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HOW WELL DOES A MONETARY DYNAMIC EQUILIBRIUM MODEL ACCOUNT FOR CHILEAN DATA?

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Resumen

El objetivo de este trabajo es averiguar cuán bien un modelo con dinero en la función de utilidad y regla de Taylor, puede replicar datos de la economía chilena, especialmente algunos hechos monetarios estilizados. Se formula, resuelve y calibra un modelo dinámico y estocástico de equilibrio general para evaluar su capacidad de reproducir las características principales de la economía chilena entre 1986 y el 2000. En particular, el trabajo se enfoca en una posible explicación a lo que la literatura empírica ha denominado el "*puzzle* de precios", es decir, el movimiento conjunto de la tasa de interés y la tasa de inflación. La solución del modelo es adecuadamente alcanzada a través del método de perturbación (aproximación de segundo orden). Se concluye que un shock positivo y transitorio en la tasa de interés genera: (1) una reducción temporal (no significativa) del producto real, (2) un descenso transitorio de los saldos reales de dinero, y (3) un aumento temporal de la tasa de inflación. Estos resultados son relativamente consistentes con los obtenidos de funciones impulso-respuesta estimadas para Chile mediante vectores autorregresivos. Por ende, el modelo teórico propuesto es capaz de explicar y reproducir el movimiento conjunto de la tasa de interés y la inflación. Esta relación económica es causada por un efecto Fisher y reforzada por la presencia de una regla de Taylor que depende positivamente de la desviación de la tasa de inflación de su estado estacionario.

Abstract

The purpose of this paper is to figure out how well a money-in-the-utility-function model with a Taylor rule can match Chilean data, specially some monetary stylized facts. A dynamic stochastic general equilibrium model is formulated, solved and calibrated to evaluate its ability to replicate the main features of the Chilean economy in the 1986-2000 period. In particular, it focuses on a possible explanation to what the empirical literature calls the "price puzzle", the co-movement between interest rate and inflation. The solution of the model is adequately achieved through a perturbation method (second-order approximation). A positive transitory policy interest rate shock causes: (1) a temporary (non-significant) decline in output, (2) a decrease in real money balances, and (3) a temporary increase in the inflation rate. These findings are relatively consistent with those obtained from impulse-response functions estimated for Chile. Therefore, the theoretical model proposed is able to explain and reproduce the co-movement between interest rate and inflation. This relationship is caused by a Fisher effect and strengthened by the presence of a Taylor rule that depends positively on inflation deviation from its steady state equilibrium.

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1. Introduction

Since Kydland and Prescott published their influential work in 1982, the literature on monetary real-business-cycle models has had the chance to prove its ability to account for regularities on developed countries data.[1] Nevertheless, there are virtually a few attempts to do so for emerging Latin American economies.[2]

The aim of this paper is to figure out how well a money-in-the-utility-function model with a Taylor rule can match some particular monetary stylized facts from Chilean data between 1986 and 2000. Specially, it focuses on a theoretical explanation to what the empirical literature calls the "price puzzle", that is, the co-movement between interest rate and inflation rate, fact that is found in many VAR-type estimates for Chile and other economies.

I find that a positive transitory policy interest rate shock causes a temporary (non-significant) decline in output, a transitory decrease in real money balances, and a temporary increase in inflation rate. These findings are relatively consistent with impulse-response functions obtained from a 5-variable VAR estimated for Chile. Therefore, the theoretical model proposed is able to explain and reproduce the co-movement between interest rate and inflation (the so-called "price puzzle"). This co-movement is caused by a Fisher effect, that is, an increase in the nominal interest rate generates an increase in inflation leaving the real interest rate virtually invariant. Besides, this effect is strengthened by a monetary policy expressed by a Taylor rule that depends positively on inflation deviation. An analogous explanation is also given in some recent studies in the economic literature (see Monnet and Weber, 2001; and Alvarez, Lucas, and Weber, 2001).

The structure of this study is organized as follows. Section 2 provides an overview of the studies related to real business cycle (RBC) models calibrated for the Chilean economy, highlighting the main characteristics of the models, methods of solution, objectives, and

[1] See, for instance, Christiano and Eichenbaum (1992), Cooley and Hansen (1995), Christiano et al (1997), McCallum and Nelson (1997), for U.S.; Dhar and Millard (2000), for U.K.; Folkertsma (1998), for Netherlands.

[2] Perhaps Chile is the exception, see Acuña and Oyarzún (2001) and Bergoeing and Soto (2002). RBC models for the Chilean economy without monetary variables were formulated and calibrated by Quiroz (1991), Quiroz et al (1991), and Chumacero and Fuentes (2002).

results. Section 3 presents a brief description of the Chilean regularities during the 1986-2001 period on the basis of the most important results of estimating a Vector Autoregression model. The idea is obtain impulse-response functions that will be used as a metric to compare them with those simulated by the theoretical model. Thus, in section 4, a dynamic stochastic general equilibrium model is formulated, solved, and calibrated considering the presence of distortionary taxes in an open-economy. The solution of the model is adequately achieved using a perturbation method (second-order-approximation) proposed by Schmitt-Grohé and Uribe (2001). Section 5 describes the results of calibrating the model and examines whether it is capable of replicating the VAR impulse-response functions. Concluding remarks are provided in the last section.

2. Previous Studies about RBC Models for the Chilean Economy

The calibration of RBC models in Chile started at the beginning of the nineties (see table 1) with the work by Quiroz et al (1991). The authors used the Kydland and Prescott´s (1982) framework to replicate several second moments of Chilean output and investment rate[3] series from 1977 to 1990. They found that this model could replicate sample volatilities but had problems with autocorrelations. Simultaneously, Quiroz (1991) formulated a two-good small open economy model with costs of adjustment of labor to replicate some regularities exhibited by the real exchange rate during the 1977-90 period. He concluded that the model was able to match the real exchange rate volatility and its negative correlation with wages, the price of copper, and capital inflows, but its high autocorrelation remained unexplained.

Acuña and Oyarzún (2001) is one of the first papers that included monetary variables to an RBC framework and analyzed the role of monetary shocks on Chilean data. Using Cooley and Hansen´s (1989) cash-in-advance model, the results of their calibration showed similarities with actual data in the co-movement of the simulated variables (except capital and money stocks), but showed difficulties to replicate several volatilities (GDP, employment, prices, and productivity) and phase shifts (see table 1). They concluded that introducing an "erratic" monetary rule improves the ability of the model to reproduce consumption behavior.

[3] Defined as investment as a percentage of output.

