TESTING REAL BUSINESS CYCLE MODELS IN AN EMERGING ECONOMY

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One of the most dynamic areas of macroeconomic research in recent decades is that of real business cycle (RBC) models. Since the seminal work by Kydland and Prescott (1982), a number of papers have tested the ability of neoclassical general equilibrium models to account for economic fluctuations. The original framework of Kydland and Prescott has been extended to include labor market rigidities (Hansen, 1985), taxes and government expenditures (McGrattan, 1994b), money and inflation (Cooley and Hansen, 1995), open economies (Backus, Kehoe, and Kydland, 1995), and increasing returns to scale in production (Weber, 2000). Each of these extensions successfully solves the limitations of calibrated models in replicating particularities of the data, and they provide rich explanations of business cycles, albeit at the cost of increasing complexity.

Although RBC models have been successfully applied to developed economies, their ability to replicate the data of emerging countries remains largely unexplored. In the case of Chile, there are only a few noteworthy exceptions.[1] This paper provides the first systematic exploration of RBC models with Chilean data, starting with the original Kydland and Prescott framework and introducing increasing degrees

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1. Quiroz (1991); Quiroz and others (1991).

General Equilibrium Models for the Chilean Economy, edited by Rómulo Chumacero and Klaus Schmidt-Hebbel, Santiago, Chile.

of complexity in the analysis. The purpose of this exercise is to test the capacity of RBC models both to replicate the salient characteristics of the observed aggregate fluctuations of the economy in the 1986–2000 period and to provide insights regarding the contribution of fiscal and monetary policies to the cycle.

The challenge to RBC models posed by the Chilean experience is formidable. First, the economy experienced rapid but unstable growth in the 1986–2000 period. Although gross domestic product (GDP) grew at an average annual rate of 6.7 percent, it also experienced significant year-to-year fluctuations, from a high 10.1 percent growth in 1989 to only –0.8 percent in 1999. In the same period, GDP growth in the United States was 2.6 percent and fluctuated within a narrower range of –1 percent to 4 percent. Second, in this period Chile experienced a remarkable reduction in inflation, from a high annual rate of 27 percent in 1989 to less than 3 percent in 1999, which suggests that the contribution of both nominal and real fluctuations might have played an important role during the period. Third, the economic structure of a developing country such as Chile differs markedly from that of industrial economies precisely in those underlying parameters that govern the mechanics of RBC models. Particularly different are the stock of capital and the capital-output ratio, the size and composition of government expenditures, the composition of consumption and investment, and the size of technological shocks.

The structure of the paper is as follows. Section 1 provides a snapshot of the most salient features of economic cycles in Chile.[2] We use simple statistics to discuss the relative importance of the shocks to GDP and its components and to assess their temporal structure. Section 2 provides a brief description of the different general equilibrium models we use, stressing the role of technology shocks, the effect of real and monetary frictions (such as labor rigidities and cash-in-advance constraints), the impact of fiscal and monetary policy shocks, and the derived decision rules of optimizing agents. Section 3 of the paper describes the data—some of which was collected especially for this study—and presents the parameterization of the different calibrated models. We also discuss the main difference between Chile's key (deep) parameters and those of industrial economies, in particular the United States. Section 4 presents the main empirical results, including the simulation of the models and the analysis of impulse-response functions. In section 5,

2. For a complete description, see Bergoeing and Suárez (2001).

we follow Canova, Finn, and Pagan (1994) in viewing our artificial economies as restricted versions of more general vector autoregression (VAR) models. We thus use econometric techniques to test the restrictions imposed by the structure of the model and the linearization process. Finally, section 6 highlights our main conclusions and suggests future extensions of this work.

1. Characterizing the Economic Fluctuations of the Chilean Economy

The stylized facts that characterize business cycles in Chile were obtained from the longest available database with consistent information on a quarterly basis, which covers from 1986 to 2000. As expected, economic fluctuations in Chile present important similarities when compared to the features of business cycles in industrialized countries (see, for example, Backus, Kehoe, and Kydland, 1995), but they also present interesting peculiarities.

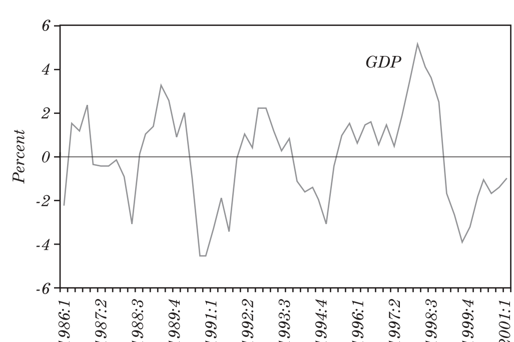
We follow Lucas (1977) in defining business cycles as deviations from their long-run trend. The definition and computation of this trend are controversial, however. The literature contains a rich debate on the abilities of different statistical methods to decompose time series into long- and short-term fluctuations (see Baxter and King, 1995; Guay and St-Amant, 1996). The relative advantages of competing techniques such as those of Beveridge and Nelson (1981), Watson (1986), Hodrick and Prescott (1997), and Baxter and King (1995) are not yet established. Harvey and Jaeger (1993) criticize mechanical filters, showing that the Hodrick-Prescott (HP) filter can induce spurious cyclicality when applied to integrated data. Guay and St-Amant (1996) find that the HP and Baxter-King (BK) filters perform poorly in identifying the cyclical component of time series that have a spectrum with the shape characteristic of most macroeconomic time series. Baxter and King (1995) note that two-sided filters such as the HP and BK filters become ill-defined at the beginning and end of samples.

Notwithstanding this debate, we follow the standard practice of the business cycle literature and report all stylized facts using the deviations of the variables from their long-run trend obtained with the Hodrick-Prescott filter. Since the purpose of our paper is to assess the capacity of this type of model to describe the regularities of Chile's economic cycles, this choice allows us to compare our results to the evidence gathered for other countries. Canova (1998) similarly supports the use of the HP filter because economists ought to be "looking through the same window" when comparing results among models.

We report several statistics for the HP-filtered data.[3] In particular, we consider four variables: the amplitude of fluctuations (volatility), represented by the standard deviation of the cyclical component of each series; the ratio of the standard deviations of the series to that of output (relative volatility); the contemporaneous correlation of the cyclical components of a variable and that of output; and the phase shift, represented by the correlation coefficients between leads and lags of each variable and output.[4] A variable leads output by *i* quarters if their cross correlation peaks *i* quarters before output. Since all variables are in logarithms, the change in the trend component represents the growth rate.

Figure 1 shows the evolution of the cyclical GDP in the period under analysis. The sample contains three clear cycles (measured from peak to peak), though they differ in magnitude and length. The size and volatility of GDP cycles are rather large: considering that the quarterly trend is 1.8 percent in the sample, the peak of the cycle would be equivalent to observing an annualized growth rate of 20 percent, while at the trough it would amount to growth rate of –15 percent.

Figure 1. Quarterly GDP Deviations from Trend



Source: Authors' calculations.

3. All series are seasonally adjusted using the X-12-ARIMA procedure and expressed in natural logarithms before being filtered, with the exception of the percent variables, such as inflation and interest rates, which are in levels.

4. As is customary, if the contemporaneous correlation is close to one, we label the variable as procyclical; if it is close to minus one, we call it countercyclical; and if it is close to zero, we use acyclical.

Additional information is presented in table 1, which reports numerical indicators of the amplitude and phase of the fluctuations of GDP and other key macroeconomic variables. This information points to several general similarities in the Chilean business cycle vis-à-vis that of industrialized countries, but it also highlights interesting differences. For example, the volatility of GDP in Chile—which reaches 2.20—is much higher than in most industrialized economies.[5] This higher volatility is partly a reflection of structural characteristics of the Chilean economy (such as the relative absence of automatic stabilizers, shallow financial markets, and a less diversified production structure), but it is also consistent with the high growth rate sustained by Chile in the sample period.

