How Well Does a Monetary Dynamic Equilibrium Model Account for Chilean Data?

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Since Kydland and Prescott published their influential work in 1982, the literature on monetary real business cycle models has proved its ability to account for regularities in the data for developed countries.[1] Few works, however, attempt to do so for emerging Latin American economies.[2]

The aim of this paper is to determine how well a money-in-the-utility-function model with a Taylor rule can match some particular monetary stylized facts from the Chilean data between 1986 and 2000. In particular, it focuses on a theoretical explanation for what the empirical literature calls the price puzzle, namely, the comovement between the interest rate and the inflation rate. This is considered a puzzle because the traditional Mundell-Fleming model predicts that a positive change in the interest rate—that is, a restrictive monetary policy—should cause a decrease in private spending and thus a fall in the inflation rate.

The price puzzle is a relationship found in many VAR-type estimates for Chile and other economies. Morandé and Schmidt-Hebbel (1997) are the first authors to find a statistically significant price puzzle for the Chilean economy. Later papers find a similar link between

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1. See, for instance, Christiano and Eichenbaum (1992), Cooley and Hansen (1995), Christiano, Eichenbaum, and Evans (1997), and McCallum and Nelson (1997) for the United States; Dhar and Millard (2000) for the United Kingdom; Folkertsma (1999) 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 and others (1991), and Chumacero and Fuentes (2002).

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prices (in levels or growth) and interest rates in certain VAR specifications, with either statistically significant or nonsignificant results.

In this paper I formulate, solve, and calibrate a dynamic stochastic general equilibrium model to evaluate its ability to replicate the main features of the Chilean economy, including the price puzzle, for the 1986–2000 period. I find that a positive transitory policy interest rate shock causes a temporary (nonsignificant) decline in output, a transitory decrease in real money balances, and a temporary increase in the inflation rate. These findings are relatively consistent with impulse response functions obtained from a five-variable vector autoregression (VAR) estimated for Chile. The theoretical model proposed is thus able to explain and reproduce the comovement between the interest rate and inflation. This comovement is caused by a Fisher effect: an increase in the nominal interest rate generates an increase in inflation, leaving the real interest rate virtually unchanged. The effect is strengthened by a monetary policy expressed by a Taylor rule that depends positively on inflation deviation. An analogous explanation is given in some recent theoretical studies (see Monnet and Weber, 2001; Alvarez, Lucas, and Weber, 2001).

The study is organized as follows. Section 1 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 results. Section 2 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 to obtain impulse response functions that will be used as a metric for comparing them with those simulated by the theoretical model. Thus, a dynamic stochastic general equilibrium model is formulated, solved, and calibrated in section 3, 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 4 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.

1. Previous Studies on RBC Models for the Chilean Economy

The calibration of RBC models in Chile started in the early 1990s with the work of Quiroz and others (1991) (see table 1). The authors use the Kydland and Prescott (1982) framework to replicate several second moments of Chilean output and investment rate series from 1977 to 1990.[3] They find that this model can replicate sample volatilities but has problems with autocorrelations. In a separate study, Quiroz (1991) formulates a two-good small open economy model with labor adjustment costs to replicate some regularities exhibited by the real exchange rate during the 1977–1990 period. He concludes that the model is 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 remains unexplained.

Acuña and Oyarzún (2001) present one of the first papers to include monetary variables in an RBC framework and then to analyze the role of monetary shocks with Chilean data. They use Cooley and Hansen's (1989) cash-in-advance model. The results of their calibration show similarities with actual data in the comovement of the simulated variables (except capital and money stocks), but they have difficulty replicating several volatilities (namely, GDP, employment, prices, and productivity) and phase shifts (see table 1). They conclude that introducing an erratic monetary rule improves the model's ability to reproduce consumption behavior.

Bergoeing and others (2001) wonder whether tax policy changes can explain the different recoveries in Chile and Mexico during the past two decades. Based on a basic RBC model with income taxes, they conclude that while tax policy is important, it can only explain a small fraction of the differences in the two countries' recoveries.

Chumacero and Fuentes (2002) formulate a small open economy model that includes 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, Bergoeing and Soto (2002) use the work of Cooley and Hansen (1989) and McGrattan (1994) as the basis for five specifications of RBC models (with cash-in-advance, labor, and wage rigidities) with which they replicate several empirical regularities and assess the role of monetary and fiscal variables in Chilean business cycles. One of their specifications achieves close fit in prices and output volatility, consumption volatility, and its correlation with output,

3. Defined as investment as a percentage of output.

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

Author (year)	*Theoretical framework*[a]	*Features of the calibration*	*Data frequency and span*	*Objective and results*
Quiroz and others (1991)	DSGE model. Infinitely lived agent in a one-good closed economy. Based on Kydland and Prescott (1982), with time-to-build restrictions.	Filter: Not reported. Method of solution: Linear quadratic. Metric: Standard deviations; contemporaneous cross-correlations; first- to third-order auto-correlations.[b]	Quarterly data, 1977:1 to 1990:4	Objective: To replicate regularities (several sample moments). Results: Good fit for volatility of output and investment and for first autocorrelation of investment. Difficulties replicating cross correlations and autocorrelations of output. Contrary signs obtained for third-order 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; first- to fourth-order auto-correlations.[b]	Quarterly data, 1977:1 to 1990:4	Objective: To replicate empirical regularities of the real exchange rate (volatility, contemporaneous cross-correlations, and auto-correlations). Results: Good fit for volatility of output and investment and for contemporaneous cross-correlation with wages, price of copper, and foreign capital inflows. Difficulties replicating real exchange rate autocorrelations.
Acuña and Oyarzún (2001)	DSGE model. Infinitely lived agent in a one-good closed economy. Based on Cooley and Hansen's (1989) cash-in-advance model.	Filter: Hodrick and Prescott (1997). Method of solution: Linear quadratic with distortions. Metric: Standard deviations: contemporaneous and first- to fifth-order cross-correlations.[b]	Quarterly data, 1986:1 to 2000:1	Objective: To replicate regularities (several sample moments) and assess the role of money in Chilean business cycles. Results: Good fit for direction of variables except capital stock and money. Difficulties replicating GDP, employment, prices, inflation, and productivity volatility; phase shift of all variables except consumption, prices, and productivity; output-money correlation.