Table 1. Characteristics of RBC Models Calibrated for the Chilean Economy

Authors (year)	Theoretical Framework	Features of the Calibration	Data Frequency and Span	Objective /Results
Quiroz et al (1991)	DSGE model. Infinitely-lived agent, 1-good, closed economy. Based on Kydland and Prescott (1982). Time-to-build restrictions were incorporated.	Filter: Not reported Method of solution: Linear quadratic Metric: Standard deviations, contemporaneous cross-correlations, and (first-third) auto-correlations.[1]	Quarterly data, 1977.1-1990.4	Objective: To replicate regularities (several sample moments) Good fit: volatility of output and investment, and first autocorrelation of investment. Difficulties to replicate: cross correlations and autocorrelations of output. Contrary signs: third autocorrelations of output and investment.
Quiroz (1991)	DSGE factor model. Infinitely-lived agent, 2-good, small open economy. Four sectors and cost of adjustment of labor. Based on Corbo (1985).	Filter: Not reported Method of solution: Linear quadratic Metric: Standard deviations, contemporaneous cross-correlations, and (first-fourth) auto-correlations.[1]	Quarterly data, 1977.1-1990.4	Objective: To replicate empirical regularities of the real exchange rate (volatility, contemporaneous cross-correlations, and auto-correlations). Good fit: volatility of output and investment, and contemporaneous cross-correlation with wages, price of copper and foreign capital inflows. Difficulties to replicate: RER autocorrelations.
Acuña and Oyarzún (2001)	DSGE model. Infinitely-lived agent, 1-good, closed economy. Based on Cooley and Hansen (1989) cash-in-advance model.	Filter: Hodrick and Prescott (1997) Method of solution: Linear quadratic with distortions Metric: Standard deviations, (contemporaneous-fifth) cross-correlations.[1]	Quarterly data, 1986.1-2000.1	Objective: To replicate regularities (several sample moments) and assess the role of money in Chilean business cycles. Good fit: direction of variables except capital stock and money. Difficulties to replicate: GDP, employment, prices, inflation, and productivity volatility; phase shift of all variables except consumption, prices, and productivity; output-money correlation.
Bergoeing et al (2001)	DGE model. Infinitely-lived agent, 1-good, closed economy. Basic growth model with income tax.	Filter: Not used Method of solution: Linear quadratic Metric: Decomposition of average annual changes in real output per worker.[1]	Annual data, 1981-2000	Objective: To explain the Chilean and Mexican recoveries (1985-2000). Tax policy was important but it cannot explain more than a small fraction of the differences in both countries recoveries. Good fit: average annual changes in real output per working-age person. Difficulties to replicate: work and capital effort in the early eighties.
Chumacero and Fuentes (2002)	DSGE model. Infinitely-lived agent, 2-good, small open economy. Includes relative price of investment and income taxes. Based on Greenwood, Hercowitz, and Krusell (2000).	Filter: Not used Method of solution: Perturbation method (second-order approximation) Metric: Set of VAR coefficients and impulse-response functions of real GDP.	Annual data, 1960-2000	Objective: To replicate regularities (several impulse-response functions) and assess the determinants of growth in Chilean economy. Good fit: response of output to a shock on terms of trade, fiscal expenditures as a percentage of GDP (fiscal distortions) and relative price of equipment with respect to consumption.
Bergoeing and Soto (2002)	DSGE models (5 specifications). Infinitely-lived agent, 2-good, closed, cash-in-advance economy, with labor and wage rigidities. Based on Cooley and Hansen (1989) and McGrattan (1994).	Filter: Hodrick and Prescott (1997) Method of solution: Linear quadratic Metric: Standard deviations and cross/autocorrelations.[1]	Quarterly data, 1986.1-2000.1	Objective: To replicate regularities (several sample moments) and assess the role of monetary and fiscal variables in Chilean business cycles. Good fit: prices and output volatility, consumption volatility and its correlation with output. Difficulties to replicate: correlations: output-price level (and inflation), hours worked-average productivity. Correlations of money and other variables not reported.

Notes: DSGE denotes dynamic stochastic general equilibrium, DGE denotes dynamic general equilibrium. 1/ Confidence intervals of the metric are not reported.
Source: Author's elaboration.

Bergoeing et al (2001) wondered whether tax policy changes could explain the different recoveries in Chile and Mexico during the past two decades. They used a basic RBC model with income taxes to conclude that even though tax policy was important, it could only explain more than a small fraction of the differences in both countries recoveries.

Recently, Chumacero and Fuentes (2002) formulated a small-open economy model that included the relative price of investment and income taxes. Their objective was to assess the determinants of growth of the Chilean economy between 1960 and 2000. They found a close fit among VAR impulse-response functions of GDP and those of simulated output when there is a shock on terms of trade, fiscal distortions (fiscal expenditures as a percentage of GDP) and the relative price of equipment.

Finally, based on Cooley and Hansen (1989) and McGrattan (1994), the work by Bergoeing and Soto (2002) used five specifications of RBC models (with cash-in-advance, labor, and wage rigidities) to replicate several empirical regularities and assess the role of monetary and fiscal variables in Chilean business cycles. One of their specifications achieved close fit in prices and output volatility, consumption volatility and its correlation with output, but has some difficulties to replicate the correlations of output-price level, output-inflation, and hours worked-average productivity. Also, they found that the inclusion of wage rigidities does not contribute significantly to match the data.

In summary, most previous works do not consider monetary variables or the relationship between these and real variables, and when they do, they have some trouble replicating sample moments. Besides, money is considered as an exogenous variable, and the economy is supposed to be closed to international trade, which might be seen as unrealistic assumptions for the past two decades in Chile. Finally, most of them use linear quadratic methods that might be inadequate in certain cases.[4]

[4] I will return to this point in section 5.2.

3. Stylized Facts: VAR-Based Impulse Responses

In this section I estimate a Vector Autorregresion (VAR) model to characterize the Chilean economy during the period of study and obtain impulse-response functions and confidence intervals. These functions and intervals will be used as metric of comparison with those from the model to be presented in the next section.

As mentioned before, the data consist of monthly series from 1986.01 to 2000.12, so the recent period of "nominalization" of the monetary policy by the Central Bank of Chile (CBC) is not taken into consideration. The purpose is to compare the data and the simulated series from the theoretical model during the period when the CBC had a unique monetary policy (in this case, an UF-indexed monetary policy).

The VAR estimated herein is a five-variable model that also considers a trend and seasonal dummy variables. The variables used are: the log of the terms of trade, the log of (gross) UF[5]-indexed policy interest rate[6], the log of (gross) inflation rate, the log of M1 in real terms, and the log of the Monthly Activity Index of Chile or IMACEC. Appendix A shows the sources of the data. It is important to say that these variables were chosen as the empirical counterpart of the variables explained by the theoretical model to be presented in the next section.

The steps that will be taken to estimate the VAR are the following. First, I will compute information criteria, such as the Schwarz or Hannan-Quinn criteria, to determine the optimal number of lags of the VAR. Second, I will test the stationarity of the representation, checking if the eigenvalues are inside the unit circle or not. Third, I will verify if residuals present a Normal multivariate distribution or not. Departures from Normality imply that the confidence intervals should be constructed through a bootstraping

[5] UF denotes *Unidad de Fomento*. It is a unit of account used for commercial and financial transactions in Chile.

[6] The interest rate paid on 90-day bonds issued by the CBC (or *Tasa Pagarés Reajustables del Banco Central*) from 1986 to 1995, and the Policy Interest Rate (*Tasa de Política Monetaria*) from 1995 to 2000. Both rates are UF-indexed.

technique as long as the residuals are white-noise process[7]. Finally, I will compute the VAR impulse-response functions and, accordingly, their confidence intervals.

From the calculation of the tests mentioned above[8] I conclude that the optimal lag length should be two following Hannan-Quinn information criterion[9]. Despite the Schwarz criteria preferred a lag length of one, the confidence intervals and the impulse-response functions in this case do not differ significantly from those when the Hannan-Quinn criterion is used (see appendix C). Since all the eigenvalues are inside the unit circle, the chosen system presents covariance stationarity. Even though the residuals are white-noise process, they show important departures from Normality. Hence, the 95% confidence intervals of impulse-response functions are calculated using bootstraping.

The ordering followed in the estimation of the VAR model is the one presented above. Also, it must be said that the confidence intervals of impulse-response functions are almost invariant to alternative orderings. Besides, following Pesaran and Shin (1998), a generalized decomposition of the variance-covariance matrix -where impulse-response analysis is invariant to the ordering of the variables- was performed and the results were very similar (see appendix C).

Figure 1 shows the main impulse-response function derived from the VAR model using Cholesky decomposition. On the outcomes obtained from the estimation I can conclude that:

- First, the output level tends to decline when it faces a temporary shock on the (UF-indexed) policy interest rate. This effect is statistically significant between the fifth and the eighteenth month. However, it is important to say that a one-lagged VAR, following the Schwarz criterion, is able to show a nonsignificant decrease in output when there is

[7] A Likelihood Ratio Test (LRT) was performed to confirm white-noise residuals.
[8] See appendix B.
[9] Hannan-Quinn criterion was chosen because of two reasons. First, it is known that Akaike criterion is inconsistent and tends to overfit. In this case, Akaike prefers an optimal lag of 24 that would imply an overparameterized model. Second, the shapes of the impulse-response functions do not vary significantly if choosing Schwarz criterion with only one lag. Later it will be clear that using a AR(1) technological shock in the theoretical model implies that output follows an AR(2) process and this fact will be consistent with a VAR(2) empirical model.