Table 1. Main Indicators of the Business Cycle in Chile, 1986–2000

Variable	*Volatility*[a]	*Volatility relative to that of output*	*Correlation with output*	
			Contemporaneous	*Peak quarter*[b]
Output	2.20	1.00	1.00	0
Consumption, total	2.43	1.11	0.83	0
Consumption, nondurables	1.88	0.86	0.60	–1
Consumption, durables	15.94	7.25	0.80	0
Investment	7.47	3.23	0.83	0
Capital	1.32	0.60	0.41	–3
Avg. hours worked	1.07	0.74	0.21	–2
Total hours worked	1.92	0.87	0.44	–2
Employment	1.23	0.56	0.48	+2
Real wages	1.37	0.62	0.38	–1
Government consumption	1.55	4.04	–0.08	+2
Money	5.47	2.49	0.64	+1
Price level	2.12	0.96	–0.26	0
Inflation	0.93	0.42	–0.06	+3

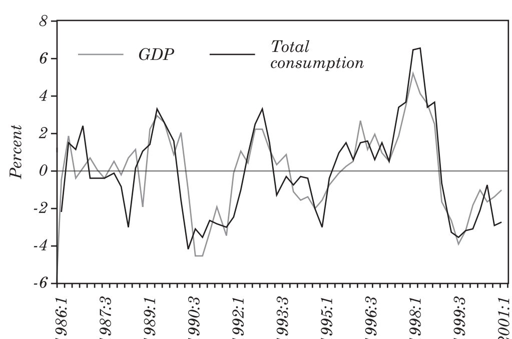
Source: Authors' calculations.
a. Volatility is measured as the standard deviation times one hundred.
b. A plus sign indicates a lead; a minus sign indicates a lag.

Private consumption is procyclical in Chile, as it is in most countries: it moves in synchronicity with GDP, with a high correlation coefficient of 0.82 (see figure 2). Consumption is highly volatile. This

5. Volatility in Europe from 1970 to the mid-1990s was only 1.01, on average (Backus, Kehoe, and Kydland, 1995). The United States exhibits higher volatility (1.72) in the 1954–1991 period (Cooley and Hansen, 1995).

feature is one of the challenges that business cycle models have to face. Since RBC models are essentially neoclassical, consumption is usually modeled under the permanent income hypothesis. In this setting, consumption volatility should be smaller than that of output, since agents that optimize intertemporally tend to smooth out consumption. The apparent excess volatility of consumption is, in part, the result of using total consumption data. When consumption is separated into purchases of durable and nondurable goods, their volatility is markedly different (see figure 3). The volatility of durable goods is 8.5 times higher than that of nondurable goods.[6] In what follows, we restrict consumption to nondurable goods and include purchases of durable consumption goods as a component of investment. Although the volatility of the purchases of nondurable consumption goods is smaller than that of total consumption or GDP, it remains rather high (1.88). This may stem, in part, from the existence of liquidity constraints (namely, credit restrictions), a characteristic that our business cycle models should also address.[7]

Figure 2. Quarterly GDP and Total Consumption Deviations from Trend

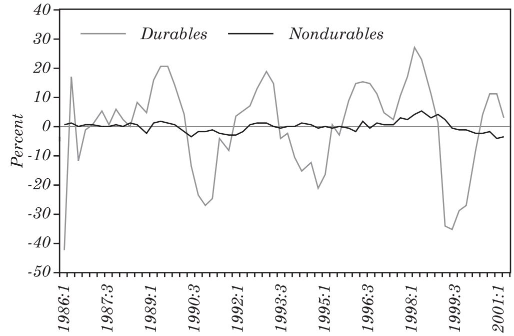


Source: Authors' calculations.

6. The higher volatility of the consumption of durable goods does not arise primarily from the changes in relative prices, as the price deflator of durable goods exhibits the same volatility as its counterpart for nondurable goods.

7. An alternative hypothesis to account for the high relative volatility of nondurable consumption is that income risk is not completely diversifiable (see Carroll, 2001). A number of industrialized countries exhibit very high volatility in consumption nondurable goods (for example, France, Germany, and Japan). In Canada, Switzerland, and the United States, volatility relative to GDP is lower than in Chile.

Figure 3. Quarterly Durable and Nondurable Consumption Deviations from Trend



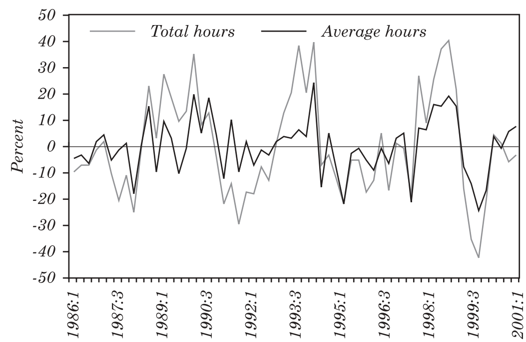
Source: Authors' calculations.

A second challenge that the Chilean data poses for business cycle models involves the nature of shocks in labor markets. Unemployment displays wide fluctuations, falling from a high 15.4 percent in 1986 to a low of 5.6 percent in 1998 and then rebounding to 9.2 percent in 2000. Total hours worked are more volatile than real wages (see table 1). In a neoclassical labor market, total hours worked should display very low volatility because most of the adjustment should fall on wages. In Chile, on the contrary, the volatility of hours worked is quite high (1.92) and much higher than that of real wages (1.37), suggesting the existence of substantial rigidities or adjustment costs in the labor market. We find additional evidence of such rigidities when we split total hours worked into average hours worked per worker and the number of workers employed (employment). As shown in figure 4, average hours worked fluctuate less than total hours, suggesting that most of the adjustment corresponds to the entry and exit of workers from the labor market rather than marginal adjustment in working schedules.[8]

An additional puzzle posed by agents' behavior in labor markets involves fluctuations in real wages and their correlation with hours worked. In the Chilean case, the volatility of labor productivity is almost as high as that of GDP, but it shows virtually no correlation with hours worked (estimated at 0.12). This is a worrisome feature for our business

8. As expected, the relative volatility of employment in Chile is higher than that in Australia (0.34) or Japan (0.34) and, surprisingly, similar to that in Europe (0.85), a continent characterized by sustained unemployment. Part of this heterogeneity in labor market performance reflects differences in institutional arrangements.

Figure 4. Quarterly Total and Average Hours Worked Deviations from Trend



Source: Authors' calculations.

cycle models because one of the weaknesses of the original Kydland and Prescott specification is its inability to replicate the low correlation between hours worked and productivity levels or wages.

A third interesting feature of the business cycle in Chile is the presence of large fluctuations in investment. As a fraction of GDP, gross fixed capital formation increased from a low of 15 percent in the mid-1980s to over 28 percent in the late 1990s. This expansion of investment was characterized by very high volatility, which reached 7.47 in the sample period, more than three times the volatility of GDP. When the purchase of durable goods is added to investment, volatility increases to 8.21.

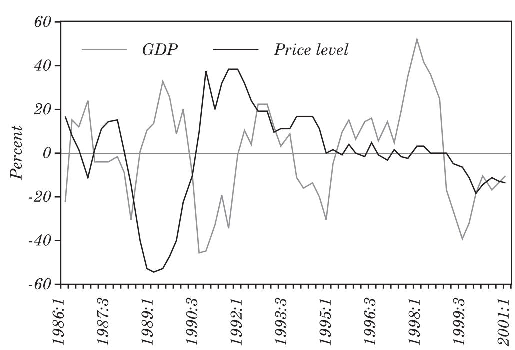
As in most emerging economies, government expenditure in Chile displays some characteristics that are very different from developed economies. The size of the government measured by public consumption (as percent of GDP) is quite small in Chile, reaching less than 10 percent in the 1986–2000 period. The government spends around 5 percent of GDP on capital formation (mostly infrastructure), which we include in total investment. Government consumption is quite unstable, with a volatility of 8.8, and it is largely uncorrelated with fluctuations in GDP.[9] This high volatility suggests that government expenditures might play an important role in causing economic fluctuations. Finally, public expenditures represent substantial transfers of goods and services (such as health and

9. Government consumption in the United States and Europe is around 18 percent of GDP (Backus, Kehoe, and Kydland, 1995). It is typically uncorrelated with GDP and displays lower volatility.

education) for many groups of the society. These groups also pay taxes, however, so that the net effect of changes in fiscal policies on economic activity and welfare may be ambiguous. The business cycle models developed below explicitly address this issue.

Chile also differs from developed economies with regard to monetary shocks. As mentioned, inflation in Chile declined slowly from 27 percent in 1989 to around 3 percent in 2000, largely as a result of the gradualist monetary policy approach employed by the Central Bank (Morandé, 2002). The volatility of money, as measured by per capita real M1, is quite high (5.84), and money shocks are strongly correlated with GDP fluctuations (0.70). As a matter of fact, money cycles display a striking synchronicity with GDP fluctuations, as depicted in figure 5, and lead the cycle by one quarter. This certainly reflects the effects on the real side of the economy of the Central Bank's choice to base its policy instruments on the real interest rate—as opposed to targeting monetary aggregates—during the last ten years. Anti-inflationary policies have, unsurprisingly, induced marked volatility in the price level (2.12). Inflation has also been quite persistent, which is a direct result of the anti-inflationary policies implemented in the period compounded by the high degree of price indexation of the Chilean economy.