Table 1. (continued)

Author (year)	*Theoretical framework*[a]	*Features of the calibration*	*Data frequency and span*	*Objective and results*
Bergoeing and others (2001)	DGE model. Infinitely lived agent in a one-good closed economy. Basic growth model with income tax.	Filter: Not used. Method of solution: Not reported. Metric: Decomposition of average annual changes in real output per worker.[b]	Annual data, 1981 to 2000	Objective: To explain the Chilean and Mexican recoveries (1985 to 2000). Results: Tax policy is important, but it cannot explain more than a small fraction of the differences in both countries' recoveries. Good fit for average annual changes in real output per working-age person. Difficulties replicating work and capital effort in the early 1980s.
Chumacero and Fuentes (2002)	DSGE model. Infinitely lived agent in a two-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: VAR coefficients; impulse-response functions of real GDP.	Annual data, 1960 to 2000	Objective: To replicate regularities (several impulse-response functions) and assess the determinants of growth in Chilean economy. Results: Good fit for response of output to a shock on terms of trade, fiscal expenditures as a percentage of GDP (fiscal distortions), and price of equipment relative to consumption.
Bergoeing and Soto (2002)	DSGE models (five specifications). Infinitely lived agent in a two-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; cross/autocorrelations.[b]	Quarterly data, 1986:1 to 2000:1	Objective: To replicate regularities (several sample moments) and assess the role of monetary and fiscal variables in Chilean business cycles. Results: Good fit for prices and output volatility, consumption volatility, and its correlation with output. Difficulties replicating correlations of output and price level (and inflation) and of hours worked and average productivity. Correlations of money and other variables not reported.

Source: Author's compilation.
a. DSGE denotes dynamic stochastic general equilibrium. DGE denotes dynamic general equilibrium.
b. Confidence intervals of the metric are not reported.

but it has some difficulties replicating the correlations between output and the price level, output and inflation, and hours worked and average productivity. They also find that the inclusion of wage rigidities does not contribute significantly to matching the data.

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

2. Stylized Facts: VAR-based Impulse Responses

In this section I estimate a vector autoregression (VAR) model to characterize the Chilean economy during the period of study and obtain impulse response functions and confidence intervals. I then use these functions and intervals as a metric of comparison with those from the model presented in the next section.

As mentioned, the data consist of monthly series from January 1986 to December 2000, so the recent period of nominalization of monetary policy by the Central Bank of Chile 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 Central Bank had a unique monetary policy (in this case, a UF-indexed monetary policy).[5]

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-indexed policy interest rate,[6] the log of the (gross) inflation rate, the log of M1 in real terms, and the log of the monthly economic activity index (IMACEC) of Chile. Appendix A shows the sources of the data. These

4. I return to this point in section 4.1.

5. The *Unidad de Fomento* (UF) is a unit of account used for commercial and financial transactions in Chile.

6. The interest rate paid on ninety-day bonds issued by the Central Bank (*tasa de 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.

variables were chosen as the empirical counterpart of the main variables explained by the theoretical model presented in the next section.

The steps taken to estimate the VAR are the following. First, I computed information criteria, such as the Schwartz or Hannan-Quinn criteria, to determine the optimal number of lags of the VAR. Second, I tested the stationarity of the representation, checking whether the eigenvalues are inside the unit circle. Third, I verified whether residuals present a normal multivariate distribution; departures from normality imply that the confidence intervals should be constructed through a bootstrapping technique as long as the residuals are a white noise process.[7] Finally, I computed the VAR impulse response functions and, accordingly, their confidence intervals. The results are presented in appendix B; the impulse response functions are shown in figures C1 and C2 in appendix C.

I conclude that the optimal lag length should be two, following Hannan-Quinn information criterion.[8] Although the Schwartz 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. Since all the eigenvalues are inside the unit circle, the chosen system presents covariance stationarity. The residuals are a white noise process, but they show important departures from normality. The 95 percent confidence intervals of impulse response functions are therefore calculated using bootstrapping.

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

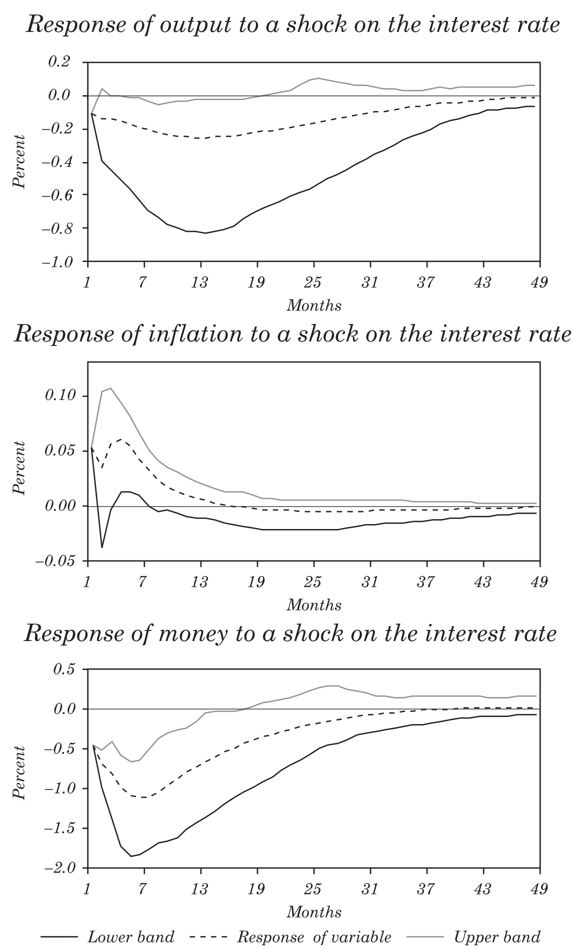
Figure 1 shows the main impulse-response function derived from the VAR model using Cholesky decomposition. Based on the outcomes obtained from the estimation, I arrive at three key conclusions. First,