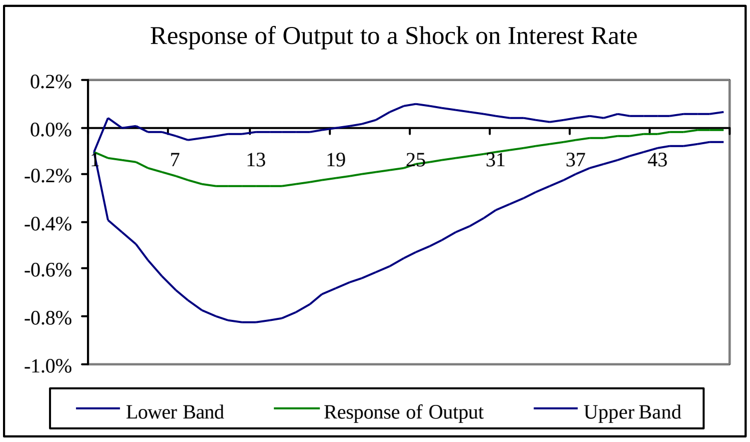
a shock on the interest rate. So this result can be summarized as a decline (slightly significant or nonsignificant) in output level.

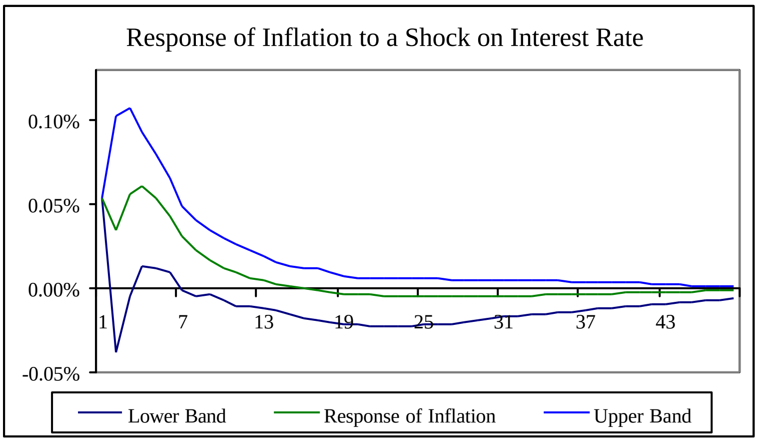
- Second, in response to a transitory interest-rate shock, the inflation rate rises. This increment is statistically significant between the third and sixth month. This is the so-called "*price puzzle*" in the economic literature. That is, if a positive innovation in the interest rate is seen as a restrictive monetary policy, then inflation rate should decrease (instead of increasing) according to the predictions of a standard Mundell-Fleming model with a Keynesian aggregate supply. This stylized fact is also found by other studies for Chile.[10] This result is robust to the use of any ordering or number of optimal lags.
- Third, a policy rate shock implies a negative effect on real money balances. Thus there is no evidence of "*liquidity puzzle*". This effect is statistically significant for more than a year and is also invariant to the use of any ordering or number of optimal lags.

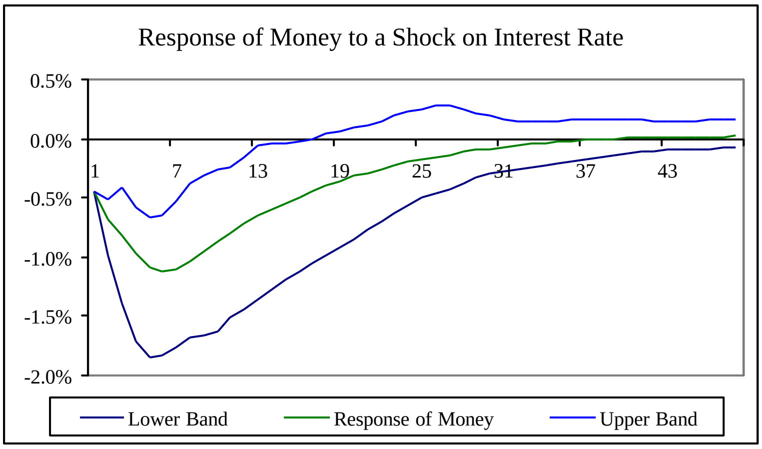
The confidence intervals of the impulse-response functions will be used as a metric of comparison to test the capability of the theoretical model –presented in the next section– to match Chilean data. Basically, I am interested in finding a theoretical framework capable of explaining and replicating the facts shown before: the co-movement between inflation and interest rates and the effects of an interest rate shock on output and money.

[10] See Parrado (2001) for a brief discussion about the "price puzzle" in the Chilean economy.

Figure 1. Impulse-Response Functions from the VAR Model (VAR(2) and Cholesky Decomposition)







4. The Model

In this section I describe the main characteristics of the proposed model. The general features to be considered are: household's utility function depends on consumption, real money holdings, and leisure; a Taylor rule followed by the monetary authority; demand for nominal and UF-indexed bonds; the presence of technological and fiscal expenditure shocks; constant distortionary taxes; and open economy.

Households

Consider an economy of an infinitely-lived agent that optimizes an utility function which depends on real private consumption c_t, real money balances m_t, and leisure l_t:

$$E_t\left\{\sum_{t=0}^{\infty}\beta^t u\left(c_t, m_t, l_t\right)\right\}, \tag{1}$$

where $0<\beta<1$ is the subjective discount factor and E{.} the expectation operator.

The representative household's constraint is:

$$\begin{aligned} c_t + i_t + b_t + b_t^U + m_t \leq (1-\tau_L) w_t L_t + (1-\tau_K) r_t K_t + q_t y_2 + T_t + \frac{m_{t-1}}{1+\pi_t} + \frac{(1+R_t) b_{t-1}}{1+\pi_t} + \\ + \left(1+R_t^U\right)\frac{U_t}{U_{t-1}}\frac{b_{t-1}^U}{1+\pi_t} + D_t, \end{aligned} \tag{2}$$

where i_t denotes real investment in period t, b_t is the real stock of bonds, b^U_t is the UF-indexed real stock of bonds, τ_L and τ_K are (constant) taxes on labor and capital income, w_t denotes real wage, L_t represents the level of employment[11], r_t is the real cost of capital, K_t is the stock of physical capital, q_t is the relative price of exportable goods to importable goods or terms of trade, T_t denotes real lump-sum transfers, π_t is the inflation rate, R_t represents nominal (net) interest rate, R_t is UF-indexed (net) interest rate, D_t are firm profits, and U_t denotes the value of one *Unidad de Fomento* (UF) in period t, that evolves according to:

$$\frac{U_{t+1}}{U_t} = (1+\pi_t)^{1-\upsilon}(1+\pi_{t-1})^{\upsilon}, \tag{3}$$

where υ is equal to 9/30. It represents the number of days in a month that the UF growth depends on inflation in period t-1 since the rest of days (21/30) it depends on inflation in period t. That is, UF growth in t+1 is a weighted geometric mean of the inflation rate in t and the inflation rate in t-1.

I assume that there are two goods produced in this economy; the first good (y_1, or importable good) is produced domestically and can be imported, but the second one (y_2, or exportable good) is not consumed domestically and it is supposed to be constant.

Next, assume the following utility function that depends on the logs of consumption, money, and employment:

$$u(c_t, m_t, l_t) = \log c_t + \phi \log m_t + \eta \log(1-L_t). \tag{4}$$

Capital accumulation has the following law of motion:

$$K_{t+1} = (1-\delta)K_t + i_t\ , \tag{5}$$

where δ is the rate of capital depreciation.

The law of motion of the exogenous terms of trade is:

$$\theta_t = (1-\rho_\theta)\theta_0 + \rho_\theta\,\theta_{t-1} + \varepsilon_{\theta t} \ \ ; \ \ \varepsilon_{\theta t} \sim iid\,(0, \sigma_\theta^2) \ \ ; \ \ \theta_0 > 0 \ \ ; \ \ 0 < \rho_\theta < 1. \tag{6}$$

To finalize the description of the economy, I suppose a Taylor rule that depends positively on the output and inflation deviations from steady-state values plus an autorregresive term:

$$R_{t+1} = (1-\theta_3)R_0 + \theta_1 \log\left(\frac{y_{1t}}{y_1^*}\right) + \theta_2 \log\left(\frac{1+\pi_t}{1+\pi^*}\right) + \theta_3 R_t + \varepsilon_{R,t+1}; \quad R_0,\ \theta_1,\ \theta_2 > 0,\ 0 < \theta_3 < 1. \qquad (7)$$

where y_1^* is the steady-state output level of (importable) goods, π^* represents the steady-state inflation rate, and ε_{Rt+1} is a zero-mean shock with variance σ^2_R. Notice that R_0 corresponds to the long-run (or steady-state) interest rate.

