captures the evolution of the net worth of entrepreneurs. In this case, when the net worth of enterprises increases, they will have greater capacity to borrow and therefore demand more capital, pushing up the price of capital. Details of the capital market, where q_t is determined, are presented below in the section 3.2.

3.1.3 Exports, Imports and Demand for Domestic Products

Intermediate goods producers export part of its production to the international market. As shown in the following equation, two variables determine the level of **exports**: world demand (y_t^*) and the relative price of exports to external CPI (t_t^X)

$$y_t^X = -\varepsilon_F t_t^X + y_t^* \tag{11}$$

where ε_F is the elasticity substitution between domestic and foreign goods. Thus, exports will increase when the world economy improves, or when they become relatively cheaper. In turn, the relative price of exports depends on exports price inflation and external inflation rates, as detailed in the following equation:

$$t_t^X = t_{t-1}^X + \pi_t^X - \pi_t^* \tag{12}$$

where π_t^X is the inflation of export prices, which has the following dynamics:

$$\pi_t^X - \lambda_X \pi_{t-1}^X = \kappa_X mc_t^X + \beta\left(E_t \pi_{t+1}^X - \lambda_X \pi_t^X\right) \tag{13}$$

where $0 \leq \lambda_X < 1$ is the degree of indexation of export prices, $\kappa_X \equiv \frac{(1-\theta^X)}{\theta^X}\left(1-\theta^X \beta\right)$ measures the sensitivity of inflation exports to marginal costs, which depends on the probability that an exporting firm does not change its price each period, θ^X . Marginal costs of the export sector are given by:

$$mc_t^X = mc_t - rer_t - t_t^X \tag{14}$$

where mc_t are the marginal costs in terms of consumption units. Importantly, in this model of exports price inflation is not equivalent to the sum of price inflation and changes in the external exchange rate. On the contrary, it is assumed that changes in the above variables are passed on gradually to the price of exports. This assumption, known in the literature as LCP (Local Currency Pricing), can better explain the dynamics of exports to changes in the exchange rate. In particular, it allows a more gradual and persistent adjustment of these variables to shocks in the economy. Also, the model assumes that there is a degree of indexation in the pricing of exports, additional factor that contributes to greater persistence in the adjustment of export prices.

In the case of **imports**, as shown in the following equation, its behavior depends on the level of domestic absorption and its relative price:

$$y_t^M = -\varepsilon_H t_t^M + abs_t \tag{15}$$

where ε_H is the elasticity of substitution between imported goods and those produced domestically. Thus, imports will grow when the level of domestic absorption is higher or when their relative price is reduced. As in the case of exports, for imports is also considered that the import price is adjusted gradually to changes in its determinants. In particular, it satisfies the following law of motion for import prices,

$$t_t^M = t_{t-1}^M + \pi_t^M - \pi_t \tag{16}$$

where π_t^M is the inflation of imported goods, which depends on their levels of past and expected future, as well as on changes in marginal costs in this sector, mc_t^M :

$$\pi_t^M - \lambda_M \pi_{t-1}^M = \kappa_M mc_t^M + \beta\left(E_t \pi_{t+1}^M - \lambda_M \pi_t^M\right) + mup_t^M \tag{17}$$

where $0 \leq \lambda_M < 1$ is the degree of indexation of imported prices and $\kappa_K \equiv \frac{(1-\theta^M)}{\theta^M}\left(1-\theta^M \beta\right)$ measures the sensitivity of imported inflation with respect to marginal costs. mup_t^M corresponds to cost-push shocks to the importing sector. In this sector, real marginal costs are given by the cost of buying goods abroad relative to the price of imports, which is equal to the rate of deviations in the law of one price,

$$mc_t^M = lop_t \tag{18}$$

the same that has the following law of motion:

$$lop_t = lop_{t-1} + \Delta s_t + \pi_t^* - \pi_t^M \tag{19}$$

It is important to note that the LCP scheme is quite flexible. Calibrating the parameters that determine κ_X and κ_M, can generate either a more or less persistent response of prices. Thus, for a calibrated low (high) price rigidity, the exports and imports price inflation also show a low (high) degree of persistence.

Similar to the demand for imports, the **demand for domestically produced goods**, y_t^H, depends on domestic absorption and its relative price:

$$y_t^H = -\varepsilon_H t_t^H + abs_t \tag{20}$$

where the relative price of domestic prices on the CPI, t_t^H is inversely proportional to the relative price of imports on CPI:

$$t_t^H = -\left(\frac{1-\gamma}{\gamma}\right) t_t^M \tag{21}$$

Another aspect that is important to highlight from the aggregate demand block, is the role that fulfill the expectations of the future state of the economy. In the model, the equilibrium depends on expectations formation, and consequently, on the way monetary policy is implemented.

3.1.3 Government expenditures

For simplicity, it is assumed that government spending follows an exogenous autoregressive process of first order:

$$g_t = \rho_G g_{t-1} + \varepsilon_t^G \tag{22}$$

3.2 Aggregate Supply

The second block of the model is the aggregate supply, which essentially determines the evolution of inflation and marginal costs of firms. In an open economy, households consume locally produced and imported goods. Consequently, inflation is a weighted average of domestic inflation and imported inflation, as shown in the following equation

$$\pi_t = \gamma \pi_t^H + (1-\gamma)\pi_t^M \tag{23}$$

In the model, the weight of imported inflation on overall inflation coincides with the degree of openness to the economy, $(1-\gamma)$. As mentioned above, the dynamics of imported inflation is determined, among other things, by the exchange rate fluctuations and by past and future levels of it. Therefore, the model implies that the more open the economy is, the greater the direct impact of changes in the exchange rate in overall inflation through imported inflation, ie the greater the pass-through effect of the exchange rate.

In turn, domestic inflation is obtained aggregating the prices of final goods. Each of these firms producing final goods have monopolistic power to set prices according to demand conditions. However, not all firms can do so because of price rigidities. Following Calvo (1983), it is assumed that in each period firms face a fixed probability of changing prices. This probability is independent of the misalignment of the relative price of the firm and the time elapsed since the last time the price change. This pricing mechanism implies that only a fraction of these price changes and that the remaining firms keeps prices unchanged, and thus their relative prices are temporarily misaligned until you have the option of changing prices.

Despite its unrealistic assumptions, the pricing mechanism to the Calvo has the advantage of facilitating the aggregation of the pricing decisions of firms and also be consistent with the empirical evidence that economies with low inflation, the frequency of price adjustment is stable, as predicted by the model of Calvo[8].

Additionally, the model considers price dollarization (PD). The PD means that a fraction δ^{DP} of the final goods producing firms set their prices in dollars. It is assumed that prices in dollars are also rigid and follow the same Calvo's pricing mechanism. In

[8] See Nakamura and Steinsson (2007) and Alvarez (2007).

this way, the domestic inflation appears to be a weighted average of inflation in soles and inflation in dollars plus the change in the exchange rate, as shown in the following equation.

$$\pi_t^H = \left(1-\delta^{DP}\right)\pi_t^S + \delta^{DP}\left(\pi_t^D + \Delta s_t\right) \tag{24}$$

The existence of price dollarization implies that a fraction of the prices of final goods are rigid in dollars, and therefore fluctuations in the exchange rate is immediately transferred to the domestic inflation[9]. However, this does not imply that prices in dollars do not meet the domestic demand conditions. Unlike the prices of imported goods, whose prices are independent of the conditions of domestic demand, domestic prices in dollars will rise when aggregate demand accelerates and will be reduced at the opposite.