7. A likelihood ratio test (LRT) was performed to confirm white noise residuals.

8. The Hannan-Quinn criterion was chosen for two reasons. First, the Akaike criterion is known to be inconsistent, and it tends to overfit. In this case, Akaike prefers an optimal lag of twenty-four, which would imply an overparameterized model. Second, the shapes of the impulse response functions do not vary significantly if choosing the Schwartz criterion with only one lag. Using an AR(1) technological shock in the theoretical model implies that output follows an AR(2) process, and this is consistent with a VAR(2) empirical model.

the output level tends to decline in the face of a temporary shock to the (UF-indexed) policy interest rate. This effect is statistically significant between the fifth and the eighteenth month. However, a VAR with one lag, following the Schwartz criterion, shows a nonsignificant decrease in output when there is a shock to the interest rate. This result can thus be summarized as a slightly significant or nonsignificant decline in the output level.

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



Source: Author's calculations.

Second, the inflation rate rises in response to a transitory interest rate shock. The increase is statistically significant between the third and sixth month. This result is robust to the use of any ordering or number of optimal lags. This phenomenon is called the price puzzle in the economic literature: that is, if an increase in the interest rate is seen as a restrictive monetary policy, then the inflation rate should decrease (instead of increasing as empirical evidence shows) as predicted in a standard Mundell-Fleming model with a Keynesian aggregate supply.

This stylized fact also appears in other studies for Chile. For example, Morandé and Schmidt-Hebbel (1997), Calvo and Mendoza (1998), and Cabrera and Lagos (1999) all find a statistically significant price puzzle. Works that find a nonsignificant price puzzle include Valdés (1998), Chumacero (2003), and Parrado (2001).[9] García (2001) attempts to solve this puzzle, but he imposes a strong assumption of the endogeneity of the inflation target. Similarly, most of the econometric specifications in Parrado (2001) only find it for the 1991–2001 period.

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 are used below as a metric of comparison for testing 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 above: the comovement of the inflation and interest rates and the effects of an interest rate shock on output and money.

3. The Model

This section describes the main characteristics of the proposed model. The general features to be considered are the household's utility function, which 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 an open economy.

9. The price puzzle is present in certain VAR specifications and sometimes when using prices in levels or growth.

3.1 Households

Consider an economy characterized by an infinitely lived agent that optimizes a utility function that depends on real private consumption (c_t), real money balances (m_t), and leisure (l_t):

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

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

The representative household's constraint is as follows:

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

where i_t denotes real investment in period t; b_t is the real stock of bonds; b_t^U is the UF-indexed real stock of bonds; τ_L and τ_K are (constant) taxes on labor and capital income, respectively; w_t denotes the real wage; L_t represents the level of employment;[10] 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 the terms of trade; T_t denotes real lump-sum transfers; π_t is the inflation rate; R_t represents the nominal (net) interest rate; R_t^U is the UF-indexed (net) interest rate; D_t are firm profits; and U_t denotes the value of one UF in period t, which evolves according to the following equation:

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

where υ is equal to 9/30. This value represents the number of days in a month that the UF growth depends on inflation in period $t-1$, whereas for the rest of the month (21/30) it depends on inflation in

10. The household is endowed each period with one unit of time, which it divides between leisure $(1 - L_t)$ and work (L_t).

period t. In other words, 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 two goods are produced in this economy; the first good (y_1, or the importable good) is produced domestically and can be imported, while the second one (y_2, or the exportable good) is not consumed domestically and is supposed to be constant.

Next, I assume the following specification for the utility function:

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

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

$$q_t = (1 - \rho_q) q_0 + \rho_q q_{t-1} + \varepsilon_{qt} \ , \tag{6}$$

where $\varepsilon_{qt} \sim$ i.i.d.$(0, \sigma_q^2)$; $q_0 > 0$; and $0 < \rho_q < 1$.

Finally, in 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 autoregressive term:

$$R_{t+1} = (1 - \theta_3) R_0 + \theta_1 \log\left(\frac{y_{1t}}{y_1^*}\right) + \theta_2 \log\left(\frac{1 + \pi_t}{1 + \pi^*}\right) + \theta_3 R_t + \varepsilon_{R,t+1} \ , \tag{7}$$

where R_0, θ_1, $\theta_2 > 0$ and $0 < \theta_3 < 1$ and where y_1^* is the steady-state output level of (importable) goods, π^* represents the steady-state inflation rate, and $\varepsilon_{R,t+1}$ is a zero-mean shock with variance σ_R^2 . R_0 corresponds to the long-run (or steady-state) interest rate.

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

$$\frac{1}{c_t} - \lambda_t = 0 \ , \tag{8}$$

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

$$-\frac{\eta}{\left(1-L_{t}\right)}+\lambda_{t}(1-\tau_{L})w_{t}=0\ , \tag{10}$$

$$-\lambda_{t}+\beta\left(1+R_{t+1}\right)E_{t}\left(\frac{\lambda_{t+1}}{1+\pi_{t+1}}\right)=0\ , \tag{11}$$

$$-\lambda_{t}+\beta\left(1+R_{t+1}^{U}\right)\frac{U_{t}}{U_{t-1}}E_{t}\left(\frac{\lambda_{t+1}}{1+\pi_{t+1}}\right)=0\ , \tag{12}$$

$$-\lambda_{t}+\beta E_{t}\lambda_{t+1}\left[\left(1-\tau_{K}\right)r_{t+1}+\left(1-\delta\right)\right]=0\ . \tag{13}$$

Since the nominal and UF-indexed bonds are risk-free assets, R_{t+1} and R_{t+1}^{U} are known in period t, they are placed out of the expectation operator. Moreover, equations (11) and (12) imply the arbitrage condition between the assets:

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

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 and investing in an asset that yields a UF-indexed return. Given that the law of motion of the UFs is known in period t + 1, equation (14) implies that any shock to the nominal interest rate is totally transferred to the UF-indexed interest rate and vice versa. Therefore, using the nominal or the UF-indexed interest rate as monetary policy is indifferent in this context.