In a decentralized equilibrium, the agent maximizes (1) subject to (2)-(7). Accordingly, the first-order conditions are:

$$\frac{1}{c_t} - \lambda_t = 0 \qquad (8)$$

$$\frac{\phi}{m_t} - \lambda_t + \beta E_t\left(\frac{\lambda_{t+1}}{1+\pi_{t+1}}\right) = 0 \qquad (9)$$

$$-\frac{\eta}{(1-L_t)} + \lambda_t(1-\tau_L)w_t = 0 \qquad (10)$$

$$-\lambda_t + \beta(1+R_{t+1})E_t\left(\frac{\lambda_{t+1}}{1+\pi_{t+1}}\right) = 0 \qquad (11)$$

$$-\lambda_t + \beta(1+R^U_{t+1})\frac{U_t}{U_{t-1}}E_t\left(\frac{\lambda_{t+1}}{1+\pi_{t+1}}\right) = 0 \qquad (12)$$

$$-\lambda_t + \beta E_t \lambda_{t+1}\left[(1-\tau_K)r_{t+1} + (1-\delta)\right] = 0. \qquad (13)$$

Notice that since the nominal and UF-indexed bonds are risk-free assets, R_{t+1} and R^U_{t+1} are known in period t, thus they are placed out of the expectation operator. Besides, observe that equation (10) and (11) imply the arbitrage condition between the assets:

$$\left(1+R^{U}_{t+1}\right)\frac{U_t}{U_{t-1}}=\left(1+R_{t+1}\right). \tag{14}$$

This is a statement of interest rate parity, which says that the representative agent is indifferent between investing in an asset that yields a nominal return, or investing in an asset that yields an UF-indexed return. Given that the law of motion of the UFs is known in period t+1, equation (14) implies that any shock on the nominal interest rate is totally transfered to the UF-indexed interest rate and viceversa. Therefore, using the nominal or the UF-indexed interest rate as monetary policy is indifferent in this context.

Firms

The representative firm maximizes its profit given by equation (15),

$$D_t = y_t - w_t L_t - r_t K_t \tag{15}$$

subject to a returns-to-scale technology:

$$y_{1t} = F\left(K_t, L_t, z_t\right) = A_0 K_t^{\alpha} L_t^{1-\alpha} e^{z_t} \quad ; \qquad A_0 > 0, \quad 0 < \alpha < 1, \tag{16}$$

where z_t is a technological shock that follows an autorregresive process[12]:

$$z_t = \rho_z z_{t-1} + \varepsilon_{zt}, \qquad \varepsilon_{zt} \sim iid\left(0, \sigma_z^2\right) \;\; ; \;\; 0 < \rho_z < 1, \tag{17}$$

and ε_{zt} is a zero-mean shock with variance σ^2_z.

[12] To assume first-order autorregresive process is quite standard in RBC literature even for Chile. This is supposed in this model to generate first or second-order autorregresive process for the simulated variables and to be consistent with the empirical model estimated in the last section, which is a VAR(2). Chumacero and Fuentes (2002) show that if the productive shocks follow an AR(1) process in a general equilibrium model, then output follows an AR(2) process.

Thus, the firm maximizes (15) subject to (16)-(17), obtaining the following first-order conditions:

$$aA_0\left(\frac{L_t}{K_t}\right)^{1-a} e^{zt} - r_t = 0 \tag{18}$$

$$(1-a)A_0\left(\frac{K_t}{L_t}\right)^{a} e^{zt} - w_t = 0 \tag{19}$$

<u>Public Sector</u>

The government budget constraint is:

$$g_t + T_t = t_L w_t L_t + t_K r_t K_t + m_t - \frac{m_{t-1}}{1+p_t} + b_t - \frac{(1+R_t)b_{t-1}}{1+p_t} + b_t^U - (1+R_t^U)\frac{U_t}{U_{t-1}}\frac{b_{t-1}^U}{1+p_t}, \tag{20}$$

where g_t is the exogenous government expenditure. The model also considers a stationary law of motion for the fiscal policy:

$$g_t = (1-r_g)g_0 + r_g\, g_{t-1} + e_{gt} \;\; ; \;\; e_{gt} \sim iid\left(0, s_g^2\right) \;\; ; \;\; g_0 > 0 \;\; ; \;\; 0 < r_g < 1, \tag{21}$$

and ε_{gt} is a zero-mean shock with variance $\sigma^2{}_g$.

<u>The Economy</u>

Finally, equation (2) and (20) imply that aggregate demand equals production in both sectors:

$$c_t + i_t + g_t = y_{1t} + q_t y_2. \tag{22}$$

Summing up, the parameters of the model are β, ϕ, η, δ, α, τ_L, τ_K, those related to the exogenous autorregresive processes (ρ_z, ρ_g, ρ_q, A_0, g_0, q_0, y_2, $\sigma^2{}_z$, $\sigma^2{}_g$, $\sigma^2{}_q$), and those related to the Taylor Rule (R_0, θ_1, θ_2, θ_3 y $\sigma^2{}_R$). The state variables are K_{t+1}, b_{t+1}, $b^U{}_{t+1}$, g_t, z_t, q_t. The controllable state variables are R_t, $R^U{}_t$, π_t. And the control variables are c_t, L_t, and m_t. The solution of the model in steady state is presented in Appendix D.

5. Calibration and Results

5.1. Parameterization

This section describes the parameterization of the model. As mentioned above, there are 22 parameters that appear in the equations that characterize behavior around steady state.

Previous works for Chilean data have assigned values to some of these parameters. Table 2 summarizes some of the most frequent values used for common parameters for Chilean economy and, as a reference, some values for US economy.

For example, it is known that the capital-share parameter values used before for Chilean data were between 0.33 and 0.6, even though most of them were in the 0.33-0.40 range, as table 2 shows.

Also it can be said that parameters such as the subjective discount factor, the autorregresive coefficient of the technological shock, the capital depreciation rate have similar values -once they are compared in the same frequency[13]- along the literature.

Therefore, I assume three criteria to assign values to each parameter of the model:

- The first criterion is to use some of the standard parameter values given in previous literature for Chile (according to table 2).
- The second criterion is to find the parameter value necessary to match some steady-state values for Chilean economy (such as the steady-state consumption as a percentage of GDP, the steady-state inflation rate, and so on).

[13] Remember that the calibration of the model must be done in terms of monthly data. For instance, a monthly subjective discount factor of 0.996 corresponds to an annual value of 0.953.

- The last criterion is to adjust the parameter values to allow the model match the metric of comparison (the confidence intervals of the impulse-response functions).

Table 2. Parameters Used in Previous Studies

Authors	Country and Period of Study	Preferences and Technology						
		b	f	a	r_z	s_z	d	
McGrattan (1994)	US, 1947-1987	0.985	...	0.397	NC	0.0980	0.0226	
Cooley and Hansen (1995)	US, 1954-1991	0.989	...	0.400	0.950	0.0070	0.0190	
Quiroz and others (1991)	Chile, 1977.1-1990.4	NR	...	NR	0.999	0.0200	0.0000	
Acuña and Oyarzún (2001)	Chile, 1986.1-2000.1	0.986	...	0.400	0.990	0.0178	0.0250	
Bergoeing and others (2001)	Chile, 1981-2000	0.980	...	0.600	NR	NR	0.0800	
Chumacero and Fuentes (2002)	Chile, 1960-2000	0.980	...	1/3	0.730	0.0400	0.0600	
Bergoeing and Soto (2002)	Chile, 1986.1-2000.1	0.979	...	0.37-0.4	0.981	0.0990	0.0200	
Walsh (1998)	US, (NR)	0.989	0.005	0.400	0.950	0.0089	0.0190	
		Exportable Sector and Fiscal Policy						
		r_q	s_q	t_l	t_k	$\mathbf{g_0}$	r_g	s_g
McGrattan (1994)	US, 1947-1987	...	...	NP	NP	70.990	NC	0.078
Bergoeing and others (2001)	Chile, 1981-2000	...	...	...	0.51-0.12	...	...	...
Chumacero and Fuentes (2002)	Chile, 1960-2000	0.892	0.14	0.25	0.25	NR	0.895	0.024
Bergoeing and Soto (2002)	Chile, 1986.1-2000.1	...	...	NP	NP	0.089	0.760	0.097

Notes: NR denotes "not reported". NP denotes that it is not considered as parameter in the study. NC means "not comparable", since the author(s) did not used an AR(1) process.