As mentioned previously, one advantage of the Calvo pricing mechanism is that it facilitates the aggregation of prices. Under this mechanism, the average price of domestic goods in the economy is simply a weighted average of the aggregate price of the previous period and setting the optimal price that firms change prices.

$$p_t^S = \theta^s p_{t-1}^S + \left(1-\theta^s\right)\left(p_t^{S,o}\right)$$
$$p_t^D = \theta^D p_{t-1}^D + \left(1-\theta^D\right)\left(p_t^{D,o}\right)$$

where θ^S and θ^D represent the probability of not changing prices in soles and. dollars respectively, and $p_t^{S,o}$ and $p_t^{D,o}$ the optimal prices set by the firms that change prices in soles and dollars, respectively. These firms choose the optimal relative price considering that with some probability the price they set will not change in the future, and therefore, should reflect not only the current cost and demand conditions but also future.

In this context, two variables determine domestic inflation: the real marginal costs of firms and expected future inflation. In the model, inflation will be higher when firms expect higher future inflation or higher real marginal costs. Higher future inflation matters because it reflects higher future marginal costs, and therefore implies the need for future increases in prices. Given the likelihood that some firms may not adjust prices, if firms expect higher inflation in the future it is best to advance those price increases today.

Additionally, to improve the fit of the model to the data, it was considered indexation. This mechanism implies that those firms that are not able to adjust prices benefit from an automatic price adjustment mechanism based on past inflation. Considering the aforementioned ingredients, the dynamics of domestic inflation in soles and dollars is determined by the following two Phillips curves:

$$\pi_t^S - \lambda_S \pi_{t-1}^S = \kappa_S mc_t^S + \beta\left(E_t \pi_{t+1}^S - \lambda_S \pi_t^S\right) + mup_t \tag{25}$$

$$\pi_t^D - \lambda_S \pi_{t-1}^D = \kappa_D mc_t^D + \beta\left(E_t \pi_{t+1}^D - \lambda_D \pi_t^D\right) + mup_t \tag{26}$$

[9] See Montoro (2006) for evidence on the degree of price dollarization for Peru.

where $0 \leq \lambda_i < 1$ is the degree of indexation and $\kappa_i \equiv \frac{(1-\theta^i)}{\theta^i}(1-\theta^i\beta)$ measures the sensitivity of the inflation rate respect to marginal costs, for $i = \{S, D\}$. mc_t^S and mc_t^D represent the marginal costs of firms with domestic prices in soles and dollars, respectively, and mup_t relates to cost-push shocks.

Marginal costs in terms of consumption units, mc_t, are defined by:

$$mc_t = \alpha r_t^H + (1-\alpha) wp_t - a \tag{27}$$

where $0 < \alpha < 1$ measures the share of capital in the production function. The marginal costs depend on the price of the two factors of production: the real wages, wp_t, and the cost of renting capital, r_t^H, prices that are determined in the labor and capital market, respectively. Also, marginal costs depend on the total productivity of factors, a_t. Thus, marginal costs will be higher when total factor productivity is lower. When there is a drop in productivity, production factors need to be used more extensively to achieve the same level of production.

Marginal costs of firms that set their prices in soles and dollars are respectively:

$$mc_t^S = mc_t - t_t^S \tag{28}$$

$$mc_t^D = mc_t - t_t^S - rpd_t \tag{29}$$

As noted, the difference between the marginal cost in units of consumption, mc_t, and marginal costs mc_t^S and mc_t^D are the relative price of goods priced in dollars on the CPI, t_t^S, and the relative price of goods priced in dollars compared to the goods with prices in soles, rpd_t. These relative prices have the following dynamics:

$$t_t^S = t_{t-1}^S + \pi_t^S - \pi_t \tag{30}$$

$$rpd_t = rpd_{t-1} + \Delta s_t + \pi_t^D - \pi_t^S \tag{31}$$

Relative prices affect real marginal costs of firms because they are deflated by the price index for each sector. For example, if the price of firms that set prices in dollars increases, its marginal cost mc_t^D is reduced with respect to mc_t^S. This difference is reflected in the relative price, rpd_t.

3.2.1 Labor Market

The labor market meets households who offer work and firms demanding it. To consider unemployment in equilibrium, it is assumed that there is a discrepancy between the marginal rate of substitution between consumption and leisure, which determines the labor supply and real wages. This discrepancy prevents households to work the number of hours they want and therefore there may be unemployment in the economy, depending on macroeconomic conditions. The following equation shows the evolution of real wages. As shown in equation (32), the real wage adjusts gradually to changes in the marginal rate of substitution between consumption and leisure.

$$wp_t = \lambda_{wp} wp_{t-1} + \left(1 - \lambda_{wp}\right) mrs_t \tag{32}$$

where $0 < \lambda_{wp} \leq 1$ measures the degree of real rigidity in the labor market and wp_t is real wages. mrs_t is the marginal rate of substitution between labor and consumption and u_{lt} is the marginal disutility of work, which are defined by:

$$mrs_t = u_{lt} - u_{ct} \tag{33}$$

$$u_{lt} = \eta l_t \tag{34}$$

which η measures the intratemporal elasticity of substitution between consumption and labor. The adjustment will be more persistent when λ_{wp} is larger. Moreover, the marginal rate of substitution between consumption and leisure in turn is increasing in the level of consumption. In this way, when the economy is expanding and consumption is increasing, workers value leisure more and, consequently, for the same level of real wages, labor supply is reduced. In turn, this lower labor supply pressure wages to rise, generating an increase in marginal costs of firms. This relationship between the marginal utility of consumption and labor supply is the channel through which the model generates a positive relationship between marginal costs and economic activity. Also, the demand for labor equals the real wage with the sum of the marginal productivity of labor and the real marginal costs:

$$wp_t = y_t - l_t + mc_t \tag{35}$$

This last equation implies that firms will demand more work when real wages are lower and aggregate demand is higher.

3.2.2 Capital Market

The demand for capital condition determines that the rental rate of capital services, r_t^H, equals the sum of marginal productivity of capital and real marginal costs:

$$r_t^H = y_t - u_t - k_{t-1} + mc_t \tag{36}$$

where u_t represents the degree of utilization of capital. Also, the capital supply is determined by investment in each period, inv_t, plus the accumulation from prior periods net of depreciation:

$$k_t = \delta inv_t + \left(1 - \delta\right) k_{t-1} \tag{37}$$

where δ is the depreciation rate. In this market is determined the price of capital and the cost of renting capital. The latter is part of the marginal costs of firms and therefore affects the dynamics of inflation. Entrepreneurs, who are the owners of capital lease a fraction of this production factor according to the following equation:

$$u_t = \psi_U r_t^H \tag{38}$$

where $\psi_U = \Psi'(\bar{u}) / \Psi''(\bar{u})$ is the inverse elasticity of marginal cost of using capital. Thus, firms use more intensively capital when the rental rate is higher. As shown in equation (38), the degree of capital utilization is determined optimally to minimize the costs of depreciation that the higher use of capital generates.

