Chilean growth dynamics

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Abstract

This paper provides a framework for analyzing the growth dynamics of Chile. Using univariate time series representations, we find that the Chilean data is more consistent with exogenous rather than endogenous growth models. Terms of trade, improvements in the quality of capital, and the presence of distortions are important factors behind a dynamic characterization of the behavior of TFP and GDP. We show that distortions not only eliminate the positive effects of improvements in the quality of capital, but also precede technology shocks and increase their volatility. A dynamic stochastic general equilibrium model, that explicitly incorporates the theoretical counterpart of capital stock quality, distortionary taxes and terms of trade, can successfully replicate the impulse–response functions found in the data. This exercise suggests that distortions play a key role in explaining the dynamics of growth in Chile.

Keywords: Economic growth; Chile

1. Introduction

When compared to other Latin American countries, Chile presents statistically significant differences, not only in the average per capita GDP growth, but also on its volatility (Lüders, 1998; Chumacero and Fuentes, 2002). It presents four characteristics that are not present (at least to the same extent) in other countries. First, until the oil crisis, Chile's economic performance (both in terms of growth rate and volatility) was similar to that of the average Latin American country. Between the oil crisis and the debt crisis, Chile displayed "atypical" vulnerability given

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the low growth and high volatility exhibited during those crises. Third, the speed of recovery after these crises is unsurpassed by the other countries. Finally, after the debt crises, Chile exhibited not only the highest growth rates of the region, but also a level of volatility that is not statistically different from the average of the region.

One would like to know which of its characteristics made Chile so average until the oil crisis, so sensitive to the two major international crises in the early seventies and eighties, and which made it exhibit the accelerated growth rates and decreased volatility that came after these episodes. This exceptional growth period was interrupted in 1999 when Chile experienced its first recession since 1982–1983.

Chile's economic performance presents an interesting case study because it has experienced major swings in its institutional arrangements and economic policies. In the past 40 years, the economy shifted from moderately inward oriented, to highly state-controlled, and ended up as a free-market economy. All these movements have occurred along with two major international crises from which it has recovered faster than any other Latin American economy.[1]

This paper provides a framework for understanding and characterizing the factors behind Chilean growth dynamics. In doing so, we follow a progressive approach. Section 2 starts by developing a simple growth model and deriving the univariate time series representation of per capita GDP. This representation provides guidelines with respect to the type of theoretical model best suited to understand the Chilean growth process and, more importantly, it provides information with respect to the characteristics of the series that a good model must capture. Section 3 incorporates factors absent in the model of Section 2 that are needed to provide a satisfactory statistical representation of the series (distortions, terms of trade, the quality of capital, openness, etc.). Using these findings as a guideline, Section 4 develops a stochastic general equilibrium model that is able to replicate the dynamics described in Section 3. Finally, Section 5 concludes.

2. Univariate time series analysis

This section analyzes the univariate time series properties of per capita GDP and GDP per worker. We contend that a rigorous statistical analysis of these series can shed light on several key properties of the economy. Careful characterization of these variables is useful to assess whether the evidence is consistent with endogenous or exogenous growth models. Furthermore, univariate time series models can be used to recover "deep parameters" of the aggregate production function. Finally, the statistical properties of residuals from the univariate representation can be helpful to understand which factors are behind the volatility and other moments of the innovations of the Solow residual.

Two sources of information are available for constructing these series. The first consists of official records obtained from the Central Bank of Chile and the National Bureau of Statistics, for the period 1960–2000. The second period is longer (1810–1995), and is based on Braun et al. (2000), Díaz et al. (1999) and Jofré et al. (2000), who discuss the methodologies used for constructing them.[2]

[1] Comparisons of the economic performance of Chile and the rest of Latin America economies can be found in Elías (1992) and De Gregorio and Lee (1999). Edwards (1995) discusses Latin American reforms and the effects of institutions. Alternative explanations for the rapid take-off of the Chilean economy after the debt crisis are found in Schmidt-Hebbel (1998). Extensive analyses of the reforms can be found in Corbo et al. (1997) and Chumacero et al. (2005). See Edwards and Edwards (1991), Chumacero and Fuentes (2002), and references therein.

[2] All the series used in this paper can be found in Chumacero and Fuentes (2002).

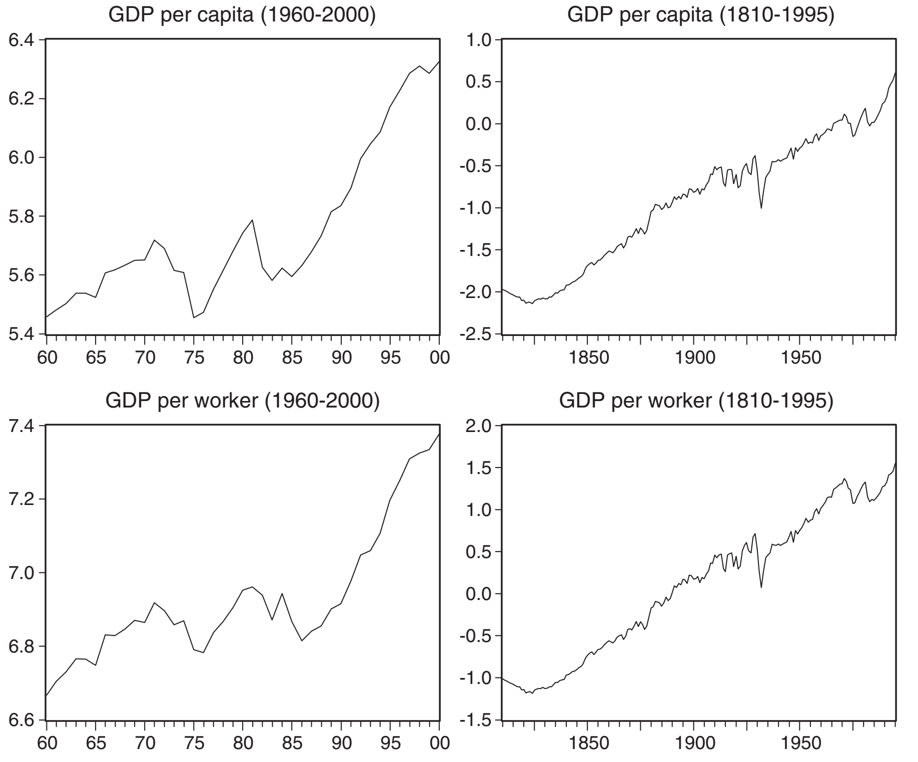

Fig. 1. Log of GDP per capita and per worker.