Thus, table 3 reports the parameter values assumed for the calibration and the corresponding criterion used in each case.

Table 3. Parameterization of the Model

Parameter	Symbol	Value	Criteria of Choice
Subjective discount factor	β	0.996	Previous literature. The value implies a steady-state real interest rate of 5%
Utility sensitivity to money	ϕ	0.005	Calibration of impulse-response functions and previous literature
Utility sensitivity to leisure	η	1.2	Calibration of steady-state labor between 0.3 and 0.4
Capital share	α	0.35	Previous literature (between 0.33-0.4)
Technological constant	A_0	0.9	Calibration of consumption as a percentage of GDP (63% +/- 2.3%)
Technological-AR1 coefficient	ρ_z	0.9	Calibration of impulse-response functions and previous literature
Technological volatility	σ_z	0.0001	Calibration of impulse-response functions and GDP volatility
Depreciation rate	δ	0.09/12	Previous literature and calibration of investment as a percentage of GDP (22% +/- 3.3%)
Steady-state terms of trade	q_0	1.072	AR(1) estimates (data: 1986.01-2000.12)
Terms-of-trade-AR1 coefficient	ρ_q	0.961	AR(1) estimates (data: 1986.01-2000.12)
Volatility	σ_q	0.0127	AR(1) estimates (data: 1986.01-2000.12)
Capital taxes	τ_l	0.25	Source: Chumacero and Fuentes (2002)
Labor taxes	τ_k	0.25	Source: Chumacero and Fuentes (2002)
Steady-state government expenditure	g_0	1.22	Calibration of government expenditures as a percentage of GDP (13.3% +/- 5%)
Government-AR1 coefficient	ρ_g	0.76	Source: Bergoeing and Soto (2002)
Government Expend. volatility	σ_g	0.008	Source: Bergoeing and Soto (2002)
Taylor Rule constant	R_0	0.0061	Calibration of steady-state inflation around 2.64%
Taylor Rule AR1 coefficient	θ_1	0.67	Calibration of impulse-response functions
Output deviation coefficient	θ_2	0.1	Calibration of impulse-response functions
Inflation deviation coefficient	θ_3	0.2	Calibration of impulse-response functions
Taylor Rule volatility	σ_r	0.68e-4	Calibration of impulse-response functions

Notes: AR(1) denotes first-order autoregressive process.

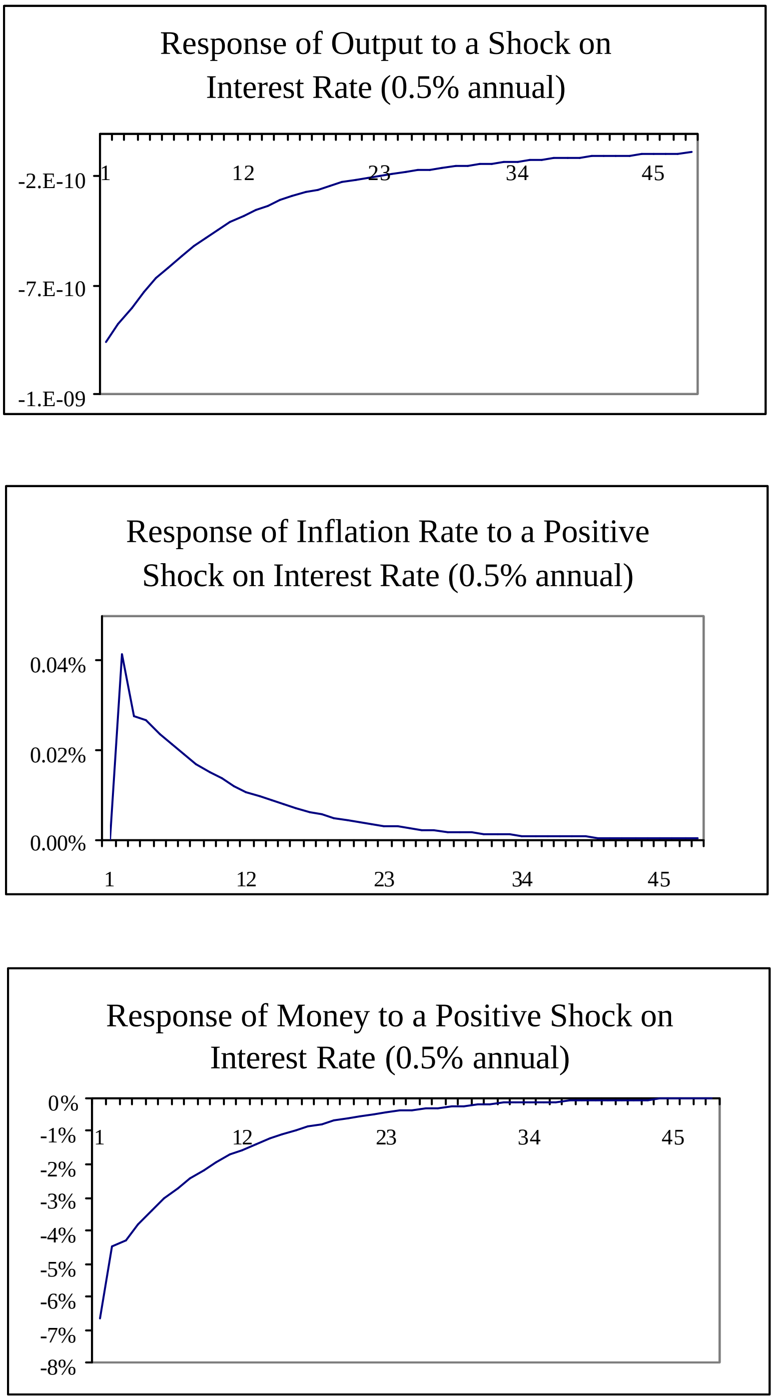
5.2. Main Results

The solution of the model is achieved using a perturbation method (second-order approximation) developed by Schmitt-Grohé and Uribe (2001). This method consists of a second order approximation to the policy functions of the dynamic equilibrium model. As the authors state, the inconvenience with the use of first order approximation methods is that they are not well suited to handle questions such as welfare comparisons across alternative stochastic or policy environments. Aside from that, the problem of linearized decision rules to evaluate second-order approximations to the objective function is that some second-order terms of such objective function are ignored. Therefore, such problems do not arise with the use of second or higher order approximations.

Figure 2 presents the responses of a transitory shock on the log of (gross) interest rate. The shock given is positive so it represents a restrictive monetary policy. The increment is 0.5% (50 basis points) of the annual policy rate (or 0.04% in monthly terms). The following results are found:

- The positive shock on the interest rate has a transitory negative -but not significant- effect on output level. The increase in interest rate implies -by the arbitrage condition between the physical capital and the financial capital markets- an increment in the cost of capital. This generates a reduction in the demand for capital (that is only partially overweighed by the increase in labor due to a substitution effect) and, consequently, the fall in output. The insignificant fall in output is probably because of the absence of rigidities, such as nonflexibilities in the good market or the labor market.

Figure 2. Impulse-Response Functions from the Theoretical Model



- Second, the policy shock causes a transitory increase in the inflation rate. As was mentioned in section 3, this is called in the empirical literature the *"price puzzle"*. Notwithstanding, this effect has a straightforward explanation according to the theoretical model proposed here: an increase in the interest rate produces a similar effect on inflation leaving real interest virtually invariant due to a Fisher effect. That is, the Fisher equation implies that higher interest rates are associated with higher inflation rates, exactly the relationship shown in figure 2 and, also, in figure 1. The explanation to the co-movement of interest rate and inflation has been given in previous studies but without a specific application for a particular economy. Monnet and Weber (2001) presents a discussion that reconciles the positive relationship (Fisher view) between interest rate and inflation and the negative relationship between those variables (liquidity view). Also, Alvarez, Lucas, and Weber (2001) raised an analogous explanation with the inclusion of segmented markets. In the model presented above, the reason is that the nominal interest rate has effect only on inflation but not on the real interest rate. Besides, this effect is strengthened in the model because of the assumption of a Taylor rule that depends positively on inflation deviation from steady state.

  Does this result mean that a central bank should increase the policy interest rate to fight an inflation process? The answer is no. According to equation (7), a reduction of long-run inflation rate target should increase the interest rate, then the central bank would follow a monetary policy consistent with economic agents expectations. Thus, both inflation and interest rate should decrease converging to the new steady state equilibrium.

