Banco Central de Chile
Documentos de Trabajo

Central Bank of Chile
Working Papers

N° 419

Junio 2007

MEASURING TFP: A LATENT VARIABLE APPROACH

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BANCO CENTRAL DE CHILE

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Documento de Trabajo
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MEASURING TFP: A LATENT VARIABLE APPROACH

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Resumen

A pesar del importante rol que la productividad total de factores (PTF) ha jugado en la literatura de crecimiento, se han hecho sólo algunos intentos por cambiar la metodología utilizada para su estimación. Este artículo propone una metodología basada en el modelo espacio-estado para estimar la PTF y sus determinantes. Con esta metodología es posible reducir "la medida de nuestra ignorancia". Como subproducto, la estimación entrega la participación de la remuneración del capital en el producto y la tasa de crecimiento de largo plazo. Aplicado al caso de Chile, la estimación muestra una participación del capital cercana a 0.5 y una tasa de crecimiento de largo plazo de la PTF cercana a 1%. Para este caso, la acumulación de capital tiende a explicar una mayor proporción de la tasa en los períodos de rápido crecimiento bajo la estimación econométrica, comparado con la metodología tradicional de contabilidad de crecimiento.

Abstract

Despite the important role that total factor productivity (TFP) has played in growth literature, few attempts have been made to change the methodology to estimate it. This paper proposes a methodology based on state–space model to estimate TFP and its determinants. With this methodology it is possible to reduce the measurement of our ignorance. As a by-product, this estimation yields the capital share in output and the long-term growth rate. When applied to Chile, the estimation shows a capital share around 0.5 and long term growth of TFP around 1%. Capital accumulation tends to explain more the growth rate in the fast growth periods under the econometric estimation compared to the traditional growth accounting methodology.

We would like to thank Klaus Schmidt-Hebbel, Raimundo Soto and the participants to the seminar "Cycles and Economic Growth in Chile" organized by the Central Bank of Chile. The usual disclaimer applies.

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1. Introduction

Total factor productivity has played a central role in the discussion of empirical growth. Since Solow (1957), many studies have tried to measure the contribution of production factors and technology to economic growth. Despite criticism, this methodology has experienced a revival, in the words of Klenow and Rodriguez-Clare (1997), and it has been widely used in the past fifteen years, not only to decompose the growth rate of output per worker, but also to explain cross-country differences in income per capita.

Although the growth accounting methodology does not provide an explanation for economic activity, it is a simple first step in the search for the sources of growth. This line of research has provided strong evidence that total factor productivity (TFP) growth is an important source of overall growth (Easterly and Levine, 2001; Bosworth and Collins, 2003). Others have used this methodology to show that the TFP level can explain a big deal of the cross-country differences in per capita GDP (e.g., Mankiw, Romer and Weil, 1992; Hall and Jones, 1999).

But what is TFP, after all? The first idea that comes to mind is technological progress.[1] This concept rests on nice models of endogenous technological change that explain growth on the grounds of endogenous technological progress (Romer, 1990; Aghion and Howitt, 1998). However, negative TFP growth for several years cannot originate in negative technological progress. Therefore, many other explanations have come up, such as cost reduction or efficiency gains (Harberger, 1988), externalities and increasing returns (Lucas, 1988; Romer, 1986), or policies favoring the adoption of new technologies (Parente and Prescott, 1994; Prescott, 1997).

The importance of this methodology in the empirical growth literature is undeniable; however, there are a couple of caveats. First, TFP may be hiding measurement errors for factors of production. The growth rate of TFP is measured as a residual calculated as the difference between the growth rate of output and the combined growth rates of

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[1] Another interpretation for TFP comes from the real business cycle literature, where this parameter is associated to technological shocks that drive the cycle. Nevertheless, they do not take growth accounting to estimate TFP; they rather assume that this variable has a trend plus stationary shocks.

capital and labor weighted by their respective output-input elasticities. Therefore, the methodology imposes the need for an accurate measure of output, capital, labor and the capital and labor shares[2] in total output. If improvements in the quality of labor and capital are not included, then the contribution of TFP will be overestimated. Second, TFP and production factors will be moving together. For instance, TFP will increase marginal productivity of capital, affecting capital accumulation. In this case, the contribution of TFP to growth will be understated, while the contribution of capital accumulation will be overestimated.