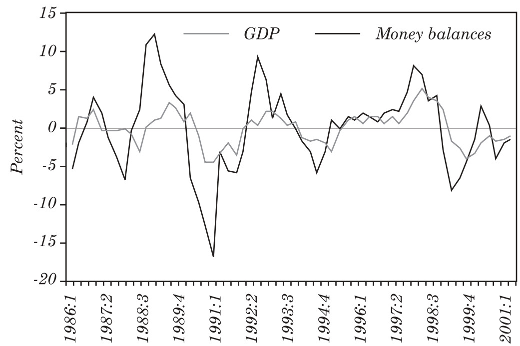
Figure 5. Quarterly GDP and Prices Deviations from Trend



Source: Authors' calculations.

Prices, on the other hand, display a negative correlation with GDP (see figure 6). This, together with the fact that real wages are procyclical, suggests that supply shocks are an important source of fluctuations in aggregate activity.

Figure 6. Cyclical Components of GDP and Money Balances



Source: Authors' calculations.

2. Business Cycle Models

The original model by Kydland and Prescott has been extended to include, among other issues, household production (Benhabib, Rogerson, and Wright, 1991); labor hoarding (Burnside, Eichenbaum, and Rebelo, 1993); a limited version of open economies (Backus, Kehoe, and Kydland, 1995); money and inflation (Cooley and Hansen, 1995); incomplete markets and heterogeneous agents (Rios-Rull, 1992); and increasing returns to scale (Devereux, Head, and Lapham, 1996). In this section, we present a stylized business cycle model for the Chilean economy and discuss the rationale for the main extensions we later test. Based on the description of the salient characteristics of economic cycles in Chile presented in section 1 and with the purpose of evaluating the relative contribution of macroeconomic policies, we develop a model that focuses on government expenditures and monetary shocks and includes real-side shocks as captured by technological shocks. The main characteristic of our model is that it encompasses within the framework of a general equilibrium setup a number of important features of the economy, including productivity growth, fiscal expenditures, monetary policy, and labor market rigidities. The main drawback is that it neglects some the real and financial aspects of international business cycles and their effect on the private sector.

This section also presents the algorithms to obtain analytical and numerical solutions to the general equilibrium optimization problem. Here, our discussion only sketches the main issues, and we refer the reader to Cooley (1995) for detailed discussions on the different techniques.

2.1 A Model with Monetary and Fiscal Policy and Labor Rigidities

We analyze the importance of technological, fiscal, and monetary shocks as the sources of aggregate fluctuations in Chile. The analysis emphasizes the role of real and monetary frictions, such as quantitative labor rigidities, a cash-in-advance constraint, and wage contracts.

We develop a general model economy characterized by a government that engages in fiscal and monetary policy, a large number of identical firms, and a large number of identical consumers, all of whom are infinitely lived. Later, we simplify this general model on several dimensions to emphasize specific features of the model economy. In all models calibrated below, the production function is taken to be the same, while the different specifications we test are obtained through changes in the utility function and the nature of government policies.

In our general model, money is held because it is required to purchase consumption goods or some subset of consumption goods. We introduce this cash-in-advance motive for holding money into the basic indivisible labor RBC model. Money is created by the government according to an exogenous law of motion. In addition, government taxes consumption and collects the revenues of taxation to finance government consumption and lump sum transfers. Initially, there is no money illusion; nonneutralities arise only because anticipated inflation acts as a distortionary tax on activities involving the use of cash. The economy will be neutral with respect to unanticipated changes in the money supply. Later, we incorporate wage contracts into the model, in order to analyze the properties of an economy in which monetary policy is not neutral.

Each household's objective is to choose sequences of cash and credit consumption of goods, represented by $\{c_{1t}\}_{t=0}^{\infty}$ and $\{c_{2t}\}_{t=0}^{\infty}$, respectively; hours of leisure $\{h_{1t}\}_{t=0}^{\infty}$; investment $\{i_{1t}\}_{t=0}^{\infty}$; and money to be carried into the next period $\{m_{1t}\}_{t=0}^{\infty}$. The households maximize the expected discounted utility,

$$\max E\sum_{t=0}^{\infty}\beta^t\left[\alpha\log c_{1t}+(1-\alpha)\log(c_{2t}+\pi g_t)-\gamma h_t\right], \tag{1}$$

subject to several constraints. The first is their budget constraint,

$$(1+\tau_t)P_t c_{2t}+p_t i_t+m_{t+1}=P_t(w_t h_t+r_t k_t)+m_t\ , \tag{2}$$

which states that expenditures in period t on cash goods, c_{1t}, on credit goods, c_{2t}, on investment goods, i_t, and on money to be carried into the next period, m_{t+1}, cannot exceed their income. They have various sources of income, including income from renting capital to firms, $r_t k_t$, and from allocating part of their one unit of time to work, $w_t h_t$. Another source is currency carried from the previous period, m_t, plus a nominal transfer (or tax) paid at the beginning of period t, T_t, as shown next in the cash-in-advance restriction:

$$\left(1+\tau_t\right)P_t c_{1t} = T_t + m_t \ . \tag{3}$$

The government taxes both types of private consumption at the tax rate τ_t. P_t is the price level in period t. Capital next period is assumed to be equal to new investment plus what remains after depreciation:

$$k_{t+1} = \left(1-\delta\right)k_t + i_{t+1} \ . \tag{4}$$

The utility function specification follows Hansen (1985) in assuming that households can work a fixed number of hours, h_t, or none at all. At the aggregate level, the model predicts that a certain fraction of workers is employed h_t hours per period and a certain fraction is unemployed. This assumption, which is represented by the linearity of leisure in the utility function, allows greater substitution between leisure at different dates.[10] Finally, government consumption in period t, g_t, is assumed to be weighted in utility by π. This weight depends on the relative price of private consumption of the cash good and public consumption. If $\pi = 1$, then public consumption and private cash-consumption goods are perfect substitutes. If $\pi = 0$, however, public consumption does not affect the utility of the households.

The per capita money supply is assumed to grow at the rate $e^{\mu_t} - 1$ every period, that is,

$$M_{t+1} = e^{\mu_t} M_t \ , \tag{5}$$

10. The standard specification, called divisible labor, introduces leisure as γ log h into the utility function. For a detailed description of the indivisible labor setting, see Rogerson and Wright (1992).

where μ is revealed at the beginning of period *t*. In this context, the government budget constraint is given by,

$$P_t g_t + T_t = \tau_t P_t \left(c_{1t} + c_{2t}\right) + M_{t+1} - M_t \,. \tag{6}$$

The representative firm seeks to maximize profit, which is equal to $Y_t - w_t H_t - r_t K_t$. Aggregate output, Y_t, is produced according to the following constant-return-to-scale technology,

$$Y_t = e^{z_t} K_t^{\theta} H_t^{1-\theta} \,, \tag{7}$$

where K_t and H_t are the aggregate capital stock and labor input, respectively.

The technology shock, z_t, is assumed to be revealed at the beginning of period *t*. The fist-order conditions for the firm's problem yield the following functions for the wage rate and the rental rate of capital:

$$w_t = \left(1-\theta\right) e^{z_t} \left(\frac{K_t}{H_t}\right)^{\theta} \text{ and} \tag{8}$$

$$r_t = \theta e^{z_t} \left(\frac{H_t}{K_t}\right)^{1-\theta} . \tag{9}$$

Finally, the following market-clearing constraint is assumed to be satisfied:

$$c_{1t} + c_{2t} + i_t + g_t = e^{z_t} K_t^{\theta} H_t^{1-\theta} \,.$$

The stochastic shocks evolve according to the following laws of motion:

$$\begin{aligned}
z_{t+1} &= \left(1-\rho_z\right)\overline{z} + \rho_z z_t + \varepsilon_{t+1}^{z} \,, \\
\mu_{t+1} &= \left(1-\rho_\mu\right)\overline{\mu} + \rho_\mu \mu_t + \varepsilon_{t+1}^{\mu} \,, \\
g_{t+1} &= \left(1-\rho_g\right)\overline{g} + \rho_g g_t + \varepsilon_{t+1}^{g} \,, \text{ and} \\
\tau_{t+1} &= \left(1-\rho_\tau\right)\overline{\tau} + \rho_\tau \tau_t + \varepsilon_{t+1}^{\tau} \,.
\end{aligned} \tag{10}$$

To guarantee a stationary solution in the limit, we transform variables so that all variables in the deterministic version of the household's problem converge to a steady state. In particular, we define

$$\hat{m}_t = \frac{m_t}{P_t}\ ;\ \hat{P}_t = \frac{P_t}{M_{t+1}}\ ,$$

and we use this to eliminate m_t and P_t from the problem.