- Third, the positive policy shock produces a temporary decrease in real money holdings through the function of the demand for money. That is, the agents respond with higher demand for nominal bonds (and, consequently, they lower their money holdings) when they face a positive interest shock.

On this point, it should be underlined that values for the inflation and output deviation coefficients higher than those assumed in table 2 (θ_2=0.1 and θ_3=0.2), generates explosive equilibrium or indeterminacy, results that are consistent with those found by Christiano and Gust (1999). This topic could be a matter of interest and future research for Chilean economy.

5.3. How Well is the Matching?

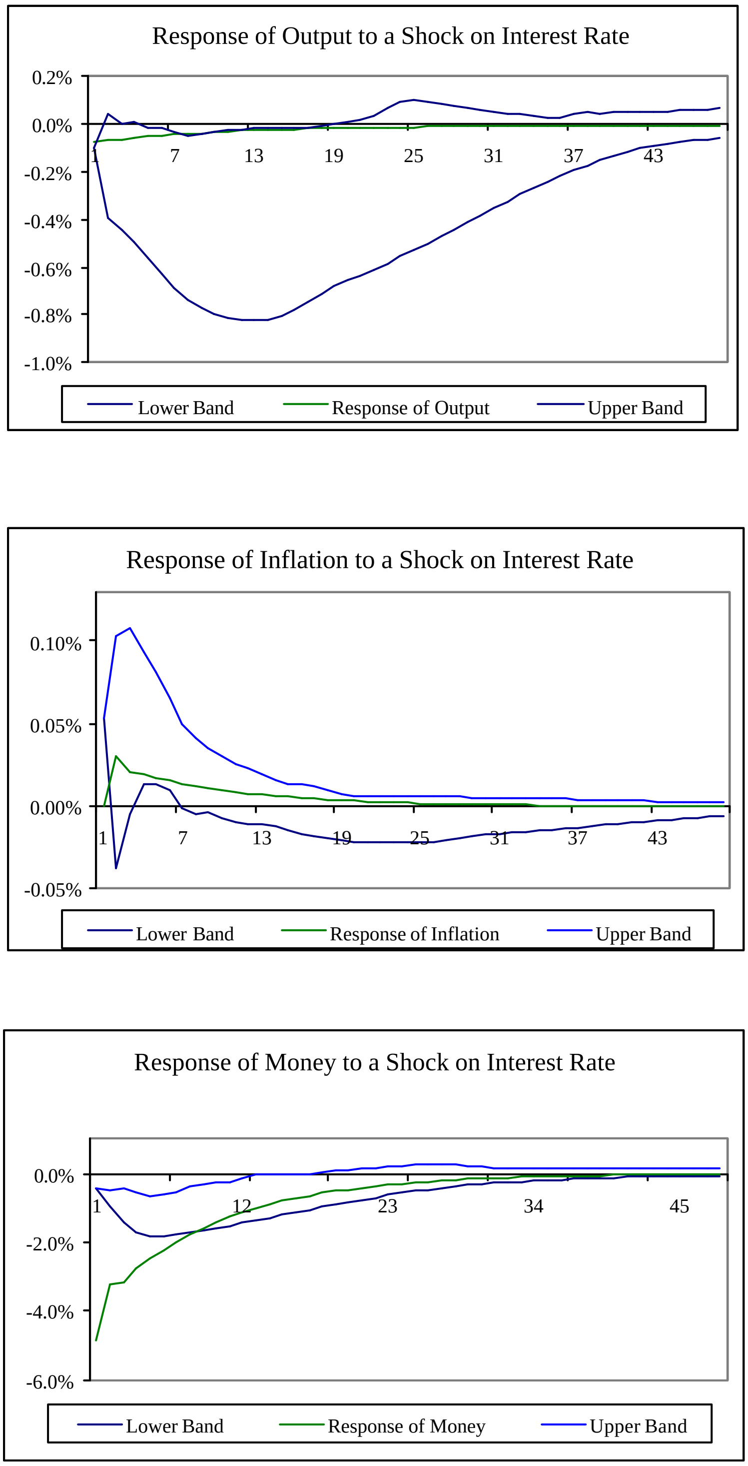
In this section I compare the responses of the variables from the empirical model (the VAR) and those from the theoretical model when they face an equivalent positive temporary policy rate shock. As before, the interest of the analysis is on the responses of output, inflation and money.

Figure 3 reports the confidence intervals of the impulse-response functions (the upper and lower bands) and the response of each variable from the theoretical model. The shock consists of an increase of 0.03% in the interest rate (0.36% in annual terms).

As it can be seen, the matching is relatively well, but with some observations. The response of output given by the theoretical model is not as significant as the real response showed by the data. The response of inflation rate is inside the confidence intervals from the second period. Finally, the response of real money balances is negative as in the VAR, but its trajectory falls out of the bands from the first to the nineth period.[14]

[14] An analogous exercise with generalized decomposition was performed obtaining similar results (see appendix E).

Figure 3. VAR Confidence Intervals and Impulse-Response Functions from the Theoretical Model (VAR(2) and Cholesky Decomposition)



6. Conclusions

As the literature review shows, most previous RBC-type works for Chilean economy do not consider monetary variables or the relationship between these and real variables, and when they do, they have some trouble replicating sample moments. Besides, money is considered as an exogenous variable, and the economy is supposed to be closed to international trade, which might be seen as unrealistic assumptions for the past two decades in Chile. On the other hand, most of them use linear quadratic methods that might be inadequate in certain cases as was discussed in section 5.2.

The goal of this paper was to find out how well a money-in-the-utility-function model with Taylor rule could account for some monetary stylized facts from Chilean data during the 1986-2000 period. Basically, I focused the attention on a theoretical explanation to what is called the "price puzzle" (the co-movement between interest rate and inflation rate), fact that is found in many VAR-type estimates for Chile and other economies.

As seen in section 2, the previous works that consider real business cycle models with monetary variables, practically ignore or are only capable of explaining a few features of monetary relationships, generally some second moments.

This paper formulates, solves and calibrates a dynamic stochastic general equilibrium model for the Chilean economy between 1986 and 2000. The solution of the model is adequately achieved using a perturbation method (second-order-approximation) proposed by Schmitt-Grohé and Uribe (2001). The metric consists of confidence intervals of impulse-response functions from a 5-variable VAR. These variables were chosen as the empirical counterpart of the variables explained by the theoretical model presented in section 4.

I find that a positive transitory policy interest rate shock causes a temporary (not significant) fall of output. From a theoretical viewpoint, the increase in interest rate implies an increment in the cost of capital, and, consequently, a reduction in the demand for capital and output. The decline is consistent with the sign of the impulse-response function from de

VAR estimated in section 3. Even though this effect is statistically significant in that case, it is important to say that one-lagged VAR, following the Schwarz criterion, is able to show a nonsignificant decrease in output when there is a shock on the interest rate.

The policy shock causes a transitory increase in the inflation rate. As was mentioned in section 3, this is called in the literature the "*price puzzle*". According to the theoretical model proposed here, this effect has a straightforward explanation: an increase in the interest rate produces a similar effect on inflation leaving real interest virtually invariant due to a Fisher effect. Therefore, the theoretical model proposed is able to explain and reproduce the co-movement between interest rate and inflation. Besides, this effect is strengthened by a monetary policy expressed by a Taylor rule that depends positively on inflation deviation. A similar explanation is also given in some recent studies in the economic literature (Monnet and Weber, 2001; and Alvarez, Lucas, and Weber, 2001).

Finally, a transitory increment in interest rates decreases real money balances. This effect is relatively consistent with the impulse-response functions obtained from the VAR from the eighth period of analysis.