These time series (in logs) are presented in Fig. 1 along with some descriptive statistics of their growth rates (Table 1). The first database indicates that the average annual growth rate of per capita GDP was 2.2%, while GDP per worker grew 1.8%. These figures are significantly lower for the period prior to 1960. In fact, the second database shows growth rates of 1.4% and 1.3% for the two series, respectively. These lower growth rates are heavily influenced by the Great Depression which produced declines of more than 25%.[3] Furthermore, both data sets indicate that the unconditional distribution of per capita GDP growth presents important departures from normality. This last characteristic is not shared by the GDP per worker series when using the first data set. Finally, independently of the time series considered, growth is highly volatile given that the standard deviation is always more than double the average growth rate.

The rest of this section analyzes the stochastic properties of the four time series and describes some of the key characteristics that will be used in the following sections.

2.1. Unit roots and economic theory

Lau (1997) and Lau (1999) show that a necessary condition for an economy to be consistent with endogenous growth models is that the marginal process for per capita GDP must contain a

[3] The resemblance between series of GDP per capita and per worker in the second database is due to the fact that between 1810 and 1853 there is information of the labor force but not of the number of workers. A constant participation rate of 38.4% is assumed for the period.

Table 1
Descriptive statistics of the first difference of per capita GDP and GDP per worker

	GDP per capita		GDP per worker	
	1960–2000	1810–1995	1960–2000	1810–1995
Mean	0.022	0.014	0.018	0.013
Median	0.036	0.018	0.021	0.018
Maximum	0.099	0.194	0.089	0.198
Minimum	−0.161	−0.253	−0.078	−0.261
Standard deviation	0.057	0.065	0.042	0.065
Skewness	−1.541	−0.730	−0.598	−0.764
Kurtosis	5.606	6.130	2.798	6.348
JB	0.000	0.000	0.294	0.000

JB=p-value of the Jarque-Bera test for normality.

unit root. This, however, is not a sufficient condition, as exogenous growth models may also be consistent with a unit root on GDP as long as technology shocks have one. Nevertheless, rejection of a unit root firmly suggests that endogenous growth models may not offer valid theoretical approximations for a particular economy. In this sense, unit root tests provide useful guidelines regarding the type of theoretical model that best matches the empirical evidence, particularly if stochastic trends are rejected.

Given their low power, unit root tests have a long but conflicting tradition in econometrics. Chumacero (2005) shows that it is difficult to make a case for a unit root in scale variables, such as GDP or consumption, unless one is willing to accept the idea that interest rates are deterministic functions of present and past realizations of the variable's growth rate. Furthermore, even when applying traditional unit root tests for the Chilean economy, Chumacero (2000) shows that the evidence for a unit root is rather weak.

Table 2 presents the results of applying several unit root tests to each of the four series introduced above. The tests correspond to the PP test (Phillips and Perron, 1988), the KPSS test (which takes deterministic trends as its null hypothesis and stochastic trends as the alternative, Kwiatkowski et al., 1992), the ZA tests (which consider the alternative hypothesis of a break in level and a break in trend, Zivot and Andrews, 1992), the ERS test (which conducts the procedure known as GLS detrending, Elliott et al., 1996), the Bierens test (which considers as alternative hypothesis that the deterministic trend may be non-linear, Bierens, 1997), and the NP test (which is a modification of the ERS point optimal test, Ng and Perron, 2001). Although the power of most tests that take the presence of a unit root as the null

Table 2
Unit root tests

	GDP per capita		GDP per worker	
	1960–2000	1810–1995	1960–2000	1810–1995
PP	Yes	No	Yes	No
KPSS	No	No	No	No
ZA (level)	Yes	No	Yes	No
ZA (trend)	Yes	No	Yes	No
ERS	No	No	No	No
Bierens	No	No	No	No
NP	No	No	No	No

No=a unit root is rejected at a 5% significance level. Yes=a unit root is not rejected at a 5% significance level.

hypothesis is questionable, the results suggest that when considering more general alternative hypotheses (as in the case of the Bierens test), a large sample (second data set), or more robust procedures (ERS and NP tests), the evidence with respect to the presence of stochastic trends disappears.

Thus, the evidence just provided constitutes a strong case for a univariate time series representation that is more consistent with deterministic trends and, thus, exogenous growth models. Furthermore, when using the latest tests available, the international evidence against unit roots is also strong.