Given the importance of this variable for understanding growth, the efforts in the literature have concentrated on finding betters ways to measure the factors of production, including corrections for quality of factors (Jorgenson and Griliches, 1967; Greenwood and Jovanovic, 2000) and factor utilization (Costello, 1993), better measures of labor share (Gollin, 2002), and the relationship between factor accumulation and TFP (Klenow and Rodriguez-Clare, 1997). However, TFP is still estimated as a residual.

This paper works with a natural methodology to estimate TFP. As with any unobservable, a latent variable approach seems appropriate. The state–space model used here allows for the TFP growth rate to vary over time, and for estimating the effect of several of its determinants proposed in the literature. Thus, capital accumulation, labor, TFP growth and a residual may explain the growth rate of GDP, which is the “true” measure of our ignorance.

Section 2 presents the empirical model and the methodology, with a brief discussion of the determinants, which motivates the empirical approach. This model is applied to Chilean time series data that is readily available. Section 3 presents the results and compares them with previous studies. Section 4 concludes.

2. Methodology

This section explains the alternative methodologies to estimate TFP. In the first place, it presents the basic growth accounting approach, followed by some examples for the

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[2] If the production function is homogenous of degree 1, the output-input elasticity corresponds to the share of each factor cost in total revenue. Under the same assumption, capital share will be equal to 1 minus labor share.

econometric estimation of TFP in the existing literature. It also proposes two possible specifications for the state-space model. TFP is modeled first as a pure AR process—like in the RBC literature—and, second, as a function of exogenous variables in addition to lags of TFP.

2.1 Growth accounting

Traditionally, growth accounting started with an aggregate neoclassical production function exhibiting positive and decreasing marginal productivity to all factors, constant returns to scale and satisfied Inada's conditions. Let the production function be written as

$$Y_t = F(K_t, h_t L_t, Z_t) \ ,$$

where *Y* represents total output, *K* physical capital, *L* raw labor, *h* human capital, and *Z* a TFP index. In this setting, *Z* could be interpreted as another factor of production that in the neoclassical framework is not remunerated. The traditional decomposition can be written as

$$\Delta \ln Y_t = \alpha_t \Delta \ln K_t + (1-\alpha_t) \Delta \ln h_t L_t + \Delta \ln Z_t \, , \qquad (1)$$

where α—under perfect competition and profit maximization—is the share of capital cost in total revenues. Note that if labor is not corrected by human capital, the residual becomes the change in *Z* plus the contribution of human capital.

In the case of a Cobb-Douglas production function, we can write the neoclassical production function as

$$y_t = Z_t k_t^{\alpha} = e^{z_t} (1+\gamma)^t k_t^{\alpha} \ , \qquad (2)$$

where *y* and *k* represent output and capital per worker (adjusted by human capital), respectively. Variable *Z* is modeled as a trend stationary variable that could be associated directly to a technological level plus a technological shock, z_t, which could be modeled as an AR(q) process. However, in equation (1) the "Solow residual" $\Delta \ln Z$ will include technological change not involved in either capital or labor, the efficiency gains or losses that have not affected the marginal productivity of capital or labor, and the path of these production factors. In this setting, TFP is explained by a deterministic trend that captures the technological change plus other variables capturing distortions and supply shocks, for example terms of trade shocks in open economies. If that is the case, we need to modify equation (2) to include those determinants.

Given that usually capital is not corrected for quality, the residual should include a measure of capital quality. However, Greenwood and Jovanovic (2000) suggest that the price of investment goods relative to consumption goods could be used as a proxy for quality of capital.[3] Their idea is that technological progress is embodied in the latest vintages of capital. So the observed decline in the price of capital goods relative to consumption goods in the postwar period is consistent with the idea of obsolescence of old capital due to the arrival of a new generation. If this technological change (which is specific to investment goods) is not captured in the measurement of capital, it will be implicitly included in the variation of TFP.