The Bellman equation for the household's problem can now be written as follows:

$$v(z_t, \mu_t, \tau_t, g_t, K_t, k_t, \hat{m}_t) = \max\begin{bmatrix}\alpha \log c_{1t} + (1-\alpha)\log(c_{2t} + \pi g_t) - \gamma h_t \\ +\beta E_t\,(z_{t+1}, \mu_{t+1}, \tau_{t+1}, g_{t+1}, K_{t+1}, k_{t+1}, \hat{m}_{t+1})\end{bmatrix}$$

subject to

$$c_{1t} = \frac{1}{1+\tau_t}\left[T_t + \frac{m_t}{P_t}\right],$$

$$c_{2t} = (1-\theta)e^{z_t}\left(\frac{K_t}{H_t}\right)^{\theta} h_t + \theta e^{z_t}\left(\frac{H_t}{K_t}\right)^{1-\theta} k_t - i_t - \frac{m_{t+1}}{P_t}\ , \tag{11}$$

$$T_t = \frac{e^{\mu_t} - 1}{P} - g_t y_t\ ,$$

$$I_t = K_{t+1} - (1-\delta)K_t\ , \text{ and}$$

$$i_t = k_{t+1} - (1-\delta)k_t\ ,$$

and to the decision rules

$$K_{t+1} = k(z_t, \mu_t, \tau_t, g_t, K_t)\,,$$

$$H_{t+1} = h(z_t, \mu_t, \tau_t, g_t, K_t)\,, \text{ and} \tag{12}$$

$$P_{t+1} = p(z_t, \mu_t, \tau_t, g_t, K_t)\,.$$

The last line gives the perceived functional relation between the aggregate state, $(z_t, \mu_t, \tau_t, g_t, K_t)$, and per capita investment, per capita hours, and the price level. In equilibrium, these functions must satisfy the requirements of the following definition: A recursive competitive equilibrium consists of a set of decision rules for the household,

$c_{1t}\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$, $c_{2t}\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$,

$k_{t+1}\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$, $h_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$, and

$m_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$;

a set of per capita decision rules, $K_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$ and

$H_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$;

pricing functions, $P_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$,

$w_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$, and $r_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$;

a government transfer function, $T_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$; and

a value function, $v_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$,

such that households optimize, solving the functional equation $v_t\left(z_t,\mu_t,\tau_t,g_t,K_t,k_t,\hat{m}_t\right)$ from the previous Bellman problem, given the pricing functions and the per capita decision rules and the associated decision rules of c_1, c_2, k, h, and $\hat{m}$; the firm optimizes, solving the functions w and r given by equation (8); the government satisfies its budget constraint, given by equation (6); and individual decisions are consistent with aggregate outcomes:

$$
\begin{aligned}
&k'\left(z,\mu,\tau,g,K\right)=K'\left(z,\mu,\tau,g,K\right), \\
&h'\left(z,\mu,\tau,g,K\right)=H'\left(z,\mu,\tau,g,K\right), \text{ and} \qquad (13)\\
&\hat{m}'\left(z,\mu,\tau,g,K\right)=1 .
\end{aligned}
$$

We solve for the linear per capita decision rules to yield a linear-quadratic approximation of this economy. The methods employed are described in detail in Hansen and Prescott (1995).

Finally, if we introduce several simplifications, we can transform the previous general model into a standard real business cycle model (as in Prescott, 1986) or a real business cycle model with fiscal policy as the only policy source of aggregate shocks (as in McGrattan, 1994a). For example, if we eliminate the cash-in-advance constraint and set $m_t = g_t = \tau_t = 0$, for all t, and $\alpha = 1$, the model converges to a standard real business cycle economy, where technology shocks are the sole source of fluctuations.

2.2 Introducing Nominal Wage Rigidities

The empirical evidence, presented in section 1, shows that both prices and wages are highly persistent in Chile. Furthermore, a significant portion of the labor force (especially manufacturing) participates in long-term contracts, and labor markets show evidence of rigidities in that aggregate hours fluctuate more than wages do. A relevant question, within this context, is how relevant nominal contracts are, in practice, as a propagation mechanism of nominal shocks in Chile.

Several papers have studied the implications of nominal wage contracts in the United States, within the equilibrium business cycle literature (see, for example, Cooley and Hansen, 1995). Here, we incorporate nominal wage contracts to evaluate the relevance of nominal rigidities for the main features of the Chilean business cycles.

We modify the cash-in-advance model studied in the previous section, following Cooley and Hansen (1995). Specifically, we impose the constraint that the nominal wage rate for period t be agreed one period in advance. In other words, at the end of period $t-1$, the nominal wage rate for period t is competitively determined on the basis of expectations about the technology, fiscal, and monetary shocks. Households then choose consumption and investment in period t, after the shocks are revealed. In addition, firms unilaterally choose employment to equate the marginal product of labor to the realized real wage.

From the first-order condition for the firm's problem, we know that

$$w_t = (1-\theta)e^z\left(\frac{K_t}{H_t}\right)^\theta . \tag{14}$$

In this setting, this implies that

$$\log W_t^c = \log(1-\theta) + \theta\left(\log K_t - \log \hat{H}_t\right) + E\left[z + \log P_t \middle| \Omega\right], \tag{15}$$

where W_t^c is the nominal wage rate, which is a function of z_{t-1}, μ_{t-1}, g_{t-1}, and τ_{t-1}. Individual's consumption and investment choices are functions of the full state vector, (z_{t-1}, μ_{t-1}, τ_{t-1}, g_{t-1}, K_t, k_t, m_t) while per capita consumption, investment, and employment are functions of the aggregate full state vector (z_{t-1}, μ_{t-1}, τ_{t-1}, g_{t-1}, K_t). Furthermore, Ω is the aggregate information set, consisting of (z_{t-1}, μ_{t-1}, τ_{t-1}, g_{t-1}, K_t). Finally, $\hat{H}_t$ is the expected labor input given Ω, for which W_t^c is the market-clearing wage. Taking W_t^c as given, households choose their desired labor supply, $\hat{H}_t$, as a function of (z_{t-1}, μ_{t-1}, τ_{t-1}, g_{t-1}, K_t, k_t, m_t). The firm, also taking W_t^c as given, chooses its demand for the expected labor input by maximizing expected profits given the information set, Ω. The resulting equilibrium contract wage will equate the conditional expected value of the marginal product of labor multiplied by the price level, given Ω.
Once the full state vector (z_{t-1}, μ_{t-1}, τ_{t-1}, g_{t-1}, K_t) is revealed, the firm chooses the actual hours worked, H, such that the marginal product of labor is equal to the realized real wage. Together with equation (14), we have that

$$H\left(z_{t-1}, \mu_{t-1}, \tau_{t-1}, g_{t-1}, K_t\right) = \left[\frac{(1-\theta)e^{z_t} P_t}{W_t^c(\Omega)}\right]^{\frac{1}{\vartheta}} K_t . \tag{16}$$

Using equation (16) to eliminate W_t^c, we obtain

$$\log H_t = \log \hat{H}_t + \frac{1}{\theta}\left[\log P_t - E\left(\log P_t \middle| \Omega\right)\right] + \frac{1}{\theta}\varepsilon^z . \tag{17}$$

Equation (17) implies that $\log H_t - \log \hat{H}_t$ is an independent and identically distributed (i.i.d.) random variable with zero mean. Finally,

$$\log h_t = \log \hat{h}_t + \frac{1}{\theta}\left[\log P_t - E\left(\log P_t \middle| \Omega\right)\right] + \frac{1}{\theta}\varepsilon^z , \tag{18}$$

and, therefore, households understand that their choice for $\hat{h}_t(z_{t-1}, \mu_{t-1}, \tau_{t-1}, g_{t-1}, K_t, k_t, m_t)$ will differ from their actual hours worked, $h(z_{t-1}, \mu_{t-1}, \tau_{t-1}, g_{t-1}, K_t, k_t, m_t)$, by the realization of this random variable.

As before, in order to solve the representative household dynamic programming problem, we transform the price level and monetary stock so that all variables are stationary in the limit.

3. Parameterization of the Chilean economy

The models were parameterized using quarterly data for the 1986–2000 period. The data are expressed in real 1986 pesos and were deseasonalized using the X-12-ARIMA procedure (sources and detailed definitions of the data are described in the appendix). Most macroeconomic variables such as GDP, consumption, and investment were obtained from national accounts compiled by the Central Bank. The data were adjusted to match the variables in the model. We used Gallego and Soto's (2001) breakdown of private consumption into durable and nondurable goods. These series does not cover housing, so output series were adjusted to exclude the imputed housing services and include the services provided by the stock of durable goods. Total consumption includes private consumption in nondurable goods and government consumption. Gross investment figures were also adjusted to exclude residential construction (that is, housing) and include purchases of durable goods and public investment.