2.2. A simple model

Following Chumacero (submitted for publication), consider a representative, infinitely lived household that maximizes

$$\mathcal{U}_0 = \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t L_t \frac{c_t^{1-\gamma} - 1}{1-\gamma},$$

where $0<\beta<1$ is the subjective discount factor, $\gamma>0$ is the Arrow-Pratt relative risk aversion coefficient, $\mathcal{E}_t$ is the expectation operator conditional on information available for period t, and c_t ($=C_t/L_t$) is per capita consumption.[4] There is no utility for leisure and the labor force is equal to L_t. Utility is maximized with respect to per capita consumption, and per capita capital stock, k_{t+1}, subject to the budget constraint:

$$K_{t+1} + C_t = e^{z_t} K_t^{\alpha} \left[(1+\lambda)^t L_t\right]^{1-\alpha} + (1-\delta)K_t,$$

where α is the compensation for capital as a share of GDP. In this economy, technological progress is labor-augmenting and occurs at the constant rate λ. Production is affected by a stationary productivity shock z_t. It is straightforward to show that capital and consumption per unit of effective labor, $\hat{k}_t$ and $\hat{c}_t$ are stationary.[5] We can represent the above economy in terms of a stationary economy and obtain exactly the same solutions for $\hat{k}_t$ and $\hat{c}_t$ as follows:

$$\max_{\{\hat{k}_{t+1},\hat{c}_t\}} \mathcal{E}_0 \sum_{t=0}^{\infty} \left[\beta(1+\lambda)^{1-\gamma}\right]^t L_t \frac{\hat{c}_t^{1-\gamma} - 1}{1-\gamma}, \tag{1}$$

subject to

$$(1+\eta)(1+\lambda)\hat{k}_{t+1} + \hat{c}_t = e^{z_t}\hat{k}_t^{\alpha} + (1-\delta)\hat{k}_t, \tag{2}$$

where η is the rate of population growth.

The law of motion of the technology shock is given by

$$z_t = \rho z_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}\left(0, \sigma_\varepsilon^2\right). \tag{3}$$

Given specific values for the parameters that describe the model, numerical methods can be used to derive the optimal policy functions for the problem's control variables. If $\gamma=1$ and $\delta=1$, the dynamic programming problem maximizing the objective function (1) has logarithmic

[4] Lower case letters denote per capita; upper case total; and a hat above a variable denotes per unit of effective labor.

[5] $\hat{k}_t = k_t/(1+\lambda)^t$ and $\hat{c}_t = c_t/(1+\lambda)^t$.

preferences subject to a Cobb-Douglas constraint (2), in which case an analytical expression for the capital stock policy function is available and is expressed as:

$$\ln\hat{k}_{1+1} = \ln(\alpha\beta) - \ln(1+\lambda) + \ln\hat{y}_t, \tag{4}$$

where $\hat{y}_t = e^{z_t}\hat{k}_t^{\alpha}$ is the per unit of effective labor GDP.

Recalling that $\hat{y}_t(1+\lambda)^t = y_t$ we can use (3) and (4) to obtain a compact representation of the Data Generating Process (DGP) of per capita GDP:

$$\ln y_t = B + Dt + (\alpha+\rho)\ln y_{t-1} - \alpha\rho\ln y_{t-2} + \varepsilon_t, \tag{5}$$

or equivalently

$$(1-\alpha L)(1-\rho L)\ln y_t = B + Dt + \varepsilon_t, \tag{6}$$

with L now denoting the lag operator and B and D being constants.[6]

Four features of (5) are worth mentioning: first, as is typical of exogenous growth models, per capita GDP is trend stationary.[7] Second, as a direct implication of the first, with trend stationary processes, temporary shocks have temporary effects on the levels and growth rates. Permanent shocks have permanent level and transitory growth effects. Third, given that the technology shock follows an AR(1) process, ln y follows an AR(2) process.[8] Finally, this specification can be used to recover α (share of capital in GDP) and ρ (persistence of the technology shock) by imposing a non-linear restriction among the parameters of the AR(2) representation.

Next, we estimate the univariate representation compatible with (5), using both data sets for per capita GDP and per worker GDP.[9]

2.3. Estimating univariate time series models

Even a simple model as the one just described involves important empirical implications for the univariate time series representation of GDP per capita or per worker. It states that in the exogenous growth model framework, an AR(2) representation of the series is compatible with an AR(1) law of motion for the technology shock. A simple way to evaluate if such specification constitutes a good statistical description of the data is to find the best univariate autoregressive model that also contains a deterministic trend. Using either the Akaike or Schwarz criterion an AR(2) representation is preferred to less parsimonious models.

Given that a characterization such as (5) is consistent with the data, we can recover α and ρ by estimating the referred non-linear restrictions in the autoregressive parameters. The results of such estimation, along with statistics that summarize key properties of the model and the resulting residuals are reported in Table 3.

In general, the results suggest that a representation such as (5) provides a good statistical representation of the univariate time series properties of per capita and per worker GDP. In particular, all the models are able to induce white noise residuals. Furthermore, the model

[6] $B = \alpha(1-\rho)\ln(\alpha\beta) + \rho(1-\alpha)\ln(1+\lambda)$ and $D = (1-\alpha)(1-\rho)\ln(1+\lambda)$.

[7] In fact, (13) makes clear the statement from Section 2.1. A unit root in the scale variable is present if $\alpha = 1$ (in which case we end up with the familiar AK model of endogenous growth) or $\rho = 1$ (where we still have exogenous growth with a random walk on the technology shock). Thus, a unit root is a necessary but not a sufficient condition for endogenous growth.

[8] In general, if the productivity shock follows an AR(j) process, ln y follows an AR($j+1$) process.

[9] The model assumes that the labor force and the population coincide. Empirically, the distinction would be irrelevant if the participation rate were constant. As this is not the case in practice, we use (5) as a representation for both per capita and per worker GDP.