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Appendix A

Data and Sources

Variable	Definition	Source
Terms of trade	Log of terms of trade	Bennett and Valdés (2001)
Interest rate	Log of (gross) UF-indexed interest rate paid on 90-day bonds issued by the Central Bank of Chile or PRBC from 1986 to 1995; and UF-indexed policy interest rate from 1995 to 2000.	Central Bank of Chile
Inflation rate	Log of (gross) inflation rate (or growth of Consumer Price Index)	Central Bank of Chile
Money	Log of M1 deflated by the Consumer Price Index	Central Bank of Chile
Output	Log of Monthly Economic Activity Index of Chile (IMACEC)	Central Bank of Chile

Appendix B

Model Selection Criteria by Lag

Lags	Akaike	Schwarz	Hannan-Quinn
0	-39.7464	-38.5934	-39.2789
1	-48.2636	**-46.6611**	-47.6138
2	-48.7046	-46.6490	**-47.8710**
3	-48.8589	-46.3467	-47.8401
4	-48.8376	-45.8653	-47.6320
5	-48.7458	-45.3098	-47.3520
6	-48.6101	-44.7066	-47.0266
7	-48.4469	-44.0724	-46.6722
8	-48.3882	-43.5389	-46.4207
9	-48.3986	-43.0707	-46.2368
10	-48.2807	-42.4702	-45.9229
11	-48.1470	-41.8501	-45.5916
12	-48.3558	-41.5686	-45.6012
13	-48.4710	-41.1895	-45.5156
14	-48.4252	-40.6452	-45.2672
15	-48.4216	-40.1391	-45.0595
16	-48.3456	-39.5563	-44.7775
17	-48.3687	-39.0685	-44.5929
18	-48.6789	-38.8634	-44.6936
19	-48.6367	-38.3015	-44.4402
20	-48.8233	-37.9641	-44.4138
21	-49.1056	-37.7179	-44.4812
22	-49.6766	-37.7558	-44.8354
23	-50.0693	-37.6108	-45.0095
24	**-51.3365**	-38.3356	-46.0561

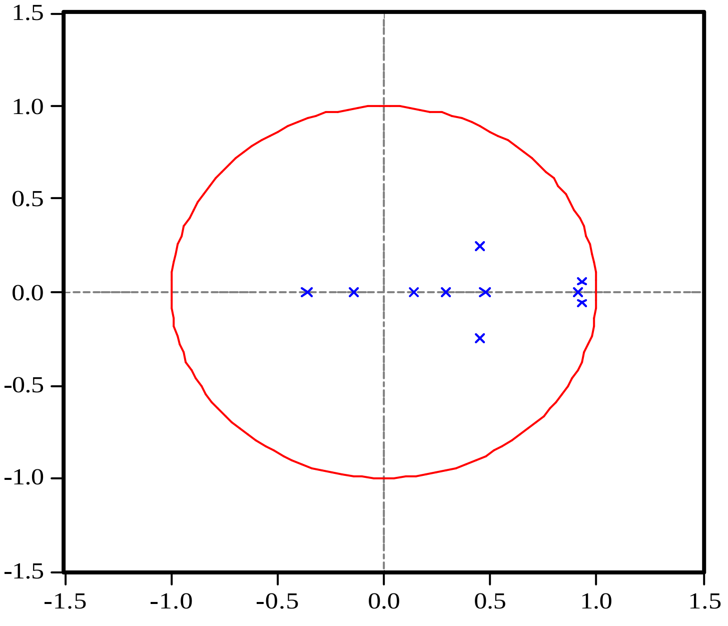
Appendix B (continued)

Roots of Characteristic Polynomial[/a]

Root	Modulus
0.934535 + 0.058543i	0.936366
0.934535 - 0.058543i	0.936366
0.914147	0.914147
0.447973 - 0.246248i	0.511193
0.447973 + 0.246248i	0.511193
0.477309	0.477309
-0.359732	0.359732
0.292091	0.292091
-0.143706	0.143706
0.139073	0.139073

a. No root lies outside the unit circle. The VAR specification satisfies the stability condition.

Inverse Roots of AR Characteristic Polynomial



Appendix B (continued)

Test for Gaussian Residuals [/a]

Test Statistic Value	P-value
236.16599	0.00000

a. Based on Doornik and Hansen (1994). The null hypothesis is the Normality of the residuals. This statistic is distributed Chi-square with 10 degrees of freedom (18.3 at 5%, 16 at 10%). In this case, the null is rejected.

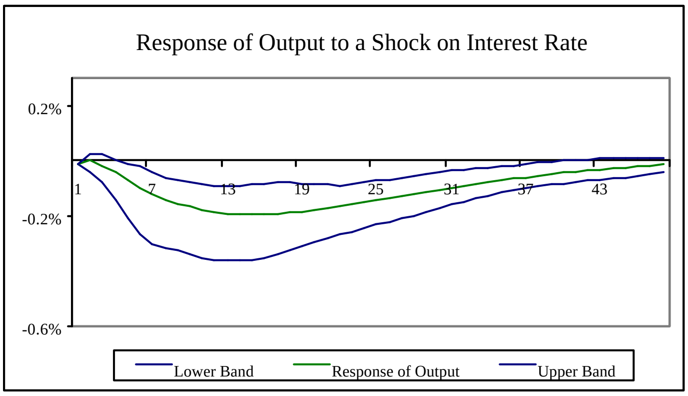
Tests for White Noise Residuals [/a]

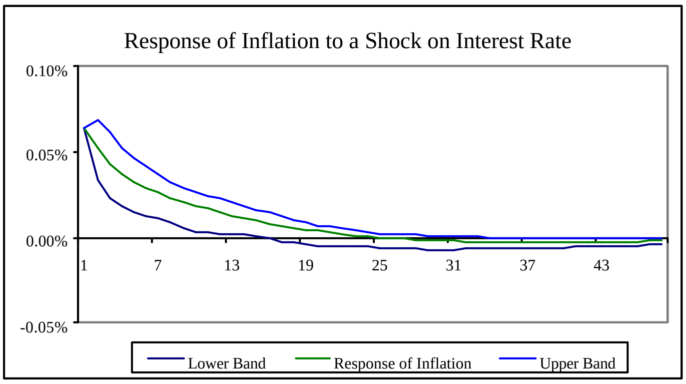
Lags	Akaike	Schwarz	Hannan-Quinn	P-value
0	**-49.94057**	**-49.85120**	**-49.90433**	0.00000
1	-49.70763	-49.16930	-49.48930	0.99951
2	-49.72778	-48.73700	-49.32593	0.28513
3	-49.63219	-48.18544	-49.04535	0.25980
4	-49.57946	-47.67313	-48.80613	0.15253
5	-49.46626	-47.09673	-48.50496	0.23385
6	-49.33143	-46.49502	-48.18062	0.40569
7	-49.17585	-45.86884	-47.83401	0.65555
8	-49.13442	-45.35301	-47.59997	0.61258
9	-48.98032	-44.72070	-47.25169	0.83095
10	-48.80885	-44.06711	-46.88442	0.95898
11	-48.86645	-43.63868	-46.74461	0.90691
12	-48.93915	-43.22134	-46.61825	0.84894

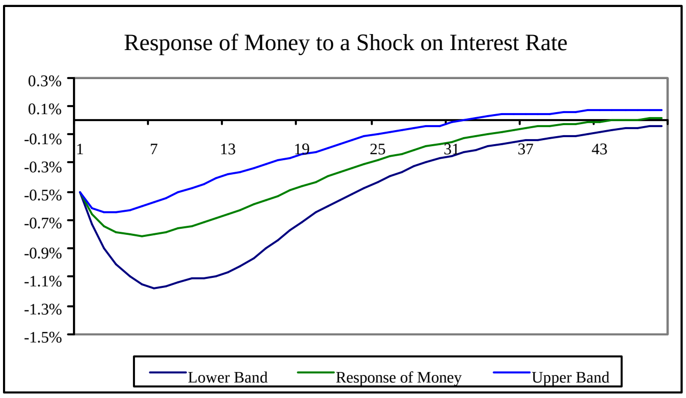
a. The p-value of the LRT test refers to the null hypothesis that the residuals are White Noise at different number of lags. All the information criteria prefer 0 as an optimal lag for the VAR estimate of the residuals. In this case, the null can not be rejected.