The capital stock series were obtained recursively using the perpetual inventory method, based on an estimate of the end-of-period capital stock in machinery and nonresidential buildings for 1985 by Hofman (2000). We included also the stock of durable goods calculated by Gallego and Soto (2001). We assumed a quarterly depreciation rate (δ) of 2.0 percent. The depreciation rate computed by regressing the depreciation series on the capital stock yields a similar estimate of 1.9 percent. For the 1986–2000 period the capital-to-quarterly output ratio is 9.2.

The breakdown of time between work and leisure was obtained as follows. Total available hours per week were computed by multiplying the labor force by 100 hours per week. Total hours worked per week were computed using average hours worked and employment. We obtained an estimated share of leisure of 57 percent, which is substantially below the standard 70 percent in benchmark models for developed economies. Casual evidence suggests our estimate is likely to be accurate since part-time work is very uncommon in the formal labor market in Chile and occasional surveys tend to support the notion that work schedules are markedly longer than in developed economies. The complete set of parameters is displayed in table 2.

Table 2. Parameterization

	Parameter						
Model	β	δ	γ	θ	π	μ	α
Frictionless labor, no government	0.9787	0.02	1.0302	0.4	—	—	—
Labor rigidities, no government	0.9787	0.02	1.8654	0.4	—	—	—
Labor rigidities, government	0.9787	0.02	1.7829	0.37	0.45	—	—
Labor rigidities, government and money	0.9787	0.02	1.7829	0.37	0.45	0.04	0.753

Source: Authors' calculations.

Some of the parameters were obtained from the Euler conditions of the general equilibrium models described before. For example, the discount factor was obtained from the Euler condition for consumption, $\beta = (1 + r)^{-1}$. We used the 1986–2000 annualized average of the real interest rate (9.1 percent) to obtain an estimate of β of 0.978. The share of capital in output, θ, was also obtained from the first-order conditions of the optimization problem,

$$\theta = \frac{1-\beta\left(1-\delta\right)}{\beta\left(y/k\right)} .$$

The calibrated parameter is 0.40 in models that exclude the government and 0.36 in models that include the government. These values are much lower than the factor share of capital in GDP reported by the Chilean national accounts (0.59). We do not use this estimate for two reasons. First, measured labor compensation in countries like Chile fails to account for the income of most self-employed and family workers, who make up a large fraction of the labor force. Gollin (2002) shows that for countries with sufficient data to adjust for this mismeasurement, the resulting capital shares tend to be close to 0.30. In fact, the estimate for the Chilean economy is 0.367. Second, a high capital share implies implausibly high rates of return on capital in our numerical experiments. A capital share of 59 percent would imply an annual real interest rate of over 22 percent.

The parameter of leisure in the utility function (γ) also depends on the specification of the labor market and the presence of the government. For models that assume a frictionless labor market and no government, parameter γ was calibrated as

$$\gamma = \frac{(1-\theta)h}{n\left[1-\delta(k/y)\right]}, \tag{19}$$

while in models that consider both institutional rigidities in the labor market and the presence of the government, this parameter was calibrated as

$$\gamma = \frac{(1-\theta)h}{(1+\tau)n\left[1-\delta(k/y)-g(1-\pi)\right]}. \tag{20}$$

The calibrated γ parameters are in the range [1.05, 1.76], suggesting that there is little curvature in the labor supply function.

In the absence of microeconomic studies of the Chilean case, the proportion of government expenditures that is valued by consumers, π, was estimated using the following Euler equation:

$$\frac{U'(c_t)}{\beta U'(c_{t+1})} = 1 + r_t - \delta = \frac{c_{t+1} + \pi g_{t+1}}{\beta(c_t + \pi g_t)}. \tag{21}$$

From this first-order condition, we ran the following nonlinear regression:

$$c_t = \frac{1}{\beta(1+r_t-\delta)}c_{t-1} + \pi\left[g_t - \frac{g_{t-1}}{\beta(1+r_t-\delta)}\right] + \varepsilon_t. \tag{22}$$

The estimated parameter is $\pi = 0.45$ (with a standard deviation of 0.26), implying that less than half of government expenditures is valued by consumers as a substitute for private consumption.

To obtain an estimate of the proportion of the transactions made by consumers using cash, we used the Euler equations for consumption, which implies

$$\frac{C_t}{C_t^R} = \frac{1}{\alpha} + \frac{1-\alpha}{\alpha} R_t \,, \tag{23}$$

where C_t/C_t^R is the inverse proportion of cash goods in total consumption. Since cash-in-advance restrictions hold, $C_t/C_t^R = C_t/M_t$. Following Cooley and Hansen (1995), we regressed the ratio of nondurable consumption money (M1) on the nominal interest rate. We estimated the model using nonlinear least squares and obtained a point estimate of 0.753 (with a standard deviation of 0.005). This estimation is not necessarily an accurate measure of cash goods, since M1 includes money held by firms, but the latter is a very small proportion of money balances in the Chilean case.

The dynamic stochastic general equilibrium models consider four forcing variables (namely, technology shocks, government consumption, taxes, and money growth). Technology shocks were obtained directly from the data using the calibrated factor shares as $\lambda_t = y_t/(k_t^{\theta} h_t^{1-\theta})$. As mentioned in section 1, the processes of the four shocks are parameterized estimating the following canonical regressions:

$$\Delta \log x_t = \bar{x}_t \left(1-\rho_x\right) + \rho_x \log x_{t-1} + \varepsilon_t^x \,. \tag{24}$$

The values of $\bar{x}$ correspond to the average sample values of each variable. The average technology shock, $\bar{\lambda}$, was set at 1.0 since it is only a scale parameter. The average growth in the per capita money supply is 4.0 percent, while government consumption amounts to 8.9 percent of GDP and taxes 14.8 percent. The AR(1) processes fitted to the detrended variables yield the coefficients in table 3 and show no sign of residual correlation. We also computed the variance of the innovations of these shocks ($\sigma^2_{\rho_x}$), as shown in table 3.

Table 3. Stochastic Processes of Innovations

Forcing variable	$\bar{x}$	ρ_x	$\sigma^2_{\rho_x}$
Technology shock	1.000	0.981	0.0099
Money growth	0.040	0.506	0.0084
Government consumption	0.089	0.760	0.0094
Taxes	0.165	0.846	0.0124

Source: Authors' calculations.

4. Testing Real Business Cycle Models in an Emerging Economy

Before we present the simulation results, we evaluate how the parameters of the Chilean economy compare with those used in studies of developed economies. Table 4 presents a summary of the key parameters. The Chilean economy, like other emerging economies, differs from developed economies in fundamentals aspects. First and foremost, capital is more scarce in emerging economies than in developed economies. As presented in the table, the ratio of capital to annual output in Chile is markedly lower than in the United States. Real interest rates are therefore substantially higher, reaching 9.1 percent in the 1986–2000 period; this is almost twice as high as the rates considered in benchmark models for developed economies (McGrattan, 1994a; Cooley and Hansen, 1995; Backus, Kehoe, and Kydland, 1995). This, in turn, implies that intertemporal effects are less important in Chile because the future is more heavily discounted.

Table 4. Comparison of Key Parameters[a]

Parameter	*Chile (1986–2000)*	*United States (1947–1987)*	*United States (1954–1991)*
Capital-output ratio	9.25	10.70	13.30
Discount rate	0.98	0.99	0.99
Leisure time	0.58	0.73	0.69
Labor curvature			
Frictionless market	0.99	2.33	2.53
Market rigidities	1.70	3.22	—
Share of gov. expend. in utility function	0.47	0.00	—
Volatility of GDP	2.20	1.81	1.72
Variance of innovations			
Technology	0.0099	0.0096	0.0070
Money	0.0251	—	0.0089
Government expenditures	0.0094	0.0061	—

Source: Authors' calculations.
a. The values for Chile are the authors' calculations for this paper; the values for the United States (1947–1987) are from McGrattan (1994a); and the values for the United States (1954–1991) are from Cooley and Hansen (1995).

A second important difference is the working of labor markets. The most striking feature is the curvature of labor in the utility function. Substitution—a feature that does not depend on labor market rigidities—is in the range of 2.33–3.22 in the United States; it is less than half that in Chile. This reflects the smaller amount of leisure time allocated by Chilean workers, as well as the larger share of capital in factor incomes. Moreover, Hansen (1985) substantially improves the ability of real business cycle models to replicate the U.S. data on output and labor markets when he increases this parameter from 2.33 to 3.22.