3.2 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:

$$y_{1t}=F\left(K_{t},L_{t},z_{t}\right)=A_{0}K_{t}^{\alpha}L_{t}^{1-\alpha}e^{zt}\ , \tag{16}$$

where $A_0 > 0$ and $0 < \alpha < 1$. Also, z_t is a technological shock that follows an autoregressive process:[11]

$$z_t = \rho_z z_{t-1} + \varepsilon_{zt} \ , \tag{17}$$

where $0 < \rho_z < 1$ and where $\varepsilon_{zt} \sim$ i.i.d. $(0, \sigma_z^2)$.

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

$$\alpha A_0 \left(\frac{L_t}{K_t} \right)^{1-\alpha} e^{zt} - r_t = 0 \quad \text{and} \tag{18}$$

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

3.3 Public Sector

The government budget constraint is

$$\begin{aligned} g_t + T_t = {} & \tau_L w_t L_t + \tau_K r_t K_t + m_t - \frac{m_{t-1}}{1+\pi_t} + b_t - \frac{(1+R_t) b_{t-1}}{1+\pi_t} \\ & + b_t^U - (1+R_t^U) \frac{U_t}{U_{t-1}} \frac{b_{t-1}^U}{1+\pi_t} \ , \end{aligned} \tag{20}$$

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

$$g_t = (1-\rho_g) g_0 + \rho_g g_{t-1} + \varepsilon_{gt} \ , \tag{21}$$

where $g_0 > 0$ and $0 < \rho_g < 1$ and where $\varepsilon_{gt} \sim$ i.i.d. $(0, \sigma_g^2)$.

11. Assuming a first-order autoregressive process is quite standard in RBC literature, even for Chile. In this model, this is supposed to generate a first- or second-order autoregressive process for the simulated variables and 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.

3.4 The Economy

Equations (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 basic structure are α, β, δ, η, τ_K, τ_L, ϕ, A_0, and y_2; those related to the exogenous autoregressive processes are ρ_g, ρ_q, ρ_z, σ_g, σ_q, σ_z, g_0, and q_0; and those related to the Taylor rule are θ_1, θ_2, θ_3 , σ_R, and R_0. The state variables are b_{t+1}, b^U_{t+1}, g_t, K_{t+1}, q_t, and z_t. The controllable state variables are π_t, R_t, and R^U_t , and the control variables are c_t, L_t, and m_t. The steady-state solution of the model is presented in appendix D.

4. Calibration and Results

This section describes the parameterization of the model and then presents the main results. As outlined above, twenty-two parameters appear in the equations that characterize behavior around the steady state. Previous studies based on Chilean data have assigned values to some of these parameters. Table 2 summarizes some of the most frequent values used for common parameters for the Chilean economy and, as a reference, some values for the U.S. economy. For example, the capital-share parameter values used in these studies for Chilean data are between 0.33 and 0.60, even though most of the studies use a value in the 0.33–0.40 range. Parameters such as the subjective discount factor, the autoregressive coefficient of the technological shock, the capital depreciation rate have similar values throughout the literature when they are compared in the same frequency.[12]

I therefore assume three criteria for assigning values to each parameter of the model. First, I use some of the standard parameter values given in previous literature for Chile (according to table 2). Second, I find the parameter value necessary to match some steady-state values for the Chilean economy (such as the steady-state consumption as a percentage of GDP and the steady-state inflation rate).

12. Remember that the calibration 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.

Table 2. Parameters Used in Previous Studies

Study	*Country and period*	*Preference and technology*						
		β	ϕ	α	ρ_z	σ_z	δ	
McGrattan (1994)	U.S., 1947–1987	0.985	NP	0.397	NC	0.0980	0.0226	
Cooley and Hansen (1995)	U.S., 1954–1991	0.989	NP	0.400	0.950	0.0070	0.0190	
Quiroz and others (1991)	Chile, 1977–1990	NR	NP	NR	0.999	0.0200	0.0000	
Acuña and Oyarzún (2001)	Chile, 1986–2000	0.986	NP	0.400	0.990	0.0178	0.0250	
Bergoeing and others (2001)	Chile, 1981–2000	0.980	NP	0.600	NR	NR	0.0800	
Chumacero and Fuentes (2002)	Chile, 1960–2000	0.980	NP	0.333	0.730	0.0400	0.0600	
Bergoeing and Soto (2002)	Chile, 1986–2000	0.979	NP	0.37–0.4	0.981	0.0990	0.0200	
Walsh (1998)	U.S., (NR)	0.989	0.05	0.400	0.950	0.0089	0.0190	
		Exportables sector and fiscal policy						
		ρ_q	σ_q	τ_l	τ_k	g_0	ρ_g	σ_g
McGrattan (1994)	U.S., 1947–1987	NP	NP	NP	NP	70.990	NC	0.078
Bergoeing and others (2001)	Chile, 1981–2000	NP	NP	NP	0.51–0.12	NP	NP	NP
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, 1986–2000	NP	NP	NP	NP	0.089	0.760	0.097

Source: Author's compilation.
NR: Not reported.
NP: Not a parameter in the study.
NC: Not comparable, since the study did not use an AR(1) process.

Finally, I adjust the parameter values to allow the model to match the metric of comparison (the confidence intervals of the impulse response functions). Table 3 reports the parameter values assumed for the calibration and the corresponding criterion used in each case.