2.2 Econometric Estimation of TFP

But, why estimate TFP considering a deterministic aggregate production function as in the growth accounting approach? The neoclassical production function represents the maximum output that could be obtained from a given combination of inputs; however, at the aggregate level there could be several omitted "factors" that would make it impossible to achieve the production frontier. Examples of these excluded variables are adjustment costs for intersectoral reallocation of resources and diffusion of technology. The effect of these potentially omitted variables must be captured then by a stochastic disturbance term in the aggregate production function.

Starting from equation (1), and assuming that the TFP index *Z* takes the form of an exponential time trend, the stochastic function for growth in product per worker is given by

$$\Delta \ln y_t = \gamma + \alpha \Delta \ln k_t + \varepsilon_t \ ,$$

where the constant term stands for the average TFP growth rate. The main problem with this approach is that it does not allow for the estimation of TFP growth from year to

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[3] Chumacero and Fuentes (2006) find that this variable is positively correlated with TFP in the case of Chile. In the next section we extend their database to estimate TFP and to compare the results.

year, making it less attractive in terms of growth policy analysis or of the identification of the exogenous determinants for total factor productivity.

From a statistical standpoint, in order to allow for a changing productivity growth rate, Harvey *et al.* (1986) consider a stochastic trend for productivity, modeled as a structural time series, where the constant and slope of the trend are allowed to change over time, governed by a Markovian process. With a similar approach, French (2001) implements several alternative trend-cycle decomposition methods to extract the trend in TFP from the Solow residual, including the possibility of switching regimes to capture discrete changes in the estimated trend growth of TFP.

On the other hand, always considering productivity and technology as latent variables, several studies apply the Kalman filter to estimate the rate and direction of change in technology at the micro level. Examples are Slade (1989) for the US primary-metals industry, and Esposti and Pierani (2000) for Italian agriculture, where both use a state-space representation derived from a factor-demand system. However, the former decomposes TFP as a stochastic trend plus cyclical components, allowing for the correction of TFP estimates for measurement errors that induce procyclical bias.[4] In the latter paper, TFP growth is approximated as a stochastic trend, and the non-conventional inputs generating technical change are formally specified (R&D, human capital accumulation, spillover effects, etc.). In a related approach, Chen and Zadrozny (2001) consider—for US manufacturing industries—capital and TFP as latent variables determined as joint endogenous processes. Their method implies specifying a dynamic economic model for a representative firm[5] in the industry, and then obtaining Kalman-smoothed estimates of unobserved capital and TFP for the sample period.

Another possibility is the one followed by Fuentes *et al.* (2006) and Chumacero and Fuentes (2006), where TFP (in log) is computed by means of growth accounting in a first step, and then a regression of TFP on exogenous variables and lags of TFP is estimated in a second step. While intuitively appealing, a wrong estimate of TFP from the first step could invalidate the statistical results and conclusions of the second step regression.

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[4] This will be the case when trend and cycle go in opposite directions, partially offsetting one another.

[5] Solving a dynamic optimization problem, where adjustment costs on capital and technology are derived from a parameterized production function.

2.3 A State–space model for TFP

The state-space model is a useful tool to represent a dynamic system involving unobservable variables.[6] However, as far as we know, this method has never been applied to the simultaneous estimation of the GDP-TFP system.

Let the pure AR(q) linear Gaussian state-space representation be defined as follows.

Signal Equation:

$$\Delta \ln y_t = \Delta \ln Z_t + \alpha \Delta \ln k_t + \varepsilon_t \tag{3}$$

State Equation:

$$A(L)\Delta \ln Z_t = \gamma + u_t \tag{4}$$

and, white noise disturbances, uncorrelated with each other:

$$\begin{pmatrix} \varepsilon_t \\ u_t \end{pmatrix} \sim NID\left[\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\varepsilon^2 & 0 \\ 0 & \sigma_u^2 \end{pmatrix}\right] \tag{5}$$

On the other hand, if we consider that the TFP growth is also determined by exogenous variables, then we have

State Equation:

$$A(L)\Delta \ln Z_t = \gamma + \beta\,'(\Delta \ln X_t) + u_t \tag{6}$$

with A(L) being a q-order polynomial on the lag operator L, and X a matrix of exogenous variables determining the TFP growth rate.