Employers in turn invest in capital until the point where the expected return on capital is equal to its cost, as shown in the following equation:

$$E_t r_{t+1}^K = rp_t + \left(1 - \delta^{DF}\right)\left(i_t - E_t \pi_{t+1}\right) + \delta^{DF}\left(i_t^* + E_t \Delta s_{t+1} - E_t \pi_{t+1}\right) \tag{39}$$

where $E_t r_{t+1}^K$ is the expected return on capital, rp_t is the risk premium paid by employers and δ^{DF} is the degree of financial dollarization. The return of capital, r_t^K, is determined by the revenues generated by the capital income, r_t^H, plus capital gains net of depreciation, $\beta(1-\delta)q_t - q_{t-1}$:

$$r_t^K = \beta\left[\bar{R}^H r_t^H + (1-\delta) q_t\right] - q_{t-1} \tag{40}$$

The cost of financing capital, however, depends on the financial conditions of enterprises via the risk premium, rp_t, that firms pay to borrow money. This risk premium is higher when the leverage level is higher. The leverage level in turn will be higher when the debt level is higher or the net worth of entrepreneurs is lower, as shown in the following equation:

$$rp_t = -\psi_\chi \left[n_t - d_t\right] \tag{41}$$

where $\psi_\chi = \frac{\overline{D/P}}{\bar{N}} \chi'\left(\frac{\overline{D/P}}{\bar{N}}\right) / \chi\left(\frac{\overline{D/P}}{\bar{N}}\right)$ is the elasticity of risk premium and d_t is corporate debt. The balance sheet relate equity and debt to the capital value of companies:

$$n_t + \left(\phi_{KN} - 1\right) d_t = \phi_{KN}\left(q_t + k_t\right) \tag{42}$$

where ϕ_{KN} is the ratio of capital on net worth in steady state. The relationship between risk premium and the leverage degree of firms creates an additional transmission channel for monetary policy shocks, known as the financial accelerator. This channel amplifies and makes more persistent the effects of monetary policy shocks, because it creates a positive correlation between risk premium and the interest rate set by the central bank. This relationship exists because the value of capital, which are the assets of the entrepreneurs, depends negatively on the interest rate. Thus, when the interest rate increases, the price of capital decreases, and thus the value of the assets of entrepreneurs. This lower level of assets increases the leverage of entrepreneurs and generates a greater risk premium, which increases the impact of the monetary policy shock. The relationship between risk premium and the entrepreneurs leverage is not only static but rather dynamic. As shown in equation (43), changes in the risk premium affects net worth in the future because it increases the liabilities of the entrepreneurs. In this way, the interest rate impacts risk premium for more than one period.

In the model, the financial accelerator has an additional ingredient generated by financial dollarization. The existence of a fraction of corporate debt in dollars means that the exchange rate also affects the leverage degree and the risk premium, inducing a higher cost of financing for capital accumulation.

The negative impact of a real depreciation on net worth will be higher when the degree of dollarization of debt is higher. The following equation illustrates the combined effect of the two factors mentioned above:

$$n_t = \frac{(1-v)}{\beta}\begin{pmatrix} \phi_{KN}\left(r_t^K + q_{t-1} + k_{t-1}\right) - (\phi_{KN} - 1)(rp_{t-1} + dp_{t-1}) \\ -\left[\left(1-\delta^{FD}\right)(i_{t-1} - \pi_t) + \delta^{FD}\left(i_{t-1}^* + \Delta s_t - \pi_t\right)\right] \end{pmatrix} \tag{43}$$

The entrepreneurs net worth evolves according to the return of their assets, measured by the revenue generated by the rent of capital plus valuation gains and the cost generated by its liabilities. The latter is determined by the real interest rates in soles and dollars, and by variations in the exchange rate, $\Delta s_t - \pi_t$.

3.3 External Sector

Two equations summarize the interaction of this economy with the external sector, the balance of payments equation and the uncovered interest rate parity. The former resume the exchange of goods, services and capital between residents and non-resident agents. In the model, this equation is obtained by aggregating the budget constraints of households, firms and the government. The log-linear representation of the balance of payments is the following equation:

$$\begin{aligned} \phi_b\left(b_t^* - \beta^{-1}b_{t-1}^*\right) &= t_t^{def} + y_t - \phi_{abs}abs_t \\ &\quad + \phi_b / \beta\left\{i_{t-1}^* + \Delta s_t - \pi_t + \psi_b b_t^*\right\} + \phi_{rest}rest_t \end{aligned} \tag{44}$$

where ϕ_b and ϕ_{rest} are the steady state value of the ratio of the net foreign assets position and the remainder of the current account over GDP, respectively. b_t^* is the net foreign assets position in terms of consumption units, and $\psi_b \equiv \phi_b \Psi_B'\left(\bar{b}\right)$ is the elasticity of the external risk premium.

Three flows are important in this equation, the flow of goods produced by foreign trade, which basically reflect the difference between GDP and the level of domestic absorption. The second is the capital flow, which is determined by the change in the net foreign assets position. Finally, the investment income flow includes the interest payments and valuation effects.

Additionally, the variable $rest_t$ considers the costs of monitoring firms, the expenditure of using more intensively the capital, profits from importers firms, the change in money holdings in dollars and the effect of debt denomination due to financial dollarization:

$$
\begin{aligned}
\phi_{rest} rest_t = & -\frac{\overline{RP}}{\beta}\frac{(\phi_{KN}-1)}{Y}\left(rp_{t-1}+i_{t-1}-\pi_t+dp_{t-1}\right) \\
& +\phi_K\left(k_{t-1}+\Psi'(u)u_t\right)-\phi_M lop_t+\phi_{M^*}\left(\Delta m_t^*-\Delta s_t+\pi_t\right) \\
& -\frac{1+\overline{RP}}{\beta}\frac{(\phi_{KN}-1)}{Y}\delta^{DF}\left(i_{t-1}^*+\Delta s_t-i_t\right)
\end{aligned} \tag{45}
$$

The other equation that reflects the behavior of the external sector is the uncovered interest parity condition. This condition is presented below, and determines the evolution of the nominal exchange rate,

$$
i_t - i_t^* = \psi_b b_t^* + \left(1-\lambda_{pdi}\right)E_t\Delta s_{t+1} - \lambda_{pdi}\Delta s_t + pdi_t \tag{46}
$$

According to this equation, the exchange rate appreciates when the domestic interest rate, i_t, increases, the interest rate in foreign currency, i_t^*, is reduced or when the country risk premium, which depends on the level of debt as percentage of GDP, $\psi_b b_t^*$, decreases. The parameter λ_{pdi} measures the degree of smoothing of the exchange rate.

If we solve s_t for in equation (46) and iterate forward, we obtain:

$$
s_t = s_{t-1} - \frac{1}{\lambda_s}\sum_{j=0}^{\infty}\left(\frac{1-\lambda_s}{\lambda_s}\right)^j\left[i_{t+j}-i_{t+j}^*-prem_{t+j}\right]
$$

where one can see that if the parameter λ_{pdi} tends to 1, the model is quite close to a fixed exchange rate. On the other hand, when λ_{pdi} tends to 0, like in the traditional case, the exchange rate is defined by

$$
s_t = -\sum_{j=0}^{\infty}\left[i_{t+j}-i_{t+j}^*-prem_{t+j}\right]
$$

and is equivalent to the sum of present and futures interest rate differentials. In the latter case, the exchange rate responds well to the expectations about what will happen in the future. The calibration of a parameter λ_{pdi} between 0 and 1 smoothes fluctuations in the exchange rate and is consistent with intervention in the foreign exchange market.