The third important difference between emerging and developed economies involves the volatility of shocks and their effect on output and its components. The volatility of output in Chile—measured as the variance of the detrended log of GDP—is 30 percent higher than in the United States and as much as 20 percent higher than in the European economies (European data are taken from Backus, Kehoe, and Kydland, 1995). The volatility of technological shocks seems to be very similar in Chile, the United States, and Europe. Money shocks, however, are three times larger in Chile than in the developed countries, and inflation and prices are therefore also twice as volatile in Chile than in the United States. Government expenditures in Chile are 50 percent more volatile than in the United States and most European economies, reflecting the dependence of the Chilean fiscal account on a narrower tax base.

The last notable difference is in consumers' valuation of the goods provided by the government. McGrattan (1994a) estimates an extreme case for the U.S. economy: zero valuation. In the Chilean case, the estimated value is substantially larger, indicating that consumers benefit from government expenditures but also need to smooth out this additional source of stochasticity.

4.1 Simulation Results

Table 5 reproduces the main indicators of the Chilean business cycle we would like to replicate using our RBC models. Our simplest model (labeled model 1 in the table) corresponds to the case in which we exclude the government, allow for divisible labor, and introduce only one source of stochasticity in the form of technological shocks (this is the simplest Kydland-Prescott type of model). The results show that the model is successful in replicating a number of the features of the data: it reproduces 75 percent of the volatility of output and investment, but falls short of matching that of consumption, labor supply, and capital stock.[11] It also produces a positive and significant correlation between hours worked

11. The estimated volatility of the stock of capital (1.32) is distorted by the 1999–2000 recession and the limitations of the HP filter. When we computed it for the 1986–1998 period, we obtained a value of 0.90, which is higher than values for the United States and Europe (0.5).

and productivity; this is at odds with the data, which shows a negative correlation. This simple model also replicates some of the correlation between the variables and output, but in general terms it is unsatisfactory. For some variables it generates excessive contemporaneous correlation (for example, consumption, investment, and labor productivity), while for others it fails to capture the true relationship, in particular in the case of capital and total hours worked. By construction the model does not replicate any nominal variable.

Table 5. Simulated Business Cycle Models for the Chilean Economy

Model feature, indicator, and variable	*Actual data 1986–2000*	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*
Model feature						
Labor rigidities		Excluded	Included	Included	Included	Included
Gov. consumption		Excluded	Excluded	Included	Included	Included
Money		Excluded	Excluded	Excluded	Included	Included
Wage indexation		Excluded	Excluded	Excluded	Excluded	Included
Volatility						
Output	2.20	1.65	2.12	2.14	2.22	2.51
Consumption	1.88	0.69	0.82	1.64	2.22	2.01
Investment	8.21	6.08	8.27	9.04	9.70	12.32
Capital	1.32	0.42	0.56	0.59	0.65	0.65
Hours Worked	1.92	0.59	1.38	1.54	1.52	2.54
Labor Product.	1.92	1.08	0.83	1.02	0.84	1.11
Prices	2.12	—	—	—	2.17	1.84
Inflation	0.93	—	—	—	1.29	0.96
Contemporaneous correlation with output						
Output	1.00	1.00	1.00	1.00	1.00	1.00
Consumption	0.60	0.94	0.92	0.64	0.36	0.47
Investment	0.83	0.98	0.98	0.81	0.93	0.94
Capital	0.41	0.08	0.09	0.12	0.10	0.04
Hours worked	0.49	0.98	0.98	0.90	0.97	0.90
Labor product	0.72	0.99	0.93	0.74	0.90	0.19
Prices	–0.26	—	—	—	–0.54	–0.34
Inflation	–0.06	—	—	—	–0.32	0.13
Correlation of hours and wages	–0.38	0.94	0.83	0.37	0.76	–0.24

Source: Authors' calculations.

The second model in the table extends the previous model to include labor market rigidities. This model better represents the data on this dimension, as it now replicates 80 percent of the volatility of hours worked. Likewise, output and investment fluctuations are now almost identical to the data, but consumption and labor productivity remain poorly represented. The model does not correctly replicate the dynamics of the economy, as it attaches too much contemporaneous correlation between most variables and output, and it fails to replicate the correlation between hours worked and labor productivity.

The third model extends the second to include the fiscal side of government activities. As displayed in the table, the introduction of government expenditures significantly improves the ability of the business cycle model to replicate the volatility of consumption. The model's reproduction of the functioning of the labor market is still disappointing, as is apparent in the insufficient volatility of labor productivity and the positive—yet much smaller—correlation between hours worked and productivity. Its estimates of the correlation of output to most variables (namely, consumption, investment, labor productivity) come close to the actual data, although it falls short of replicating the correlation of output to capital.[12]

The results of these first three models suggest, first, that business cycle models are able to replicate a substantial fraction of the observed fluctuations of the real side of the economy; second, that introducing government expenditures is a more promising way to model economic fluctuations than introducing labor market rigidities; and, third, that some dimensions of the working of the labor market are not correctly replicated by these models.

For policy purposes, one would like business cycle models to replicate not only real-side fluctuations, but also nominal variables such as inflation and prices. Moreover, one should expect a gain on the real side if the inability of these three initial models to replicate the volatility of consumption is linked to the existence of liquidity constraints. Our fourth model introduces cash-in-advance constraints to the third model. The model successfully replicates the volatility of the price level and slightly overestimates that of inflation. It would thus seem that the model is able to replicate the volatility of

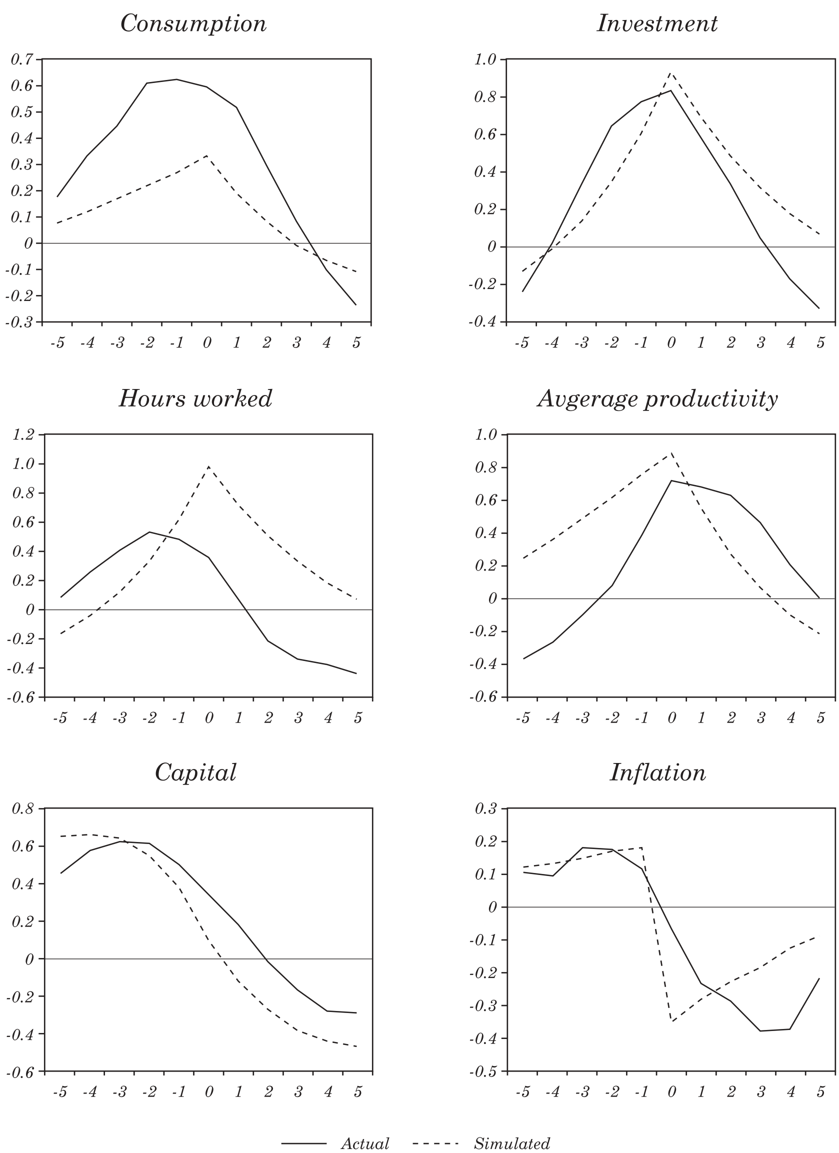
12. Again, when we exclude the 1999–2000 recession, the correlation of output and capital stock is only 0.14.

consumption and its correlation with output and that liquidity constraints are irrelevant. The results are very different, however, when we split consumption into cash goods (that is, liquidity constrained) and credit goods (unconstrained). The volatility of unrestricted consumption is 1.70 and its correlation with output cycles is 0.70; both values are very close to the data. In the case of restricted goods, the volatility of consumption is 2.30, while its correlation with output cycles is 0.34. The model thus matches the data reasonably well along this dimension, as well. Nevertheless, the model continues to produce a labor market equilibrium solution that does not match the data and is unable to find a significant correlation between output and the price level or inflation. As in all previous models that exclude government expenditures, the correlation between hours worked and average productivity levels is disappointingly high.