4.1 Main Results

The model is solved using a perturbation method 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, first-order approximation methods are not well suited to handling issues such as welfare comparisons across alternative stochastic or policy environments. Furthermore, the linearized decision rules for evaluating second-order approximations to the objective function ignore some second-order terms of the objective function. Such problems do not arise with the use of second- or higher-order approximations.

Figure 2 presents the responses of a transitory shock to the log of the (gross) interest rate. The shock given is positive to represent a restrictive monetary policy. The increase is 0.5 percent (50 basis points) of the annual policy rate (or 0.04 percent in monthly terms). The following results are found. First, the positive shock to the interest rate has a transitory negative, but not significant effect on the output level. The increase in interest rate implies an increase in the cost of capital (by the arbitrage condition between the physical capital and financial capital markets). This generates a reduction in the demand for capital—which is only partially offset by an increase in labor stemming from a substitution effect—and a fall in output. The insignificant fall in output probably results from the absence of price rigidities in the goods or labor markets.

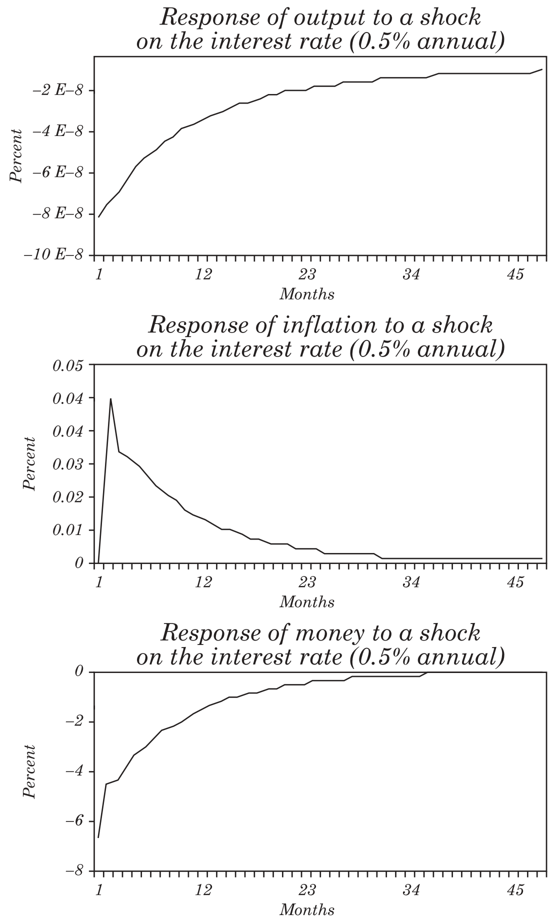
Second, the policy shock causes a transitory increase in the inflation rate. As mentioned in section 2, this is called the price puzzle in the empirical literature. This effect has a straightforward explanation based on the theoretical model proposed here: an increase in the interest rate produces a similar effect on inflation, leaving real interest virtually unchanged owing to a Fisher effect. That is, the Fisher equation implies that higher interest rates are associated with higher inflation rates, which is exactly the relationship shown in figures 1 and 2. This explanation of the comovement of the interest rate and inflation is given in previous studies, but without a specific application for a particular economy. Monnet and Weber (2001) present a

Table 3. Parameterization of the Model[a]

Parameter	*Symbol*	*Value*	*Critetrion of choice*
Basic structure			
Capital share	α	0.35	Previous literature (between 0.33–0.4)
Subjective discount factor	β	0.996	Previous literature. The value implies a steady-state real interest rate of 5%
Depreciation rate	δ	0.09/12	Previous literature and calibration of investment as a percentage of GDP (22% +/– 3.3%)
Utility sensitivity to leisure	η	1.2	Calibration of steady-state labor between 0.3 and 0.4
Capital taxes	τ_K	0.25	Source: Chumacero and Fuentes (2002)
Labor taxes	τ_L	0.25	Source: Chumacero and Fuentes (2002)
Utility sensitivity to money	ϕ	0.005	Calibration of impulse response functions and previous literature
Technological constant	A_0	0.9	Calibration of consumption as a percentage of GDP (63% +/– 2.3%)
Exportable output	y_2	1.5	Calibration of exportable output as a percentage of GDP (35% +/– 5%)
Exogenous autoregressive processes			
Government AR(1) coefficient	ρ_g	0.76	Source: Bergoeing and Soto (2002)
Terms-of-trade AR(1) coefficient	ρ_q	0.961	AR(1) estimates (data: 1986.01–2000.12)
Technological AR(1) coefficient	ρ_z	0.9	Calibration of impulse response functions and previous literature
Government expend. volatility	σ_g	0.008	Source: Bergoeing and Soto (2002)
Volatility	σ_q	0.0127	AR(1) estimates (data: 1986.01–2000.12)
Technological volatility	σ_z	0.0001	Calibration of impulse response functions and GDP volatility
Steady-state government expenditure	g_0	1.22	Calibration of government expenditures as a percentage of GDP (13.3% +/– 5%) AR(1)
Steady-state terms of trade	q_0	1.072	estimates (data: 1986.01–2000.12)
Taylor rule			
Taylor rule AR(1) 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
Taylor rule constant	R_0	0.0061	Calibration of steady-state inflation around 2.64%

Source: Author's compilation.
a. AR(1) denotes a first-order autoregressive process.

Figure 2. Impulse Response Functions from the Theoretical Model



Source: Author's calculations.

discussion that reconciles the positive relation between the interest rate and inflation (the Fisher view) and the negative relationship between those variables (the liquidity view). Alvarez, Lucas, and Weber (2001) develop an analogous explanation with the inclusion of segmented markets. In the model presented above, the reason for the comovement is that the nominal interest rate affects inflation only and not the real interest rate. This effect is strengthened in the model owing to the assumption of a Taylor rule that depends positively on inflation deviation from the steady state.