Furthermore, it is assumed that external variables such as output, the nominal interest rate and inflation (y_t^*, i_t^* and π_t^*, respectively) have the following autoregressive processes:

$$
y_t^* = \rho_{y^*}^1 y_{t-1}^* + \rho_{y^*}^2 y_{t-2}^* + \varepsilon_t^{y^*} \tag{47}
$$

$$
i_t^* = \rho_{i^*}^1 i_{t-1}^* + \rho_{i^*}^2 i_{t-2}^* + \varepsilon_t^{i^*} \tag{48}
$$

$$
\pi_t^* = \rho_{\pi^*}\pi_{t-1}^* + \varepsilon_t^{\pi^*} \tag{49}
$$

3.4 The Monetary Policy Rule

The central bank implements monetary policy controlling the short-term interest rate. To set this rate, the central bank injects money into the economy enough in such a way that the equilibrium interest rate is the rate set by the central bank. The monetary policy rule takes the following form:

$$i_t = \varphi_i i_{t-1} + (1-\varphi_i)\left[\varphi_\pi \pi_t + \varphi_s \Delta s_t + \varphi_y (y_t - y_{t-1})\right] + mon_t \tag{50}$$

where, φ_i >0, $\varphi_\pi > 1$, φ_s >0 y φ_y >0. This rule contains several elements that are important to highlight. First, the central bank reacts increasing the interest rates when inflation exceeds the central bank's target. Second, the increase in interest rates compared to deviations in inflation is more than proportional to the increase in inflation, as measured by the parameter $\varphi_\pi > 1$, in this way ensures to generate increases in real interest rate, and therefore induces a lower level of economic activity and lower inflationary pressures. Third, movements in interest rates are persistent, which is measured by the parameter φ_i > 0. Empirical evidence shows that this is a feature of monetary policy in many countries. There are several hypotheses to explain this behavior of the central bank, including one proposed by Michael Woodford, attributed this behavior of the Central Bank to its desire to affect expectations of future inflation. Other hypotheses are based on the existence of costs in the decision making process of the board of the central bank when there is heterogeneity in preferences or information of members of the Monetary Policy Committee[10].

An important aspect of the rule considered in the model is that the central bank can react systematically to changes in the exchange rate. This behavior of the central bank can be welfare improvement in an open economy with price dollarization[11]. If firms set prices in dollars and they have some rigidity, fluctuations in exchange rates generates changes in relative prices that are not efficient, and therefore, affect the allocation of resources. In this case, the central bank can contribute to the welfare of society by reducing exchange rate volatility.

[10]Montoro (2007), in a model with Monetary Policy Committees, rationalizes the existence of adjustment costs in setting the monetary policy interest rate.
[11] See for example Castillo (2007).

4. Estimation

In this section, we present the main results from the estimation of the model. Castillo, Montoro and Tuesta (2006b) present a more detailed explanation of the estimation methodology.

4.1 Data problems

The estimation of the model using Peruvian data has several problems. First, the adoption of the Inflation Target regime and change of the policy instrument to the interest rate in 2002 generated a change in the behavior of nominal variables. For example, the short-term nominal interest rate is much more volatile and has a higher mean in the period prior to the adoption of a Inflation Target regime (figure 1.A). Also, inflation was reduced gradually from high levels of the early 1990s to reach levels of inflation in developed countries in 2002 (Figure 1.B). These two features indicate the presence of changes in the data generating process, in particular the monetary policy rule and the price formation (Phillips curve).

Second, there is instability in variables that are considered as parameters by construction in the model, such as the degree of dollarization and trade openness (figures 1.C and 1.D). These variables are considered exogenous and constant in the model, but the endogenization of them would increase the complexity of the model and could bring stability problems to the equilibrium. Third, the non-stationary variables show the presence of more than one unit root, for example, real output and terms of trade (figure E). This factor creates a consistency problem between the model and the data, as DSGE models cannot work, at least so far, with more than one unit root in endogenous variables.

4.2 Estimation strategy

We use quarterly data between 1995 and 2007 of the main macroeconomic variables to estimate some parameters of the model[12]. 11 shocks were considered: a permanent shock to the global technology and 10 shocks that follow an autoregressive process of order one[13]. The unit root in the model was given by a permanent shock on global technology, which was used to convert non-stationary variables on stationary ones, and let consistency between data and the variables of the model. Regarding the trend in the nominal interest rate and inflation, the trend is removed by considering the midpoint of the announced annual inflation target in the period prior to formal adoption of the Inflation Target regime in 2002. Also, to control for changes in the monetary policy rule and the aggregate supply relations, we estimate by sub-samples those parameters associated to these equations, taking as given all the other parameters in their entire sample estimates.

[12] The macroeconomic variables used were: product, consumption, investment, real exchange rate, nominal exchange rate, terms of trade, domestic interest rate, international interest rate, inflation and imported inflation.

[13] Among these shocks are: technology, domestic inflation, mark-ups, mark-ups in the import sector, monetary policy, consumer preferences, external monetary policy, investment, uncovered interest rate parity, the purchasing power parity and external productivity.

The estimation of selected parameters of the model was performed using Bayesian econometrics. The algorithm used was the Random-Walk Metropolis-Hastings with 250.000 draws of the posterior distribution, taking as a criterion of acceptance ratio between 0.25 and 0.35. We proceeded to estimate five models: a model without any form of dollarization, three with a type of one dollar each and that includes all three types of dollarization at a time.

4.3 Results

Among the most striking results we have that, according the Bayes factor, the model with three types of dollarization dominates the other models. It was observed that the main ingredient that helps to explain Peruvian data is financial dollarization, because considering the Bayes factor, transaction and price dollarization does not add much to the model relative financial dollarization.

	Baseline Model	Transaction Dollarization	Price Dollarization	Financial Dollarization	Three types of dollarization
Log-Marginal	-950.95	-948.61	-947.86	-945.32	-944.88

Among the main results from the estimation of the parameters, we obtain that: real frictions, such as rigidities in the labor market and adjustment costs in investment, are important in all models. Also, prices are relatively more flexible than in developed economies, firms in Peru change prices on average once every 2 quarters. This is consistent with the history of high inflation in Peru. Moreover, price indexation is important in the estimation of the Phillips curve.

We also found that the standard deviations of shocks are quite large relative to those estimated for developed economies. Furthermore, the estimation of the monetary policy rule shows that the central bank has complied with the Taylor principle and that after the adoption of the Inflation Target regime the response of the interest rate to inflation has increased, while the response to output and the exchange rate has been reduced.

5. Exercises: Analysis of the Transmission Mechanisms

To show the main transmission mechanisms behind the MEGA-D, we present three simulation exercises. These exercises are based on a particular MEGA-D version that can be find in CMT(2009). Figure 2, shows the impulse response functions to a 1 percent contractionary and transitory monetary policy shock for the main macroeconomic variables. This analysis is made taking into account the effects of dollarization and exchange rate interventions on the monetary policy transmission mechanism. Impulse response functions suggest that dollarization increases the exchange rate pass-trough to inflation and reduces the impact of monetary policy on the output gap. Also, the exercise in figure 2 suggests that exchange rate intervention reduces the exchange rate volatility and its effects over inflation. When dollarization is not present, monetary policy is more effective in affecting the output gap but less effective to affect inflation, because dollarization reduces the power of the interest rate channel but makes stronger of the exchange rate channel.

In Figure 2, we display the impulse responses to an increase in the international interest rate. The results suggest that for the case of high dollarization and no exchange rate intervention, the output gap decreases significantly after three quarters. For the scenario without dollarization, the effect of an increase in the international interest rate is null after three quarters. Finally, figure 3 also plots the responses for the case of high dollarization and exchange rate interventions. In this case, exchange rate interventions completely off set the contractionary effects of an international interest rate increase, reducing vulnerability of the domestic economy to external shocks.