Finally, our fifth model attempts to overcome the inability of the RBC model to address the correlation between hours worked and productivity levels by introducing wage indexation. The logic of using wage rigidities is that the RBC model is allocating too much variation to labor supply and not enough to changes in labor demand (that is, it allows nominal wages to match changes in relative prices). Once indexation is enabled, the negative correlation between hours worked and productivity is reproduced in general terms. Most features of the nominal side of the data are also adequately reproduced, including the volatilities of inflation and prices. This comes at the cost of inducing excess volatility in almost all real variables, including output, investment, and hours worked. In addition, the working of the labor market is not well captured, since simulated labor productivity is not as volatile as in the data and exhibits little contemporaneous correlation with output.

Our artificial economies should also be able to replicate the dynamics of the different variables in the cycle. We used model 4 to compute the correlations of the main endogenous variables and output arising from the simulated economies and compared them with the same correlations observed in the data. As shown in figure 7, the model tracks the dynamics of investment, the capital stock, and inflation quite closely, but it performs less impressively with regard to consumption, hours worked, and average productivity.

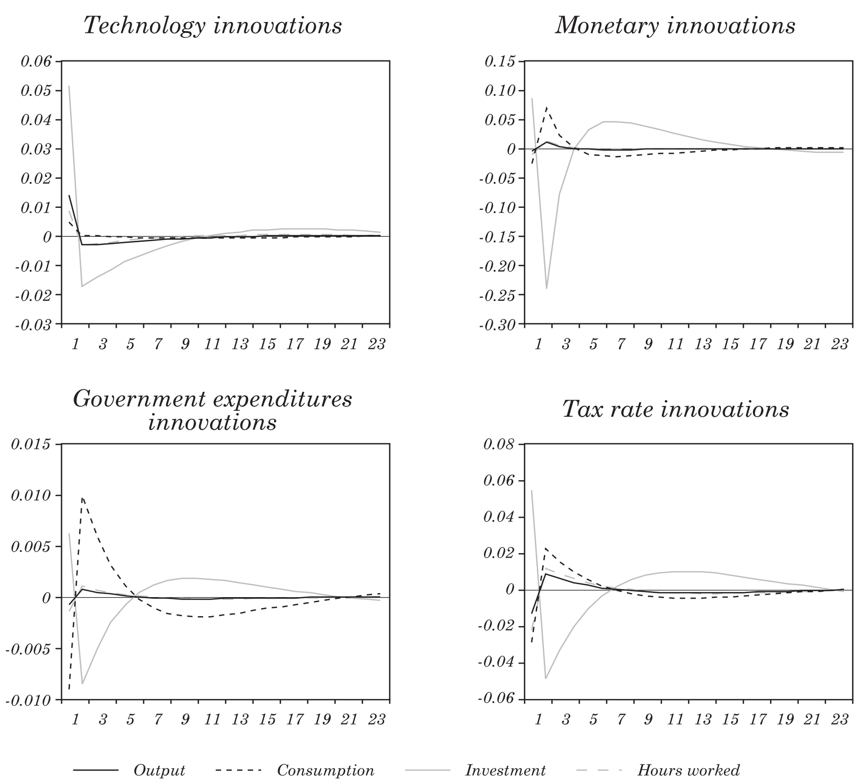
Figure 7. Actual and Simulated Cross Correlations[a,b]



Source: Authors' calculations.
a. Correlations of the respective variable's logs and leads whith GDP.
b. Quarterly series.

A second way to assess RBC models is to study their dynamic response to innovations in forcing variables. We again selected model 4 to study impulse-response functions because it is our best representation of the data and because it allows us to discuss fiscal and monetary shocks. Figure 8 plots the responses of output, consumption, investment, and hours worked to a one-standard-deviation shock to the technological process, money growth process, government expenditure process, and tax process. The responses to temporary shocks, although quite short-lived, cause agents in the model to modify their consumption, investment, and leisure decisions. The effect on prices causes firms to modify their capital and labor hiring decisions.

Figure 8. Impulse Response Functions[a]



Source: Authors' calculations.
a. Quarterly series.

Specifically, a temporary technology shock increases total factor productivity. Since the return to work is temporarily high, individuals are encouraged to substitute intratemporally from leisure to consumption, as well as intertemporally from current leisure to future leisure. Given the transitory nature of the shock, the positive wealth effect is likely to be relatively weak, and the effect on leisure should be small, such that employment is likely to respond positively to the transitory increase in productivity. The increased employment and productivity cause current period output to rise (the current period capital stock remains fixed). The consumption-smoothing motive suggests that a part of this increased output will take the form of additional new capital goods, so that current period investment spending will rise together with current period consumption.

A temporary money growth shock has almost no effect on output and hours, but it has a very large impact on consumption and investment. The transitory increase in the growth rate of money leads to an increase in investment, whereas consumption decreases since output does not change. As the cash-in-advance restriction becomes less relevant, consumption increases and investment decreases.

A temporary government expenditure shock—when the budget is balanced every period—reduces consumption, since government expenditure partially substitutes it in utility. The impact on output and hours worked is initially negative, but very low. Investment then increases and behaves in opposition to consumption through the recovery path toward the steady state.

Finally, the real response of the model to a transitory consumption tax shock is very similar to the response to a transitory government expenditure shock, since the condition of a balanced budget every period implies that increases in government expenditures are accompanied by reductions in the lump-sum transfer to consumers. The main difference resides in the distortionary effect of the consumption tax, as opposed to the lump-sum transfer. Consequently, all variables respond much more strongly than in the previous case.

4.2 How Robust Are RBC Models?

The above parameterization imposes a number of restrictions on the structure of the economy so that the calibrated business cycle model reflects a particular vision of the Chilean economy. A simple test of these restrictions is to change the structure of the parameters and the dynamic nature of forcing variables and then check whether the results depend on these key parameters. We performed this sensitivity analysis on our most ambitious specification (model 4), focusing on the two crucial policy parameters (namely, the proportion of government expenditures valued by consumers, π, and the proportion of cash goods, α) and the imputed share of capital in output, θ. The results, presented in table 6, suggest three main conclusions. First, changing the share of capital and labor in output does not induce important changes in the computed volatilities and correlations with output. Since the capital stock is a very parsimonious series, the model exhibits small volatility in general (except for consumption). Second, when the parameter for the valuation of public goods in the utility function is decreased from 0.45 to 0, the matching of variances and correlations is not evidently affected for output, investment, employment, and the nominal variables. Consumption, on the other hand, reacts in the expected way, becoming less volatile as we eliminate one source of instability for the consumer. Finally, when liquidity constraints are made more stringent (that is, when parameter α increases from 0.75 to 0.85), the general matching of variances and correlations for real variables is only marginally affected. Those for nominal variables improve slightly, suggesting that the value we used may underestimate the true value.

In summary, changing the main parameters of this real business cycle model does not produce important changes in the qualitative conclusions reached above, although in some cases it modifies the numerical outcomes of the model and their distance from the actual data. Although this is not a formal test, the results suggest that the parameterization does, in fact, reflect the underlying structure of the Chilean economy and that the selection of crucial parameters is not too arbitrary.