Table 3
Results of univariate time series regressions

	GDP per capita		GDP per worker	
	1960–2000	1810–1995	1960–2000	1810–1995
D	0.002 (0.001)	0.002 (0.001)	0.001 (0.001)	0.002 (0.001)
α	0.305 (0.174)	0.174 (0.084)	0.127 (0.173)	0.187 (0.099)
ρ	0.879 (0.111)	0.835 (0.053)	0.943 (0.089)	0.799 (0.059)
R^2	0.957	0.993	0.946	0.994
DW	2.018	1.961	2.036	1.965
Q	0.303	0.373	0.260	0.413
Q^2	0.075	0.000	0.243	0.000
JB	0.000	0.000	0.227	0.000
Ra	0.043	0.006	0.034	0.080

R^2=adjusted R^2. DW=Durbin-Watson statistic. Q=minimum p-value of the Ljung-Box test for white noise in the residuals. Q^2=minimum p-value of the Ljung-Box test for white noise in the squared residuals. JB=p-value of the Jarque-Bera normality test. Ra=p-value of the Ramsey test. Standard errors in parenthesis.

provides estimates of persistent technology shocks. Nevertheless, the only estimate of the share of capital in GDP that is in line with the international literature is the one for the 1960–2000 sample, using per capita GDP as the scale variable. At any rate, the other estimates cannot be obtained precisely and, in several cases, are compatible with a share of 1/3. This figure contrasts with official estimates from National Accounts that can provide values of α of up to 0.5. However, as noted by Gollin (2002), National Accounts estimates can severely over estimate this parameter. Thus, in the growth accounting exercise of Section 3 we consider both the capital share of National Accounts as a value in line with the international evidence and our estimate, which is close to 1/3.

There are three other features in Table 3 that are worth mentioning. First, all specifications but one show that even when the residuals are white noise processes, they present significant departures from normality. Second, when considering the longer data set (1810–1995) there is strong evidence of conditional heteroskedasticity, while this evidence is only marginally present in the shorter data set (1960–2000). Finally, the Ramsey reset test shows that non-linearities and/or conditional heteroskedasticity may have been omitted.

Fig. 2 presents non-parametric estimates for the unconditional distribution of the residuals from per capita GDP equations for the two series. In both cases the departures from normality are mainly due to leptokurtic innovations.

Fig. 3 displays the reprojection of the conditional standard deviations obtained from estimating GARCH(1,1) models for per capita GDP using both data sets. In the second panel, the peaks in volatility are associated with the Great Depression, the turmoil of the first years of 1970, and the period of the debt crisis. According to this data set, the volatility has consistently declined from 1985 onwards, while with the first data set, the volatility after 1985 is significantly lower than in the sixties and seventies, but has been increasing.

In summary, this section presents empirical evidence that suggests that the data is consistent with persistent technology shocks, but not consistent with unit roots in per capita and per worker GDP. This in turn supports the case for using exogenous growth models for characterizing the Chilean experience. When analyzing the univariate time series properties of each scale variable, we find that simple AR(2) processes can capture several key regularities of the series and help to dimension the persistence of technology shocks and recover the capital share to be used in the growth accounting exercise. There are however several properties that cannot be accounted for, such as strong departures from normality in the innovations, the possible presence of conditional

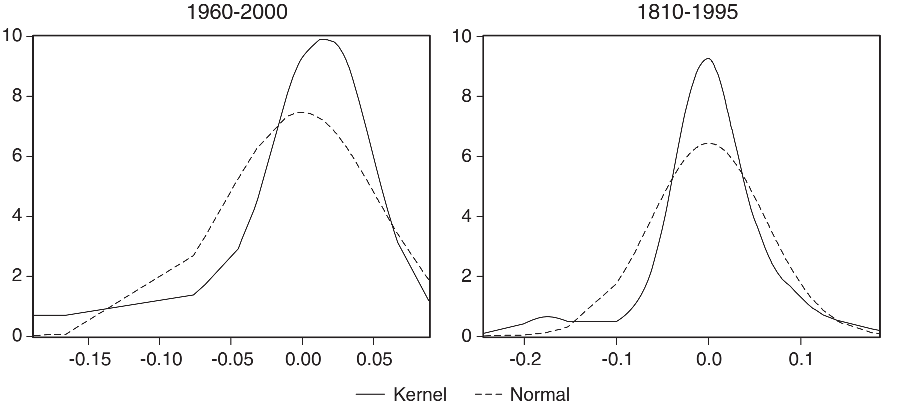

Fig. 2. Departures from normality. Kernel=Kernel estimate of the unconditional distribution of the residual. Normal=normal density with the same mean and variance.

heteroskedasticity and/or omitted non-linearities. Considering the information obtained from the residuals of the univariate representations just described, we will explore which other variables may help us to characterize them.

3. Multivariate analysis

Section 2 provided an analytical framework, used to recover what are supposed to be innovations for the scale variable. If there is relevant information on other variables available in the information set, we can better understand which factors may be behind the important departures from normality and the volatility of the distribution of these residuals. In this section we conduct several econometric exercises to establish quantitative and qualitative guidelines with respect to the type of theoretical model that can be used to understand the growth dynamics of the Chilean economy.[10]

3.1. Informational content of technology shocks

Section 2 motivated a simple time series model for the scale variable. This model was able to capture several characteristics of the series. The model, however, had two features that we try to account for here. First, the model was able to produce white noise residuals, but they appeared to involve important departures from normality and the possible presence of conditional heteroskedasticity. Furthermore, the specification presented some evidence of omitted non-linearities.

Here we evaluate if there is relevant information on other variables not included in the univariate model that are able to account for these features.[11] Among the candidates, we consider variables such as terms of trade, relative prices of equipment and investment goods with respect to consumption goods, and some measures of distortions.

For the residuals to be considered as innovations, they have to be orthogonal to the econometrician's information set. Thus, a simple way to test whether valuable information is

[10] The econometric representations of this section constitute solely quantitative frameworks. They are latter used as guidelines for choosing a theoretical model and its deep parameters.
[11] If that were the case, the model presented in Section 2 can be improved by using this information.