This difference is explained mainly by the balance sheet effect or financial accelerator mechanism in dollarized economies. The increase in the international interest rate generates a nominal depreciation of the domestic currency that increases the real exchange rate. This increase in the real exchange rate generates, when dollarization is high, a negative balance sheet effect that reduces private investment and more than offset the positive effect of a nominal depreciation on exports. Without dollarization, the negative impact of the balance sheet effect is not present anymore; therefore, any increase on the real exchange rate generates an increase on net exports and hence greater output gap. This mechanism makes monetary policy less effective when stabilizing investment, and through this channel, the output gap. Moreover, the financial accelerator in a dollarized economy makes private investment more sensitive to external shocks.

In the absence of nominal frictions, monetary policy would have a minor role in stabilizing inflation through aggregate demand. To analyze the role of nominal frictions, Figure 4 shows the responses to a monetary policy shock for both cases: price rigidities (in bold) and flexible prices. This figure suggests that following an anticipated monetary policy shock, output gap and inflation decreases and nominal exchange rate appreciates. This dynamic is qualitatively similar for both cases. However, it is clear the importance of nominal frictions to characterize the dynamics of the data.

In first place, the model with nominal frictions generates a lower but more persistent effect on inflation. On impact, the fall in inflation is not as strong as in the case with flexible prices. This is because prices are adjusted gradually. Consequently, the contraction in the output gap is more pronounced and persistent. In general, nominal frictions add endogenous persistence to the dynamics of the model. Also, in the model with flexible price the adjustment occurs through prices and to a lesser extent through quantities. In second place, the model with nominal frictions helps to replicate the hump shaped response of inflation and out put gap. This form is less evident in the flexible prices case. Note also that in the flexible prices model the greater impact on inflation (in the current period) is given by the exchange rate pass trough effect.

6. Forecasting Process

Since mid-2008 the BCRP is implementing the use of MEGA-D in forecasting. We have formed a team comprised of members of the Research Division and the Macroeconomic Modeling Division. The forecasting process consists of four main stages: the management of the database, the estimation of the initial point, the forecasting process per se and the transformation of forecasted variables in terms of national accounts.

6.1 Database management

On the data management stage, we first collect data from various sources and make all the transformation needed to make data consistent with the model. We use different data transformations such as: expressing data in logarithms, removing seasonality using Arima X12, making data stationary by applying the Hodrick-Prescott filter to all unit root variables or by estimating trends within a cointegrated long run system. Also, in order to avoid the end of sample problem of the HP filter, we extend the sample using ARMA forecasts of the variables, as explained below. The main advantage of using the HP filter to eliminate unit roots from non-stationary variables is that it is easy to use. However, the use of this filter involves several problems.

The first problem is related to the inconsistency between trends of the national accounting identities. For example, if the following identity is true for three economic variables $X_t = Y_t + Z_t$; then if each of the series is HP filtered this identity will not necessarily be maintained in trends, so $\overline{X}_t \neq \overline{Y}_t + \overline{Z}_t$.

Moreover, the HP filter suffers from the problem of end-of-sample bias, because for the last observations it brings closer the estimated trend to the observed time series. In practice, we solve this problem extending the sample of the variables using an univariate ARMA forecast of the them. However, we are aware that this methodology also generates a bias to the initial forecast and makes difficult to identify changes in trend. One last drawback when considering HP filter is that, HP filtering has no economic rationality so it makes difficult to communicate results.

Alternatively to the use of filters, we can express the variables in first differences. This methodology is similar to the use of a linear trend for each series. Also, it has the advantage that it is easier to explain and interpret than the HP filter, because the discussion focuses on the growth rates of the variables, which are of common use in the discussion. However, the inconsistency problem of trends in identities still remains as in the HP filter case.

Currently, we have designed a block independent of MEGA-D for the estimation of trends. This block consists on a group of estimated cointegration regressions between aggregate demand components, such us consumption and investment, and the potential output. From these regressions we construct a gap for each component of the aggregate demand. A similar methodology is the one proposed by Cayenne, Gosselin and Kozicki (2008), which consists on adding a separate system of equations for trends on the DSGE´s linearized system. The advantage of this procedure is that it is flexible enough to incorporate all the different relationships that affect trends in order to capture the dynamics of the data of a particular economy. In addition, the problem of inconsistency between trends and macroeconomic identities is solved.

6.2 Estimation of the initial point

A fairly important task when doing forecasting with a DSGE model is the estimation of the initial point. The initial point of the forecast is the value of all the model variables in the previous period to the forecasting exercise. The main problem in estimating the initial point is that not all the variables of the model are observable. For example, for the Peruvian economy there is no information on the Tobin's Q, the marginal costs, the net asset value of the entrepreneurs and so on. We have applied two different methodologies when estimating the initial point of the forecasting horizon.

The first methodology is the estimation of all the non observable variables by implementing the smoothing Kalman filter to the MEGA-D. The main advantage of this method is that there is consistency between the model, data and the estimation of non-observable variables. However, its use has shown that the estimation of non-observable variables is quite sensitive to the information set. The initial point estimation can vary significantly when introducing new information. Also, the estimation of some variables can be very poor. For example, when we compare the actual variables with its Kalman filter estimates, we see that both can differ significantly. For example, Figure 5 shows that the differences between the actual and the estimated value of some variables, such as nominal depreciation, government spending, foreign output and the real exchange rate can be quite considerable.

The second method consists to complete only the set of state variables with the best information set available. MEGAD-D has 40 state variables, of which of them 17 are observable. For the remaining 23 state variables we have found proxies for 9 of them. For the state variables with no information at all we have assumed that those variables are in the steady state at the initial point.

6.3 The forecasting process

The forecasting stage is quite similar to the forecasting process used in others models at the BCRP, such as the Quarterly Projection Model (MPT) [14]. To make a forecasting exercise with MEGA-D all the exogenous variables must be projected using information from specialists or satellite models. Then, we use the rational expectation solution of the model in order to forecast the endogenous variables 16 quarters ahead.

The forecasting platform is developed using the IRIS toolbox for Matlab. It consists mainly on dividing the forecasting horizon in two parts. The first one is the medium term forecast horizon, which incorporates specialists' projections of the exogenous variables until a medium term forecast horizon of 8 to 12 quarters. The second part is the long term forecast horizon, which completes the projections of the exogenous variables up to 16 quarters from autoregressive processes that define those exogenous variables. The projection of all the endogenous variables is obtained by introducing all

[14] For more details, see the paper: "Modelo de Proyección Trimestral", Documento de Trabajo N° 2009-006, Banco Central de Reserva del Perú.

the trajectories of the exogenous variables into the model solution.

6.4 Re-transforming the forecasted variables

In the last stage, we re-transform the forecasted variables in terms of national accounts variables. In other words, we recover the initial transformations that made in the data management stage, adding the estimated trends and seasonality and expressing all the variables in levels.

It is important to mention that we have added some additional variables to the model in order to make it compatible with the data. For example, in the version of the model that is used for forecasting we include a two different definitions of the exchange rate: bilateral and multilateral. The former is the one with respect to the U.S. dollar and the latter respect to a basket of currencies. We use in the model the bilateral exchange rate in the equations related to dollarization, since this is the exchange rate that is relevant for those relationships. On the other hand, we use the multilateral exchange rate in those equations related to international trade. In the original version of the model there isn’t an explicit distinction between these two variables, because the rest of the world is not modeled a block of countries but as a unique large economy.