This result does not imply that a central bank should increase the policy interest rate to fight an inflation process. According to equation (7), a reduction in the long-run inflation rate target should increase the interest rate, and the central bank would then follow a monetary policy consistent with economic agents' expectations. Both inflation and interest rate should thus 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 to a positive interest shock by increasing their demand for nominal bonds (and, consequently, lowering their money holdings). Values for the inflation and output deviation coefficients higher than those assumed in table 3 ($\theta_2 = 0.1$ and $\theta_3 = 0.2$) generate explosive equilibrium or indeterminacy, results that are consistent with those found by Christiano and Gust (1999). This topic represents an interesting avenue for future research on the Chilean economy.

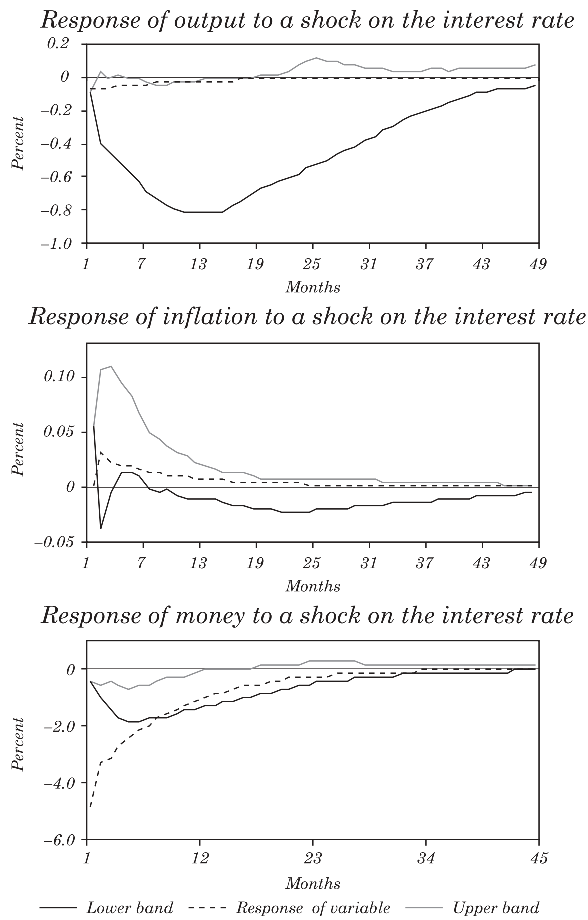
4.2 How Well Does the Model Match the VAR?

To determine whether the theoretical and empirical models correspond, I compare the responses of the variables from the VAR (the empirical model) and the theoretical model when they face an equivalent positive temporary policy rate shock. As before, the analysis focuses 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 percent in the interest rate (0.36 percent in annual terms). As shown in the figure, the theoretical model matches the VAR relatively well, albeit with some observations. The response of output given by the theoretical model is not as significant as the real response in the data. The response of the inflation rate is inside the confidence intervals from the second period. Finally, the response of real money balances is negative in both the model and the VAR, but in the model, its trajectory falls out of the bands from the first to the ninth period.[13]

13. An analogous exercise with generalized decomposition was performed, with similar results (see figure C3 in appendix C).

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



Source: Author's calculations.

5. Conclusions

Most previous RBC-type works for the Chilean economy do not consider monetary variables or the relations among these and real variables—and when they do, they have some trouble replicating sample moments. Such studies usually consider money an exogenous variable, and the economy is closed to international trade, both of which are unrealistic assumptions for the past two decades in Chile. Finally, they generally use linear quadratic methods that might be inadequate in certain cases, as discussed in section 4.

The goal of this paper was to find out how well a money-in-the-utility-function model with a Taylor rule can account for some monetary stylized facts from the Chilean data for the 1986–2000 period. Basically, I focused on the replication and theoretical explanation of what has been called the price puzzle (that is, the comovement between the interest rate and the inflation rate), which is found in many VAR-type estimates for Chile and other economies. The previous works that consider real business cycle models with monetary variables essentially ignore monetary relationships altogether or explain only a few of their features, generally some second moments.

This paper has formulated, solved, and calibrated a dynamic stochastic general equilibrium model for the Chilean economy between 1986 and 2000. The solution of the model was adequately achieved using a perturbation method proposed by Schmitt-Grohé and Uribe (2001). The metric consists of confidence intervals of impulse response functions from a five-variable VAR. These variables were chosen as the empirical counterpart of the main variables explained by the theoretical model presented in section 3.

I find that a positive transitory policy interest rate shock causes a temporary (but not significant) fall in output. From a theoretical viewpoint, the increase in the interest rate implies an increase 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 the VAR estimated in section 2. While this effect is statistically significant in that case, a VAR with one lag, following the Schwartz criterion, shows a nonsignificant decrease in output following a shock to the interest rate.

The policy shock also causes a transitory increase in the inflation rate—the price puzzle. The theoretical model proposed here provides a straightforward explanation to this puzzle: an increase in the interest rate produces a similar effect on inflation, leaving real interest virtually unchanged, owing to a Fisher effect, which is strengthened by a Taylor rule that depends positively on inflation deviation. A similar explanation is given in some recent studies (Monnet and Weber, 2001; Alvarez, Lucas, and Weber, 2001), but it has never been proved for a particular economy.

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

Appendix A

Data and Sources

The terms of trade variable is the log of terms of trade, taken from Bennett and Valdés (2001). The interest rate is the log of the (gross) UF-indexed interest rate paid on ninety-day bonds issued by the Central Bank of Chile (the PRBC) from 1986 to 1995; and UF-indexed policy interest rate from 1995 to 2000. The inflation rate is the log of (gross) inflation rate (or growth of the consumer price index). Money is the log of M1 deflated by the consumer price index. Output is the log of Chile's monthly economic activity index (Imacec). Data on the interest rate, inflation rate, money, and output are all from the Central Bank of Chile.