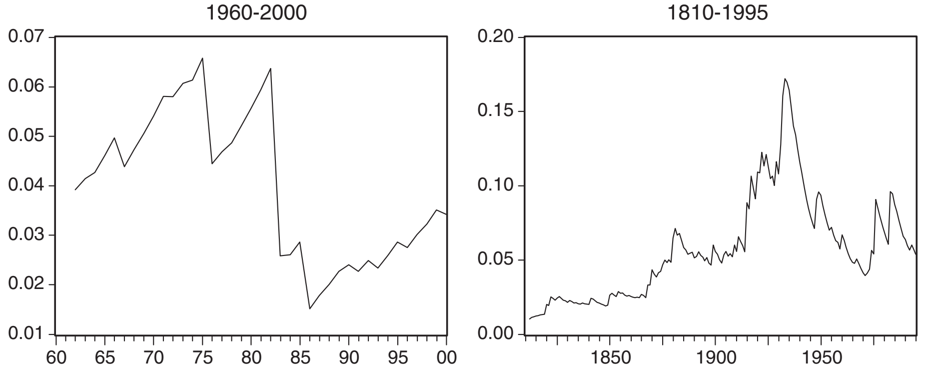

Fig. 3. Projected conditional standard deviation estimated from GARCH(1,1) models.

missing from the univariate model is to evaluate if the residuals obtained in Section 2 can be predicted with any of the variables mentioned above.

Our results indicate that the ratio between fiscal expenditures and GDP (denoted by g) has indeed predictive power over these residuals, always displaying a robust negative association. Thus, while having transitory effects, increased distortions indeed hinder the growth process. Even more instructive, we verify that this measure of distortion is not only relevant to forecast the residual, but also that it statistically precedes (Granger causes) it (first panel of Fig. 4).

Furthermore, given that we were able to recover projections for the conditional heteroskedasticity of the residuals of the univariate representation, we can also evaluate if some of these variables are useful to characterize volatility. In this case, we also find that g is robustly (and positively) associated with our measure of volatility; although in this case, volatility statistically precedes the distortion (second panel of Fig. 4).[12]

In conclusion, even though our specification is consistent with transitory shocks on distortions having transitory effects on the level of GDP, they provide important information that is relevant to characterize the series. In particular, increased distortions tend to precede reductions in GDP innovations and can also be associated with increased conditional volatility. As the innovations can be naturally associated with total factor productivity (TFP), next we evaluate the empirical characteristics of this series.

3.2. From the residuals to TFP

Chumacero and Fuentes (2002) identify a set of variables associated with TFP. The list of variables includes time series for terms of trade (T), variables to capture the evolution of distortionary policies (such as tariffs and fiscal expenditure over GDP), and relative prices of equipment and investment goods with respect to consumption goods (p).[13] Starting from over-

[12] The series of g is used here as an example of a variable that could help to improve the univariate model in a multivariate setting.

[13] The last variables are considered taking into account Greenwood and Jovanovic (2000). Thus, if either of these relative prices appears to be significant, we could subtract their participation from the TFP series given that, in the spirit of that paper, relative price movements would be related to the quality of capital stock and not directly to TFP per se. Nevertheless, a case could be made for associating these relative prices to modifications in distortionary policies; making these prices a combination of increases in the quality of capital and reduced distortions.

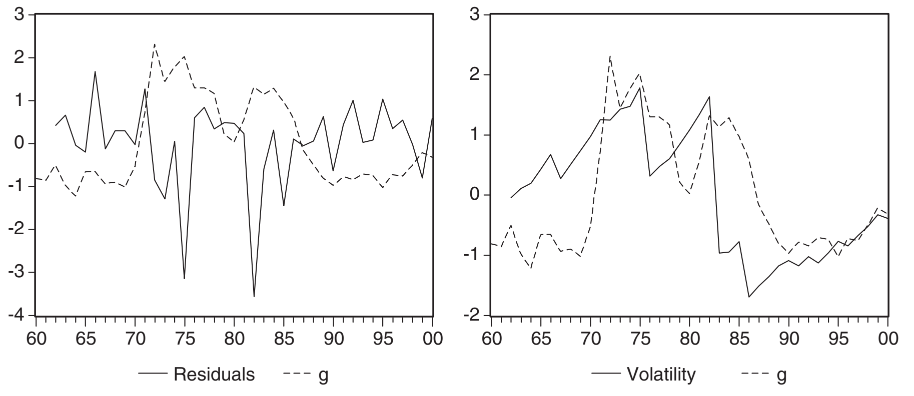

Fig. 4. Residuals, volatility, and distortions (normalized figures).

parameterized models and after careful reductions and reparameterizations the empirical models for the TFP series (in logs) can be expressed as:[14]

$$f_t = a_0 + a_1 t + a_2 f_{t-1} + a_3 f_{t-2} + a_4 p_t + a_5 p_{t-2} + a_6 T_t + a_7 T_{t-1} + a_8 g_{t-1} + e_t. \quad (7)$$

Table 4 shows the result of estimations for four measures of TFP constructed in Chumacero and Fuentes (2002). In all the cases, reductions in the relative price of equipment goods with respect to consumption goods, improvements in the terms of trade, and reductions in the participation of government expenditures in GDP increase TFP. Furthermore, consistent with the model presented in Section 2, TFP can be characterized as trend stationary, i.e., every transitory shock affecting the independent variables would have only transitory effects on TFP levels.

The fact that shocks in the variables included in the regression have transitory effects does not mean that policies are unimportant. It means that permanent changes on policy variables have permanent effects on levels and transitory effects on growth rates. The relative price of equipment to consumption goods is interpreted by Greenwood and Jovanovic (2000) as a proxy for changes in quality of capital stock. Thus, a reduction in this relative price would signal improvements in the quality of capital. However, as mentioned above, this price could also be considered as heavily influenced by policy changes (since Chile is a net importer of machinery and equipment and this price is strongly affected by the trade policies). Another policy variable that appears as important is the government size as a fraction of GDP. Used as a proxy for domestic distortions, its coefficient is negative and significant. It may be argued that this variable cannot be considered as exogenous given that it may have been used to conduct countercyclical policies. However, we find evidence that g is weakly exogenous to the parameter of interest (in Hendry's, 1995 sense); thus conditioning our estimates of TFP on g is a valid econometric practice.