We have made other adjustments to the model, such as a difference of imported inflation that affects the CPI and the one that affects the GDP deflator. Also, we include other important mechanisms not included in the model CMT (2009). These mechanisms are related to the conclusion of Non Ricardian agents, which helps to capture the effects of fiscal policy, and inclusion of a commodities exporting sector.

In Figure 6 we present a forecasting exercise for core inflation using information at the end of each quarter of 2007 using both models: MEGA-D and MPT. The main observation is that in all cases the MEGA-D projected an increase in inflation in the following periods slightly higher than the one projected by the MPT. This would be explained because in the MEGA-D inflation and the output gap depend more on future expectations of these variables.

7. Conclusions

This paper summarizes the development of MEGA-D, a DSGE model for policy analysis, at the Central Reserve Bank of Peru. Among the main findings is that dollarization reduces the power of monetary policy to affect output and increases the vulnerability of the economy to shocks from the external interest rate. Also, the estimation of model parameters by Bayesian econometrics show that financial dollarization is important to explain the Peruvian data. Furthermore, it is found that compared with developed economies, prices are more flexible and the volatility of shocks is greater. It also shows the first results of the implementation of the model in the projection of macroeconomic variables, including inflation. We also describe the forecasting process with the MEGA-D currently in development at the BCRP.

This research is part of a project developed by the Research Division of the Economic Studies Department at the Central Reserve Bank of Peru, which aims to improve the projection of inflation of BCRP. The structure of the model presented is quite flexible and therefore can be expanded to incorporate other ingredients that are considered important to explain the transmission mechanism of monetary policy and to make policy analysis for Peru.