Table 6. Sensitivity Analysis of the Business Cycle Model of the Chilean Economy

Indicator and variable	*Actual data 1986–2000*	*Model 4 (1)*	*Increase θ from 0.37 to 0.45 (2)*	*Increase α from 0.75 to 0.85 (3)*	*Reduce π from 0.45 to 0 (4)*
Volatility					
Output	2.20	2.22	2.08	2.26	2.16
Consumption	1.88	2.22	2.31	2.22	1.65
Investment	8.21	9.70	7.80	9.92	9.15
Capital	1.32	0.65	0.54	0.66	0.10
Hours worked	1.92	1.52	1.48	1.57	1.41
Labor productivity	1.92	0.84	0.72	0.82	0.85
Prices	2.12	2.17	1.99	1.91	2.21
Inflation	0.93	1.29	1.13	1.03	1.33
Contemporaneous correlation with output					
Output	1.00	1.00	1.00	1.00	1.00
Consumption	0.60	0.36	0.28	0.36	0.39
Investment	0.83	0.93	0.94	0.93	0.97
Capital	0.41	0.10	0.08	0.10	0.10
Hours worked	0.49	0.97	0.97	0.97	0.97
Labor productivity	0.72	0.90	0.89	0.89	0.93
Prices	–0.26	–0.54	–0.44	–0.40	–0.57
Inflation	–0.06	–0.32	–0.27	–0.26	–0.33
Correlation of hours and wages	–0.38	0.76	0.76	0.76	0.82

Source: Authors' calculations.

4.3 Do RBC Structures Fit the Data?

Business cycle models can be viewed as restricted versions of more general VAR models. These restrictions, imposed by the structure of the model and the linearization process, can be tested using relatively simple statistical procedures (see Canova, Finn, and Pagan, 1994). The debate among econometricians about the empirical evaluation of these models remains controversial, however (Kydland and Prescott, 1996; Hansen and Heckman, 1996).

Following Canova, Finn, and Pagan (1994), we consider the following representation of model 4 described above (which includes government expenditures, taxes, labor rigidities, and cash-in-advance restrictions):

$$\mathbf{y}_t = \mathbf{A}\mathbf{z}_t \quad \text{and}$$

$$\mathbf{z}_t = \mathbf{F} z_{t-1} + \mathbf{G}\varepsilon_t , \tag{25}$$

where **y** is the vector of variables of interest, **z** represents the controlled and uncontrolled states (the latter are labeled *x*), ε represents the innovations, and **A**, **F**, and **G** are matrices of coefficients. These matrices are, in general, combinations of the deep parameters presented in table 2; model 4 thus imposes on matrices **A** and **F** particular structures that can be tested directly against the sample data.

The first type of test arises from the long-run restrictions contained in matrix **A**. When the forcing variables (or uncontrolled states, *x*) are integrated variables, matrix **F** takes the following particular form:

$$\begin{vmatrix} \gamma & \delta \\ 0 & I_p \end{vmatrix},$$

where *p* of the eigenvalues of **F** are unity, while the rest are the eigenvalues of γ. Since the latter are assumed to be less than one in business cycle models, there must be $(n - p)$ cointegrating vectors among the states. This is the first testable hypothesis that can be confronted with the data. In our particular case, the **z** vector includes λ, *g*, μ, τ, and *k*.

The second testable implication of the RBC model as represented by equation (25) is that the residual of $\mathbf{y}_t - \mathbf{A}\mathbf{z}_t$ ought to be stationary and the cointegrating vector must be **A**. Hence, a simple test of stationarity can be conducted to test this restriction.

Table 7 presents unit root tests for the deseasonalized data. The unit root tests do not reject the null hypothesis of nonstationarity in the state variables *k* and *n* or in the main variables of interest (output, consumption, and investment). The null is rejected, however, in all forcing variables except tax rates. The evidence is less robust for technology shocks. It is widely accepted that unit root tests can be very misleading as a result of low power, structural breaks, and the like (Hamilton, 1994).

Table 7. Unit Root Tests: Phillips-Perron Methodology[a]

	Level		
Variable	*Without trend*	*With trend*	*First difference*
Money growth	–2.71	–4.00	–9.96*
Technology shock	–0.87	–1.76	–5.78*
Government expenditures	–2.04	–3.39	–6.04*
Taxes	–2.34	–2.84	–6.61*
Capital stock	–0.34	–2.34	–2.29
Output	–1.65	0.04	–4.54*
Consumption	–1.26	–0.58	–4.69*
Investment	–2.04	–1.08	–3.33*
Rejection value			
At 5 percent significance	–2.92	–3.50	–2.92
At10 percent significance	–2.60	–3.18	–2.60

Source: Authors' calculations.
* Rejection of the null hypothesis at the 1 percent significance level.
a. The sample period is from 1986:1 to 2000:4. All data are seasonally adjusted, three-lag truncation.

Treating forcing variables as integrated processes implies that, according to the business cycle model, there should be three cointegrating vectors ($n = 5$, $p = 2$). Table 8 presents the result of estimating cointegrating vectors within the sample data using the Johansen procedure. The RBC restrictions are weakly supported by the data in the sense that we cannot reject the null hypothesis of three cointegrating vectors.

Table 8. Cointegration Tests: Johansen Methodology[a]

Eigenvalue	*Trace statistic*	*Critical value: 5 percent*	*Critical value: 1 percent*	*No. cointegrating equations*
0.63	112.58	76.07	84.45	None **
0.35	58.65	53.12	60.16	At most 1 *
0.28	34.98	34.91	41.07	At most 2 *
0.20	17.39	19.96	24.60	At most 3
0.10	5.43	9.24	12.97	At most 4

Source: Authors' calculations.
* Rejection of the null hypothesis at the 5 percent significance level.
** Rejection of the null hypothesis at the 1 percent significance level.
a. The sample period is from 1986:1 to 2000:4. All data are seasonally adjusted, with four lags. The series used are capital, hours worked, technology shocks, money growth, and government expenditures.

Although the data suggest the existence of three cointegrating vectors, our RBC model does not necessarily produce exactly the same three vectors contained in the data. The second set of tests considers the implied reduced form of output, consumption, and investment, as described in equation (26), in terms of a combination of the deep parameters of the model. Since all endogenous variables are I(1), under cointegration η should be I(0).

$$y_t = f_1(k_t, \tau_t, \lambda_t, g_t, \mu_t) + \eta_{y_t},$$

$$c_t = f_2(k_t, \tau_t, \lambda_t, g_t, \mu_t) + \eta_{c_t}, \quad \text{and} \tag{26}$$

$$i_t = f_3(k_t, \tau_t, \lambda_t, g_t, \mu_t) + \eta_{i_t}.$$

Augmented Dickey-Fuller tests of cointegration generated values of –3.85 for output, –5.43 for consumption, and –3.59 for investment. The three equations thus cointegrate, providing econometric support for the RBC model, its implied decision rules, and the dynamics of endogenous variables.

5. Summary and Conclusions

The goal of this paper was to test the ability of various RBC type of models to replicate the salient characteristics of the observed aggregate fluctuations of the Chilean economy in 1986–2000 and to provide insights into the contribution of fiscal and monetary policies as sources of business cycles. The Chilean economy provides an interesting case because it presents both similarities with developed economies and important idiosyncrasies that challenge RBC theory.

Our main findings can be summarized as follows. First, business cycle models are able to replicate much of the observed fluctuations of both the real and monetary sides of the economy. Second, of the five models considered in this paper, an economy with government expenditures and labor indivisibility emerges as the best representation to account for short-term fluctuations in Chile. Although monetary shocks and nominal contracts improve the predictions of that model in some dimensions, they either generate excessive volatility or fail even further to account for the observed labor market behavior. Finally, replicating the fluctuations in consumption observed in the data may require placing additional constraints on the optimizing behavior of agents in our models.

This paper provides strong evidence of the relevance of supply-side shocks as sources of aggregate fluctuations in Chile. The main challenge for the future consists in better understanding the connection between international business cycles and local market dynamics, together with the behavior of labor markets.

Appendix
Data Sources and Definitions

The data are expressed in real domestic currency (1986 pesos) and were deseasonalized using the X-12-ARIMA procedure. The following series were obtained from *Indicadores económicos y sociales de Chile, 1960–2000* (Central Bank of Chile, 2001) and its companion CD and correspond to national accounts definitions: GDP, total consumption, gross investment, and housing services. We obtained money (M1A), interest rates, the consumer price index, population, and labor force from the same source. GDP series were adjusted to include the services provided by the stock of durable goods and exclude the imputed housing services. The breakdown of consumption into durable and nondurable goods, as well as the stock of durable goods and its imputed services, were obtained from Gallego and Soto (2001). Gross investment figures were adjusted to exclude housing (residential construction) and include purchases of durable goods. The capital stock series was obtained recursively using the end-of-period capital stock in machinery and nonresidential buildings estimated for 1985 by Hofman (2000), the gross investment series including durable goods, and a quarterly depreciation rate of 2 percent. Quarterly tax revenues by category were obtained using annual revenue data from the tax authority's webpage (www.sii.cl) and the standard related-series method. Labor force and average hours worked were obtained from the survey *Encuesta de ocupación y desocupación* released quarterly by the University of Chile Economics Department. Total available time was fixed at 100 hours a week.

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