Appendix B
Supplemental Tables

This appendix reports the results of the preliminary steps taken in estimating the VAR, including the information criteria and lags, the roots of the characteristic polynomial, and tests for white noise residuals. With regard to Gaussian residuals, a test for normality was applied to the VAR residuals. The test statistic value was 236.17 and the *p* value was 0. Based on Doornik and Hansen (1994), this statistic is χ^2 distributed with ten degrees of freedom (18.3 at 5 percent; 16.0 at 10 percent). The null hypothesis, which is the normality of the residuals, is rejected.

Table B1. Model Selection Criteria by Lag

Number of lags	*Akaike*	*Schwartz*	*Hannan-Quinn*
0	-39.75	-38.59	-39.28
1	-48.26	-46.66	-47.61
2	-48.70	-46.65	-47.87
3	-48.86	-46.35	-47.84
4	-48.84	-45.87	-47.63
5	-48.75	-45.31	-47.35
6	-48.61	-44.71	-47.03
7	-48.45	-44.07	-46.67
8	-48.39	-43.54	-46.42
9	-48.40	-43.07	-46.24
10	-48.28	-42.47	-45.92
11	-48.15	-41.85	-45.59
12	-48.36	-41.57	-45.60
13	-48.47	-41.19	-45.52
14	-48.43	-40.65	-45.27
15	-48.42	-40.14	-45.06
16	-48.35	-39.56	-44.78
17	-48.37	-39.07	-44.59
18	-48.68	-38.86	-44.69
19	-48.64	-38.30	-44.44
20	-48.82	-37.96	-44.41
21	-49.11	-37.72	-44.48
22	-49.68	-37.76	-44.84
23	-50.07	-37.61	-45.01
24	-51.34	-38.34	-46.06

Source: Author's calculations.

Table B2. Roots of Characteristic Polynomial[a]

Root	*Modulus*
0.93 + 0.06i	0.94
0.93 – 0.06i	0.94
0.91	0.91
0.45 – 0.25i	0.51
0.45 + 0.25i	0.51
0.48	0.48
-0.36	0.36
0.29	0.29
-0.14	0.14
0.14	0.14

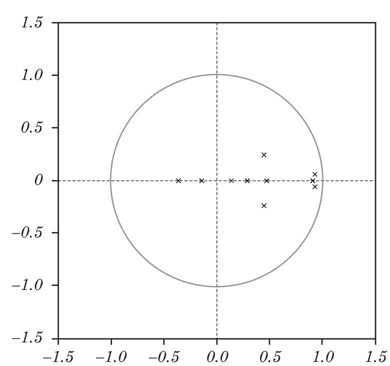
Source: Author's calculations.
a. No root lies outside the unit circle. The VAR specification satisfies the stability condition.

Table B3. Tests for White Noise Residuals[a]

Number of lags	*Akaike*	*Schwartz*	*Hannan-Quinn*	*P value*
0	-49.94	-49.85	-49.90	0.00
1	-49.71	-49.17	-49.49	1.00
2	-49.73	-48.74	-49.33	0.29
3	-49.63	-48.19	-49.05	0.26
4	-49.58	-47.67	-48.81	0.15
5	-49.47	-47.10	-48.50	0.23
6	-49.33	-46.50	-48.18	0.41
7	-49.18	-45.87	-47.83	0.66
8	-49.13	-45.35	-47.60	0.61
9	-48.98	-44.72	-47.25	0.83
10	-48.81	-44.07	-46.88	0.96
11	-48.87	-43.64	-46.74	0.91
12	-48.94	-43.22	-46.62	0.85

Source: Author's calculations.
a. The *p* value of the LRT test refers to the null hypothesis that the residuals are white noise at different numbers of lags. All the information criteria prefer 0 as an optimal lag for the VAR estimate of the residuals. In this case, the null cannot be rejected.

Figure B1. Inverse Roots of AR Characteristic Polynomial

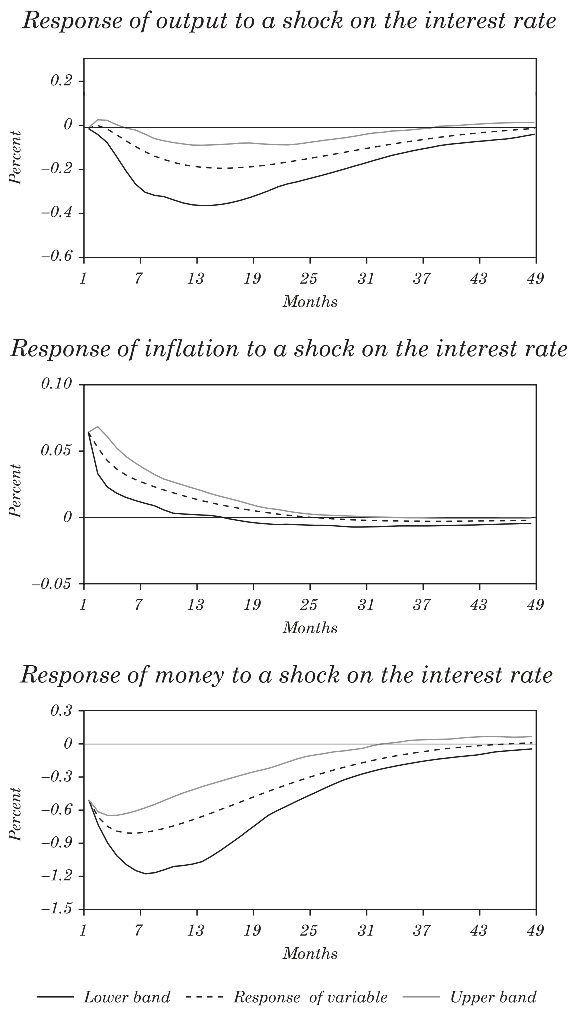


Source: Author's calculations.