Figures

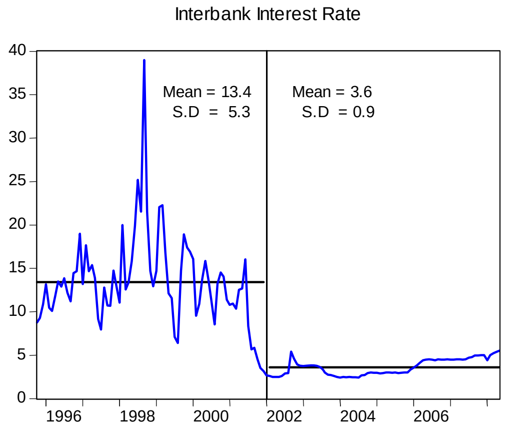


Figure 1.A

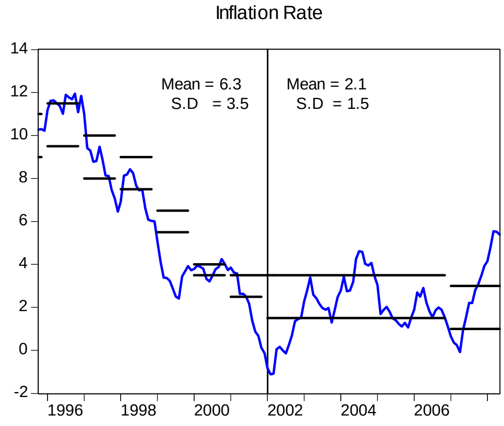


Figure 1.B

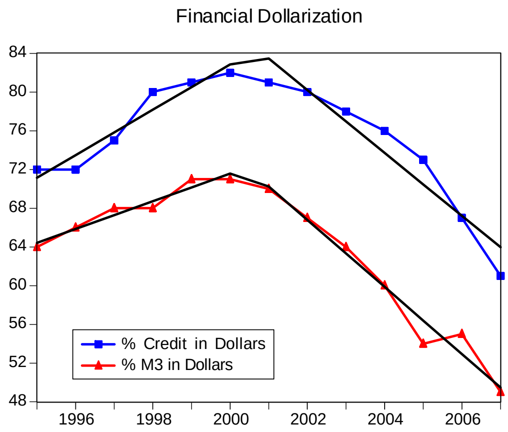


Figure 1.C

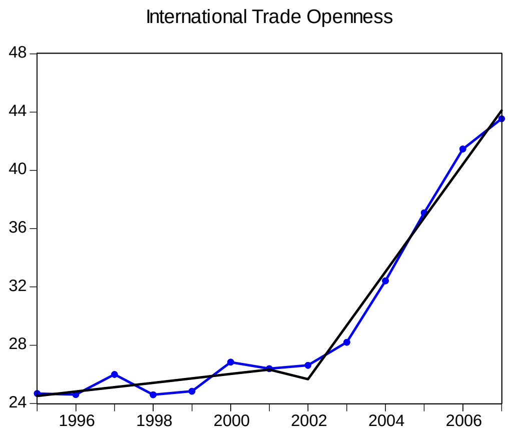


Figure 1.D

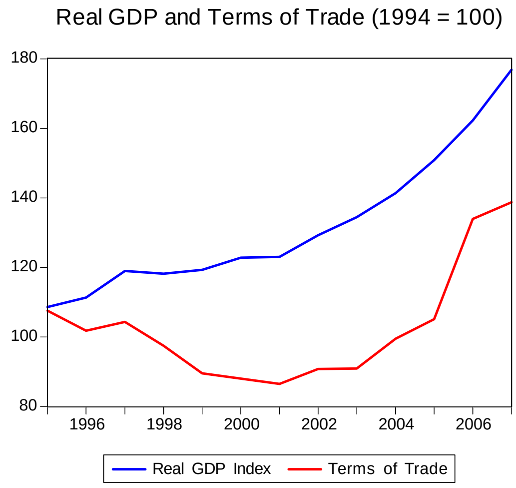


Figure 1.E

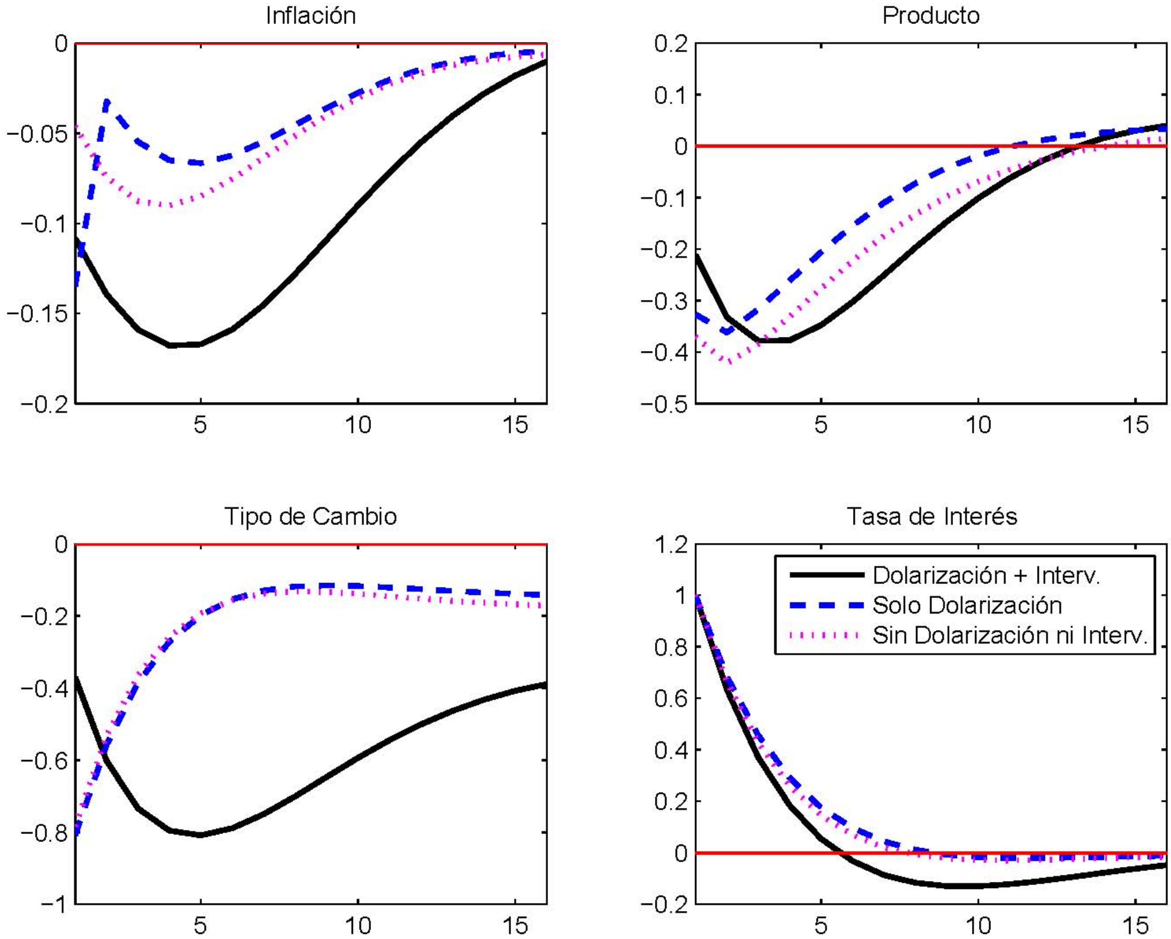


Figure 2: Dolarization Contrafactual; IRFs to a Domestic Interest Rate Shock

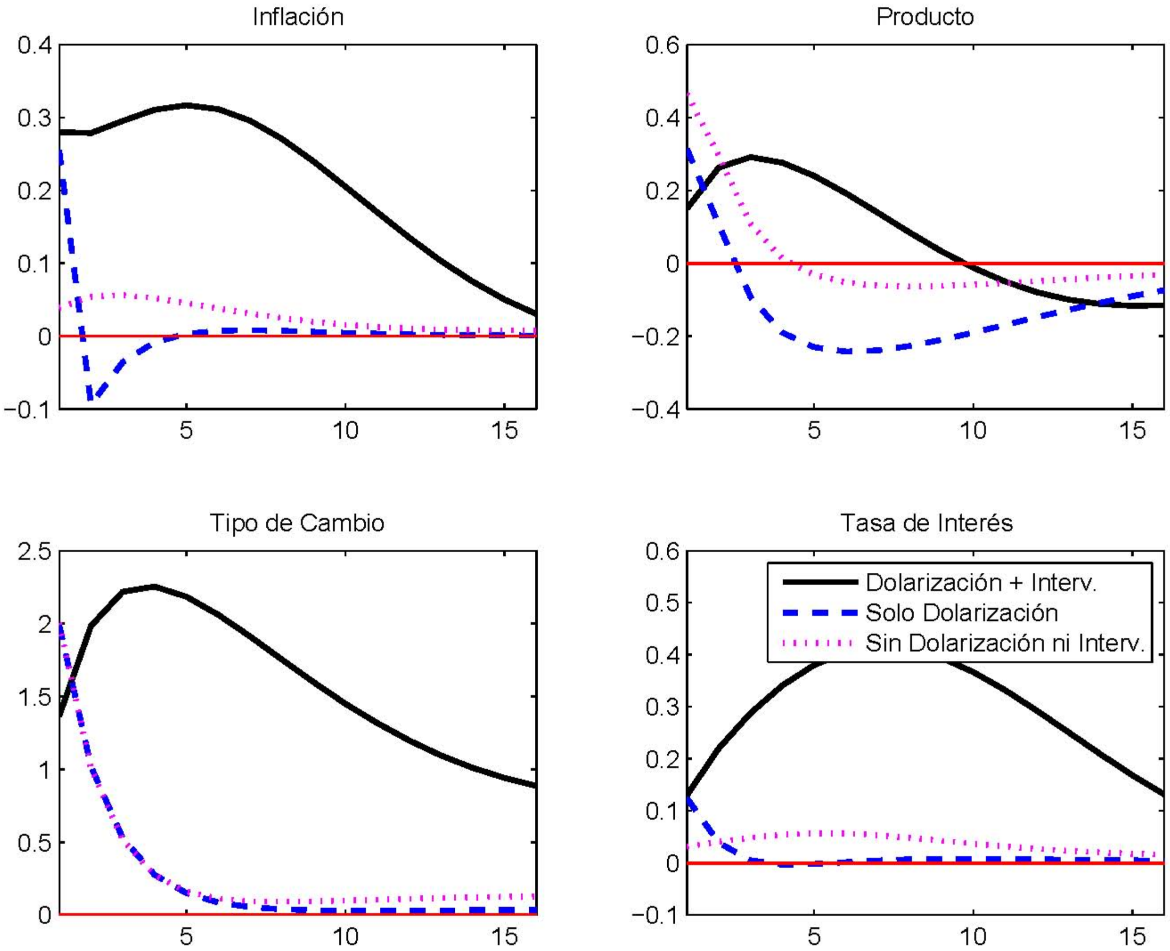


Figure 3: Dolarization Contrafactual; IRFs to a Foreign Interest Rate Shock

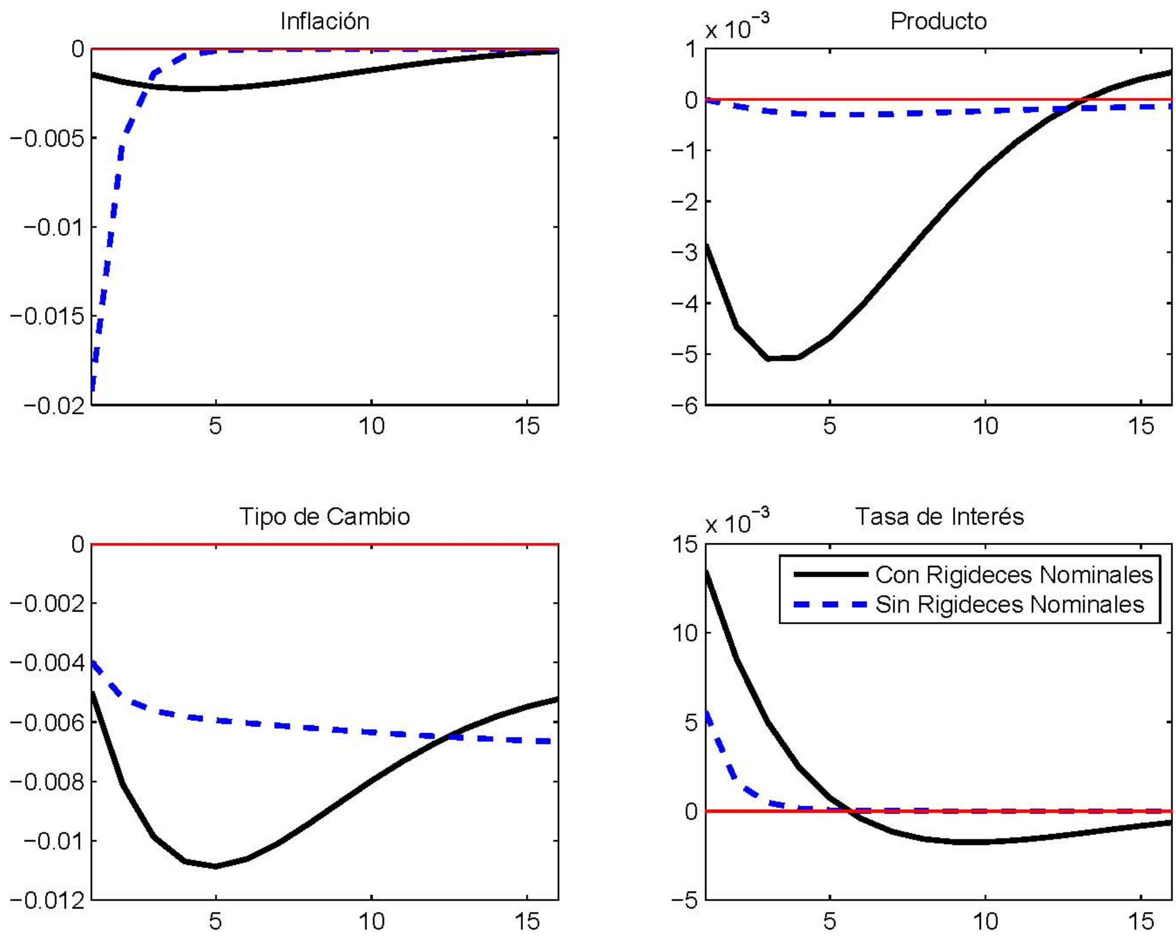