Appendix C

Impulse-Response Functions from the VAR Model (VAR(1) and Cholesky Decomposition)

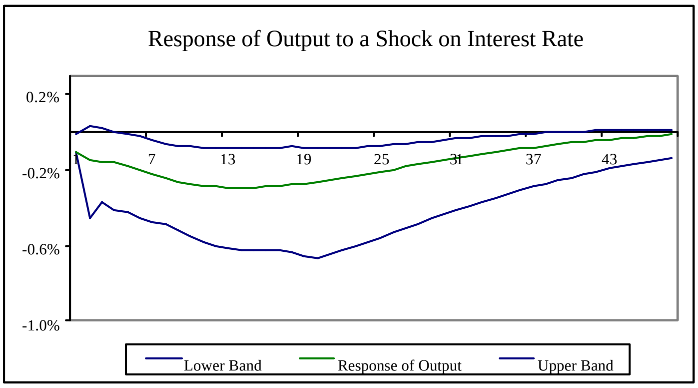


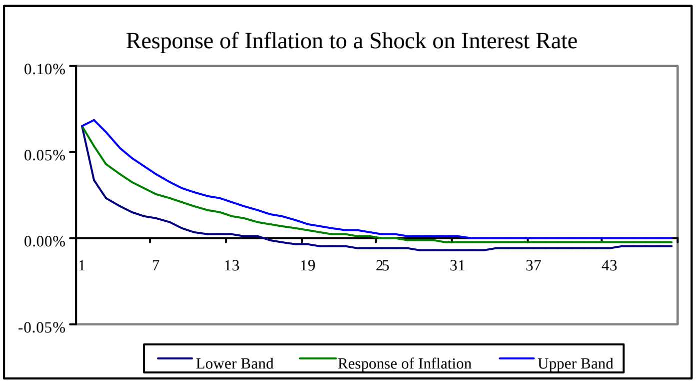


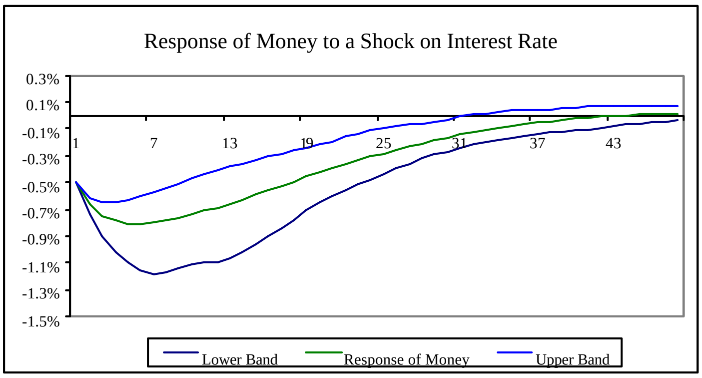


Appendix C (continued)

Impulse-Response Functions from the VAR Model (VAR(2) and Generalized Decomposition)







Appendix D
Steady-State Equilibrium of the Model

In steady state, equation (6) implies the steady-state net interest rate:

$$R^{*} = R_{0}. \tag{23}$$

Substitution of equation (23) in (11) generates the steady-state inflation rate:

$$1+p^{*} = b\left(1+R^{*}\right) \quad , \tag{24}$$

where the variables with asterisk denote steady-state values.

Rearranging equation (13) and using equation (8) and (18) yields:

$$K^{*} = L^{*}\left(\frac{aA_{0}b(1-t_{K})}{1-b\left(1-d\right)}\right)^{\frac{1}{1-a}} = w_{0}{}^{\frac{1}{1-a}}L^{*}, \tag{25}$$

where: $w_{0} = \left(\frac{aA_{0}b(1-t_{K})}{1-b\left(1-d\right)}\right) > 0.$

Using (8), (10) and (25), and rearranging one obtains an expression for the steady-state consumption that depends on the steady-state employment:

$$c^{*} = \left(\frac{\left(1-a\right)\left(1-t_{L}\right)A_{0}}{h}\right)\left(\frac{aA_{0}b(1-t_{K})}{1-b\left(1-d\right)}\right)^{\frac{a}{1-a}}(1-L^{*}) = w_{1}w_{0}^{\frac{a}{1-a}}(1-L^{*}), \tag{26}$$

where: $w_{1} = \left(\frac{\left(1-a\right)\left(1-t_{L}\right)A_{0}}{h}\right) > 0.$

Equations (22), (25), (26), the steady-state level of investment from equation (5), and the steady-state government expenditure from equation (21), allow one find the steady-state level of employment:

$$L^* = \frac{w_0^{\frac{a}{1-a}} w_1 + g_0 - q_0 y_2}{w_0^{\frac{a}{1-e}} \left(A_0 + w_1 - d w_0 \right)}. \tag{27}$$

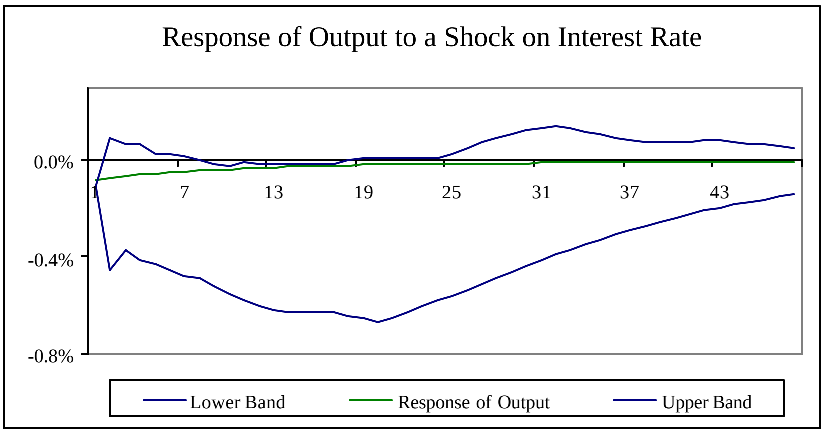
With equation (27) one can get the steady-state capital stock, investment, consumption, and production. Finally, equation (8), (9), (26) and (28) generate the steady-state money balances:

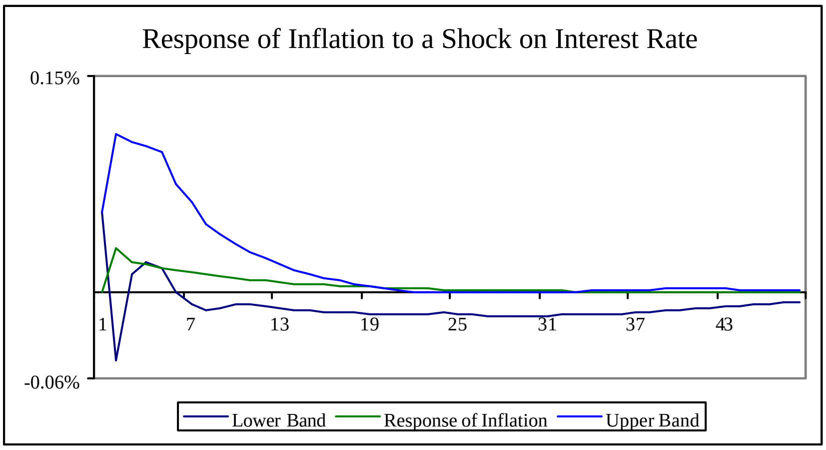
$$m^* = f\ c^* \left(\frac{1 + R^*}{R^*} \right). \tag{28}$$

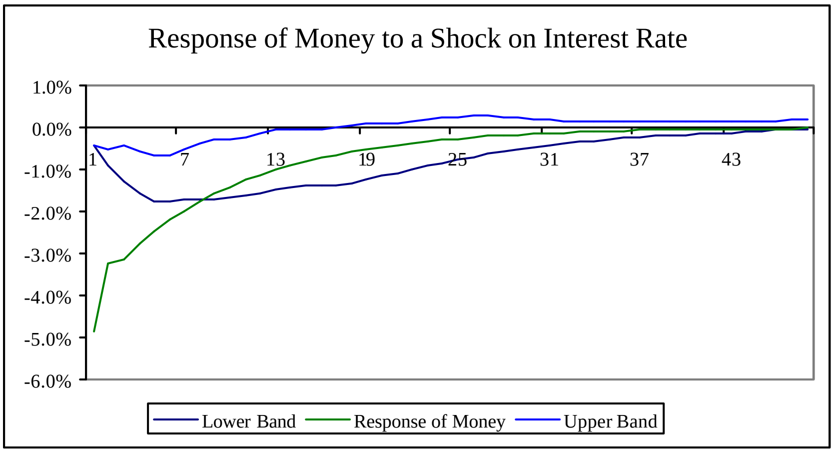
Notice that the demand for money depends positively on consumption and negatively on the nominal interest rate.

Appendix E

VAR Confidence Intervals and Impulse-Response Functions from the Theoretical Model (VAR(2) and Generalized Decomposition)







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