APPENDIX C

Impulse Response Functions

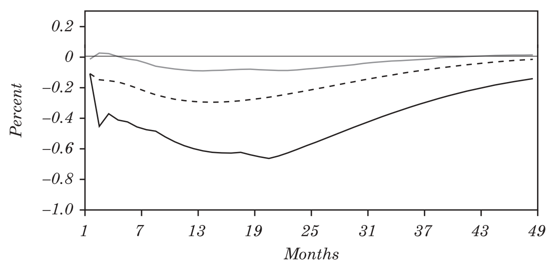
Figure C1. Impulse Response Functions from the VAR Model: VAR(1) and Cholesky Decomposition



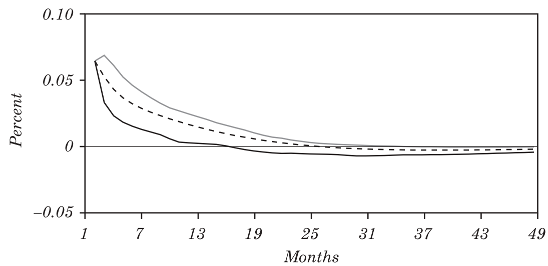
Source: Author's calculations.

Figure C2. Impulse Response Functions from the VAR Model: VAR(2) and Generalized Decomposition

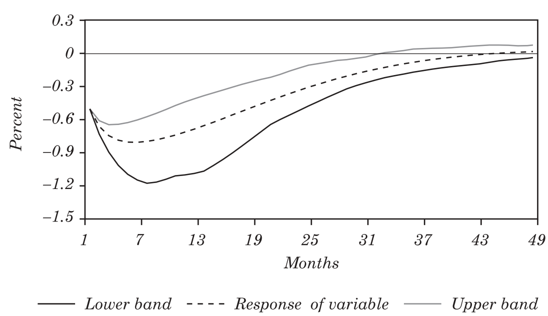
Response of output to a shock on the interest rate



Response of inflation to a shock on the interest rate



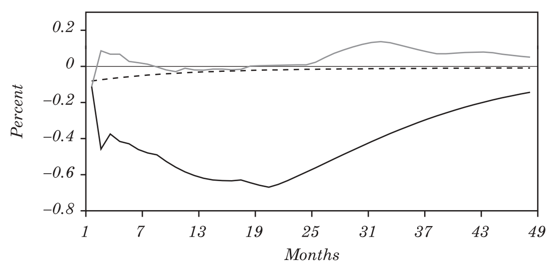
Response of money to a shock on the interest rate



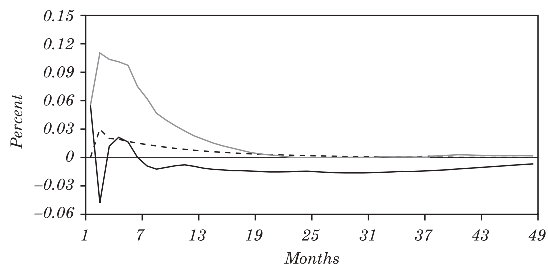
Source: Author's calculations.

Figure C3. VAR Confidence Intervals and Impulse Response Functions from the Theoretical Model: VAR(2) and Generalized Decomposition

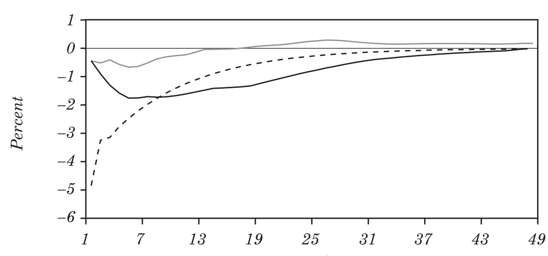
Response of output to a shock on the interest rate



Response of inflation to a shock on the interest rate



Response of money to a shock on the interest rate



Lower band - - - *Response of variable* *Upper band*

Source: Author's calculations.

APPENDIX D

Steady-state Equilibrium of the Model

In steady state, equation (7) implies the steady-state net interest rate:

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

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

$$1+\pi^{*} = \beta\left(1+R^{*}\right), \tag{24}$$

where the asterisk denotes steady-state values.

Rearranging equation (13) and using equation (18) yield the following:

$$K^{*} = L^{*}\left[\frac{\alpha A_{0}\beta\left(1-\tau_{K}\right)}{1-\beta\left(1-\delta\right)}\right]^{\alpha/(1-\alpha)} = \omega_{0}^{\alpha/(1-\alpha)}L^{*} \; , \tag{25}$$

where $\omega_{0} = \left[\frac{\alpha A_{0}\beta\left(1-\tau_{K}\right)}{1-\beta\left(1-\delta\right)}\right] > 0$.

Using equations (8), (10), (19) and (25) and rearranging, one obtains an expression for steady-state consumption that depends on steady-state employment:

$$\begin{aligned} c^{*} &= \left[\frac{\left(1-\alpha\right)\left(1-\tau_{L}\right)A_{0}}{\eta}\right] \left[\frac{\alpha A_{0}\beta\left(1-\tau_{K}\right)}{1-\beta\left(1-\delta\right)}\right]^{\alpha/(1-\alpha)} \left(1-L^{*}\right) \\ &= \omega_{1}\omega_{0}^{\alpha/(1-\alpha)}\left(1-L^{*}\right) , \end{aligned} \tag{26}$$

where $\omega_{1} = \left[\frac{\left(1-\alpha\right)\left(1-\tau_{L}\right)A_{0}}{\eta}\right] > 0$.

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

$$L^* = \frac{\omega_0^{\alpha/(1-\alpha)}\omega_1 + g_0 - q_0 y_2}{\omega_0^{\alpha/(1-\varepsilon)}\left(A_0 + \omega_1 - \delta\omega_0\right)} \ . \tag{27}$$

With equation (27), one can calculate the steady-state capital stock, investment, consumption, and production. Finally, equations (8), (9), (23), (24), (26), and (27) generate the steady-state money balances:

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

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

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