Figure 4: Effects of Nominal Rigidities; IRFs to a Domestic Interest Rate Shock

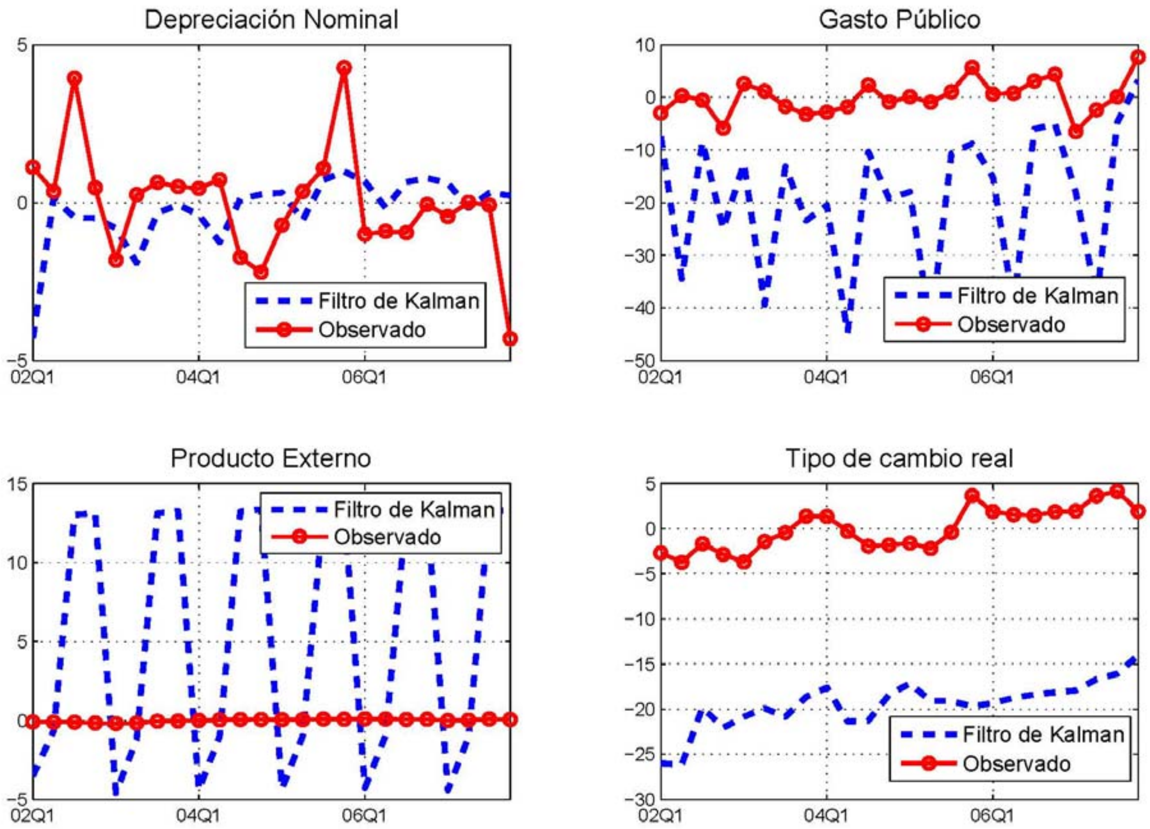
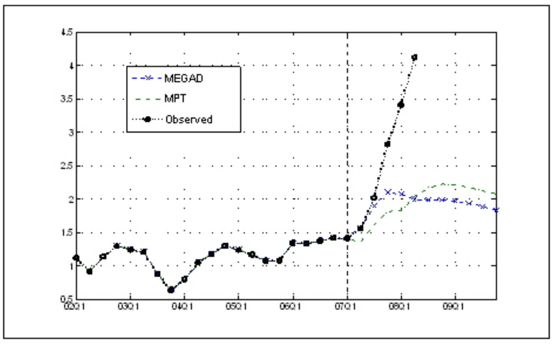
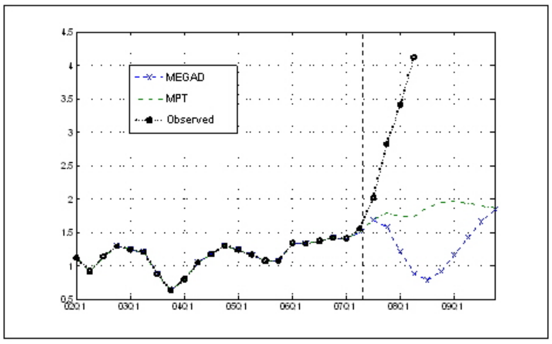


Figure 5: Estimation of the initial point with the Kalman Filter; example of observable variables.



Informacion a 2007.I



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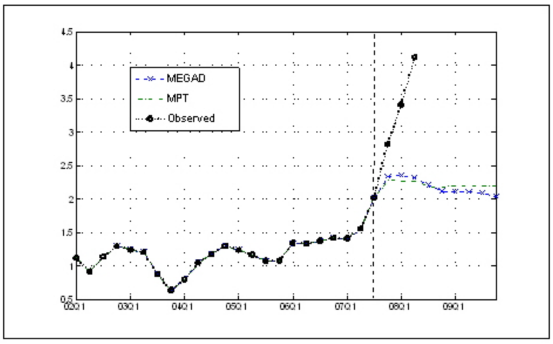

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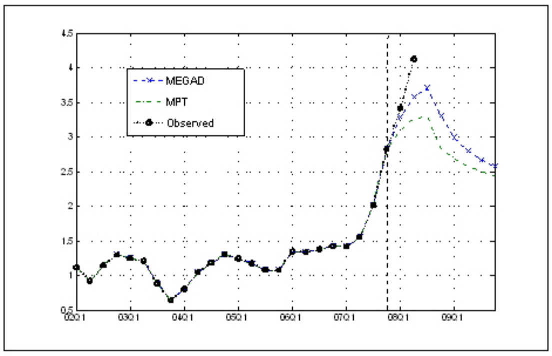

Informacion a 2007.IV

Figure 6: Forecast Exercise – Core Inflation

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