3.3. From TFP to GDP

Given the close relationship between TFP and GDP, the results of Section 3.2 can be extended to evaluate if the same variables are associated with the level of (log) GDP. Despite its

[14] The first round estimates included contemporaneous and past observations of several variables, including measures of macroeconomic stability (inflation rate and real exchange rate), openness to trade (implicit tariff), and capital market development (banking loans over GDP). None of them were statistically significant at conventional levels.

Table 4
Results of TFP regressions

	TFP	TFP	TFPH	TFPH
	$\alpha=0.507$	$\alpha=1/3$	$\alpha=0.507$	$\alpha=1/3$
a_1	0.008 (0.001)	0.010 (0.004)	0.005 (0.001)	0.006 (0.001)
a_2	0.349 (0.135)			
a_3	−0.269 (0.116)	−0.405 (0.182)	−0.501 (0.155)	−0.377 (0.156)
a_4	−0.220 (0.038)	−0.303 (0.033)	−0.259 (0.032)	−0.283 (0.035)
a_5		−0.141 (0.068)	−0.197 (0.061)	−0.210 (0.065)
a_6	0.083 (0.026)	0.082 (0.038)	0.164 (0.033)	0.116 (0.039)
a_7		0.083 (0.030)		0.072 (0.033)
a_8	−0.571 (0.119)	−0.410 (0.139)	−0.852 (0.113)	−0.576 (0.114)
R^2	0.940	0.963	0.913	0.915
DW	2.199	1.895	2.015	1.858
Q	0.115	0.199	0.241	0.793
Q^2	0.741	0.109	0.159	0.467
JB	0.629	0.572	0.852	0.365
Ra	0.174	0.286	0.081	0.167

R^2=adjusted R^2. DW=Durbin-Watson statistic. Q=minimum p-value of the Ljung-Box test for white noise in the residuals. Q^2=minimum p-value of the Ljung-Box test for white noise in the squared residuals. JB=p-value of the Jarque-Bera normality test. Ra=p-value of the Ramsey test. Standard errors in parenthesis.

simplicity, our empirical model is able to provide well-behaved residuals and successfully passes all our specification tests. Applying the same general-to-specific methodology, the final parsimonious form to be estimated is:

$$y_t = b_0 + b_1 t + b_2 y_{t-1} + b_3 p_t + b_4 T_t + b_5 g_t + e_t, \tag{8}$$

where b_i are coefficients to be determined, y is the log of GDP, and all the other variables are as defined in (7).

As Table 5 shows, the results for GDP are similar to the ones obtained for TFP. The relative price of equipment with respect to consumption goods and our proxy for distortions are negatively associated with GDP, while improvements in the terms of trade have positive effects on GDP. Consistent with the empirical implications of Section 2, y is trend stationary. Furthermore, weak exogeneity conditions are satisfied by p, T, and g.

Using the results of Table 5 and obtaining marginal densities for p, T, and g as univariate time series models, we can obtain impulse–response functions of the innovations of these variables on GDP. Then, we use these functions as a metric with which to compare the theoretical model developed in the next section.[15]

4. A dynamic general equilibrium model

The simple empirical model presented on Section 2 was able to replicate key features of Chilean per capita GDP. However we found evidence of omitted non-linearities, departures from normality, and possibly conditional heteroskedasticity in the innovations of this representation (Table 3 and the analysis of Section 3). As shown in the previous section, the relative price of

[15] VAR models were also considered for obtaining the multivariate representation of these variables. Our results do not change significantly if a VAR(1) representation is considered instead of simple univariate representations.

Table 5
Results of GDP regressions

	y
b_1	0.017 (0.005)
b_2	0.615 (0.106)
b_3	−0.163 (0.064)
b_4	0.107 (0.051)
b_5	−0.634 (0.174)
R^2	0.990
DW	1.817
Q	0.262
Q^2	0.150
JB	0.099
Ra	0.257

R^2=adjusted R^2. DW=Durbin-Watson statistic. Q=minimum p-value of the Ljung-Box test for white noise in the residuals. Q^2=minimum p-value of the Ljung-Box test for white noise in the squared residuals. JB=p-value of the Jarque-Bera normality test. Ra=p-value of the Ramsey test. Standard errors in parenthesis.

equipment to consumption goods, our measure of distortions and terms of trade have predictive power with respect to innovations of the univariate model. These variables can also account for variability in our TFP estimates and GDP itself. Thus, the model introduced in Section 2 has several flaws that lead us to question its validity as a good approximation for the Chilean economy.

This section presents a dynamic stochastic general equilibrium model in which we explicitly introduce the theoretical counterparts of p, T, and g. Next, we parameterize our model and choose its deep parameters, to replicate the impulse–response function of shocks to each variable reported in Table 5. Thus, we force our model to replicate not only the first moments, but also the dynamic interactions of the variables behind the growth dynamics.

4.1. The model

The dynamic stochastic general equilibrium to be used has to explicitly consider the introduction of variables that capture the relative price of equipment to consumption goods, terms of trade, and government expenditures dynamics. In order to incorporate the dynamics of p we consider a variant of Greenwood et al. (2000) that introduces technological change specific to new investment goods. Their model, however, does not explicitly consider government expenditures nor allow for terms of trade shocks as it models a closed economy.

4.1.1. The economic environment

The economy is inhabited by a representative agent who maximizes the expected value of lifetime utility as given by

$$\mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t),$$

with

$$u(c_t, l_t) = \theta \ln c_t + (1-\theta)\ln(1-l_t), \quad 0<\theta<1, \tag{9}$$

where c_t and l_t represent period $-t$ consumption of an importable good and labor. There are two goods produced in this economy; good 1 is not consumed domestically, while the second (the importable good) is produced domestically and can be imported from abroad. We assume that the output of the exportable good (y_1) is a fixed endowment for each period t and can be sold abroad at a price T_t (expressed in terms of the importable good). Thus, in our economy, T_t represents terms of trade. The production technology for the importable good is described by

$$y_{2,t} = e^{z_t} k_t^{\alpha} l_t^{1-\alpha}, \tag{10}$$

where α is the compensation for capital as a share of output of sector 2. As before, production in this sector is also affected by a stationary productivity shock z_t that follows an AR(1) process.[16]

The resource constraint of the economy is given by

$$c_t + i_t + g_t = T_t y_1 + y_{2,t}, \tag{11}$$

where investment (i) and government expenditures (g) are expressed in units of consumption of importables.

The capital accumulation equation is

$$k_{t+1} = (1-\delta)k_t + i_t q_t, \tag{12}$$

where, following Greenwood et al. (2000), q denotes the current state of technology for producing investment goods and represents investment specific technological change. Given that i is expressed in consumption units, q determines the amount of investment in efficiency units that can be purchased for one unit of consumption. Thus, a higher realization of q directly affects the stock of new capital that will be active in production next period. We assume that ln q follows an AR(1) process.

As discussed in Greenwood et al. (2000) the relative price for an efficiency unit of newly produced capital, using consumption of the importable good as numeraire, is the inverse of q. Thus, $1/q$ is our theoretical counterpart to p of Section 3.

Finally, the government of this economy levies taxes on labor and capital income at the rates τ_l and τ_k. Part of the revenue raised by the government in each period is rebated back to agents in the form of lump-sum transfer payments (F), and part of it is “lost” in government expenditures that do not provide services to the representative agent. The government’s budget constraint is then

$$F_t + g_t = \tau_k r_t k_t + \tau_1 w_t l_t,$$

where r and w represent the market returns for the services provided by capital and labor. Finally, we also assume that ln g follows an AR(1) process.

4.1.2. Competitive equilibrium

Here we briefly describe the competitive equilibrium of this economy, noting that the aggregate state of the world is given by $s=(k, T, z, q, g)$.

4.1.2.1. The household. The dynamic program problem facing the representative household is

$$V(s) = \max_{c,k',l} \{u(c,l) + \beta \mathcal{E}[V(s')]\}, \tag{13}$$

[16] We could also include labor-augmenting exogenous technological progress as in Section 2. This would only be needed for comparing the results of the model with coefficient b_1 of Table 5. In that case, one can always calibrate the technological progress parameter to exactly match it.

subject to

$$c + k'/q = (1-\tau_k)r_k + (1+\tau_l)wl + (1-\delta)k/q + F + \pi_1 + \pi_2$$

and $s' = S(s)$. Here, π_j denotes the profits of sector j.

4.1.2.2. The firms. The maximization problem of firms producing the importable good is

$$\max_{\tilde{k},\tilde{l}} \left[\pi_2 = e^z \tilde{k}^\alpha \tilde{l}^{1-\alpha} - r\tilde{k} - w\tilde{l}\right], \tag{14}$$

where due to the constant-returns-to-scale assumption, firms make zero profits in each period.

The firm that produces the exportable good does not hire inputs to produce y_1. Thus, profits expressed in terms of the importable good are:

$$\pi_1 = Ty_1.$$

4.1.2.3. Definition of equilibrium. A competitive equilibrium is a set of allocation rules $c = C(s)$, $k' = K(s)$ and $l = L(s)$, and a set of pricing functions $r = R(s)$ and $w = W(s)$, such that

- Households solve the problem (13), taking as given s and the form of the functions $W(s)$, $R(s)$ and $S(s)$, with the equilibrium solution to this problem satisfying $c = C(s)$, $k' = K(s)$ and $l = L(s)$.
- Firms of the importable sector solve the problem (14), taking as given s and the form of the functions $W(s)$, $R(s)$ and $S(s)$, with the equilibrium solution to this problem satisfying $\tilde{k} = k$, $\tilde{l} = l$, $k' = K(s)$ and $l = L(s)$.
- The economy-wide resource constraint (11) holds each period.

4.2. Calibration and results

Once the model is specified, we fix the deep parameters that describe preferences and technology. Some of these parameters are calibrated to match several first moments of relevant variables. Such is the case of θ, which is set to reproduce a steady state participation rate of l equal to 0.35. The depreciation rate is calibrated to match the average investment rate in steady state. Finally, the constants for the production function of sector 2, p, g and T, are set to match the first moments of their empirical counterparts.

The persistence and volatility of p, T and g are made consistent with AR(1) estimates obtained with observed data of the relative price of equipment with respect to investment, terms of trade, and government expenditures (in this case we include a time trend that is absent in the model).[17] Finally, the persistence and volatility of the technology shocks are estimated by simulation to match as closely as possible the results of Table 5. The base configuration of parameters is presented in Table 6.

Once the values of the parameters are set, we solve the model, simulate artificial realizations from it, and compare the impulse–response functions of several shocks. According to our specification, the policy functions of the control variables cannot be obtained analytically and we have to resort to numerical methods. We use a second-order approximation to the policy function using perturbation methods. This method has the advantage of explicitly incorporating in the

[17] The tax rates τ_k and τ_l are set at 25%.

Table 6
Parameters

Preference
$\beta=0.98,\ \theta=0.43$
Technology
$\alpha=1/3,\ \delta=0.06$
Shocks
$\rho_z=0.73,\ \sigma_z=0.04,\ \rho_{\mathrm{p}}=0.844,\ \sigma_{\mathrm{p}}=0.1$
$\rho_T=0.892,\ \sigma_T=0.14,\ \rho_{\mathrm{g}}=0.895,\ \sigma_{\mathrm{g}}=0.024$

decision rule the volatility of shocks and has been proven superior to traditional linear–quadratic approximations (Schmitt-Grohé and Uribe, 2004).

Fig. 5 presents the results of comparing the impulse–response functions of shocks on the innovations of the equation that describes y in (8), and innovations in p, T, and g from their univariate representations. Along with the impulse–response functions and the 95% confidence intervals obtained from the data, the figure shows the impulse–response function obtained from a long simulation of the model. Our results evidence an almost perfect match between the impulse–response functions of the model and the data, and suggest that technology shocks do not have to be as persistent as needed in Section 3.

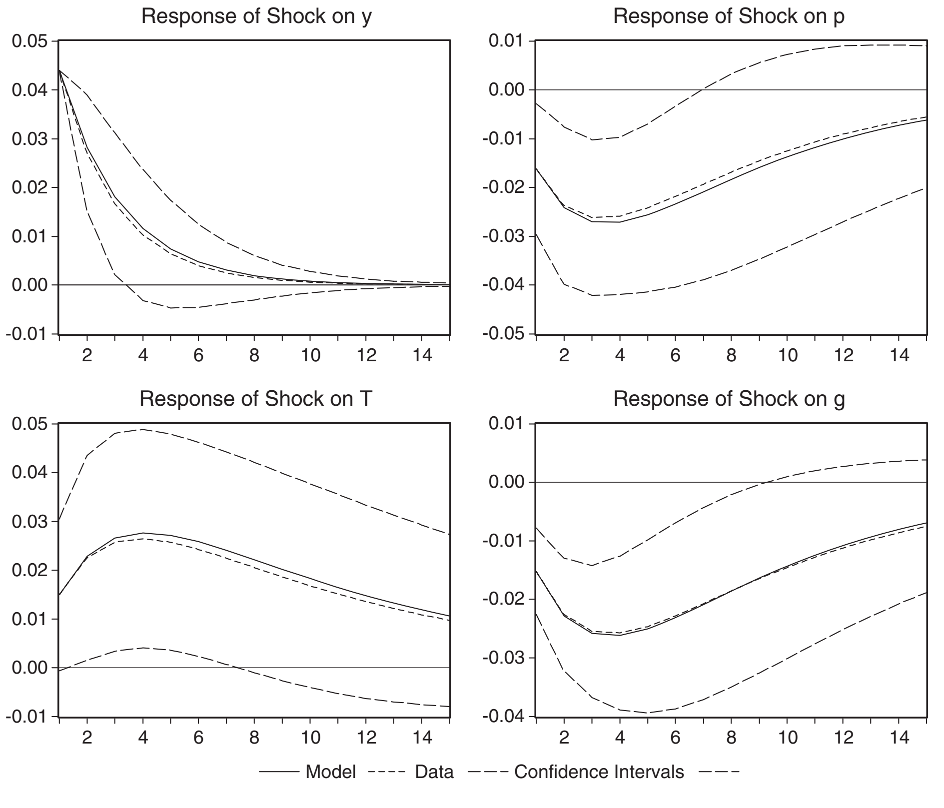

Fig. 5. Impulse–response functions: model and reality.

Analyzing the results of the impulse–response functions, we observe that a positive transitory shock of 10% on the relative price of equipment with respect to investment has a negative (but transitory) effect on GDP of almost 3% after 3 years. On the other hand, a positive shock of 14% in terms of trade has a positive effect on GDP that on average reaches its peak of almost 3% after 3 years. Finally, a transitory increase of 2.4% on the share of government expenditures over GDP has an exact, offsetting effect on GDP (decline of 2.4%) after 3 years.

5. Concluding remarks

This study provides a theoretical and empirical characterization of the Chilean economy over the past 40 years. This endeavour is challenging because, when compared to other Latin American economies, Chile is more sensitive to major external shocks but also tends to recover faster from them.

Using two different data sets (for the periods 1810–1995 and 1960–2000), we find that both per capita and per worker GDP can be better characterized as trend-stationary random variables. This evidence suggests that exogenous and not endogenous growth models are better suited to match the data.

Based on this observation, we construct a simple exogenous growth model that roughly captures key features of the univariate representation for per capita and per worker GDP. This representation can also be used to recover parameters such as the capital share of GDP and the persistence of technology shocks. Our best estimates suggest that the first of these parameters is closer to 1/3 (the share that is often used in international literature), while technology shocks are persistent, with an autocorrelation coefficient close to 0.9.

As important variables were left out of the analysis, the simple univariate model is unable to capture all the key features of the dynamic behavior of GDP. One of the usual suspects is a measure of distortions. Our results suggest that exogenous technological shocks, terms of trade, the relative price of equipment to consumption and distortions account for a good deal of the evolution of GDP and TFP.[18] Moreover we find that government expenditure over GDP not only offsets the positive effects of the improved quality of capital goods, but also that it negatively affects the volatility of the Solow residuals.

These empirical findings motivate a model that includes the theoretical counterparts of distortions, terms of trade, and the quality of capital stock. A calibrated model is able to replicate very closely the impulse–response functions of several shocks on the trajectory of GDP. In particular, we find that a 1% transitory increase in the share of government expenditures on GDP has a detrimental effect on GDP of the same order of magnitude (a decrease of 1% in GDP) by the third year. Transitory increases of 1% in the terms of trade or decreases in the relative price of investment goods have positive and temporary effects on GDP, which, however, are not as important as the quantitative effects of increased distortions.

In summary, sound economic policies matter. External shocks are also important, but they cannot be controlled by the authority. On the other hand distortionary policy can help to explain several of the episodes of mediocre growth that Chile experienced.

[18] Gallego and Loayza (2002) attribute the good performance of the Chilean economy in the last period to improvements in the political system, public infrastructure and policy complementarities, beyond the traditional variables included in the cross-country regressions. Our analysis suggests that the solid growth performance of this period is due to a combination of good policies and good luck.

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