The Kalman Filter is an updating algorithm for the linear projection of the state-vector (latent variables) based on observable variables that allow writing down—under the normality assumption—the likelihood function of the model based on the prediction error decomposition. Once the likelihood function is obtained, the coefficients are estimated by numerical optimization methods. In addition, a smoothed state-vector estimate for the full sample can be obtained if the values of the latent variables are of interest and permit a structural interpretation.

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[6] See Durbin and Koopman (2001) and Hamilton (1994) for discussions of methods and applications.

Initializing the filter requires meaningful startup conditions (parameter values) to achieve convergence. This is not a minor issue, given the potentially high nonlinearity in the likelihood function for the state-space representation of the GDP-TFP model. A possible set of initial conditions can be extracted from a regression of the Solow residual (estimated using growth accounting) on exogenous or predetermined variables (all as rates of change).

In order to see the results of this methodology, we apply it to Chilean time series data used by Chumacero and Fuentes (2006). They analyze, from the empirical perspective, which variables are correlated with TFP and per capita GDP for Chile. Then they develop a stylized stochastic general equilibrium model that captures the main characteristics of this economy and simulate impulse-response functions that match the statistical findings of the empirical analysis.

Their model assumes an economy inhabited by an infinite lived representative agent that consumes leisure and an importable good. The production side is composed by two sectors, one that produces the importable good (using a Cobb-Douglas production function with a stationary productivity shock) and the other (an endowment sector) that produces the exportable good. The exportable good can be sold abroad where the terms of trade are given.

The function for capital accumulation includes the features discussed in Greenwod and Jovanovic (2000), where the price of capital good relative to consumption good is different from 1 and can vary over time. The capital accumulation equation is:

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

In this formulation, p_t denotes the current state of the technology for producing investment goods and represents investment-specific technological change. In other words, p represents the amount of investment in efficiency units that can be purchased with one unit of consumption. This variable was proxied in the empirical part by the relative price of the investment good to the price of the consumption good.

In their economy there is a government that levies taxes on capital and labor income and spends them as lump sum transfers to the private sector plus a waste. The government’s budget is always in equilibrium. The model does not have an analytical solution.

Nevertheless, we can say that it features open economy, government that suffers losses in its expenditures and technological improvement, à la Greenwood and Jovanovic, makes per capita GDP and TFP a function of terms of trade, government consumption (as a proxy for distortions), and the relative price of capital goods to consumption goods (*p*). Additionally, we control in the empirical part for macroeconomic stability ($\inf \equiv \pi_t / (1 + \pi_t)$, where π_t stands for inflation rate).

The next section estimates both systems, the pure AR(q) model composed by equations (3) and (4) and the augmented model described by (3) and (6), using the Kalman Filter algorithm.

3. Estimation Results

The sample includes annual observations from 1960 to 2005, for the Chilean economy. This database is an extension of the one used by Fuentes *et al.* (2006), and by Chumacero and Fuentes (2006).

Table 1 presents the estimated coefficients for the two alternative state-space representations proposed above. The likelihood function is maximized by using the Berndt-Hall-Hall-Hausman (BHHH) algorithm. Starting values for the parameters come from the regression of the Solow residual on the independent variables considered for each state-space model. In addition, we compare growth accounting and Kalman filter estimates for the augmented model, as well as the estimates from the two alternative state-space specifications, for TFP growth and level index.

TABLE 1 HERE

From equation (3), we obtain an estimate for the capital-output elasticity shown in the first row of table 1. The coefficient obtained is 0.46 for the autoregressive model, and 0.52 for the augmented model. These values seem a bit high compared with Gollin (2002)'s and those used in theoretical models. However, they are consistent with the share of capital in total income in the Chilean National Accounts (0.51) and with the one used by Elias (1990) for the case of Chile (0.52).

The constant reported in table 1 corresponds to an estimate of the parameter γ of state equation (4). Note that $\gamma/A(L)$ is the estimator of the long-term growth rate. The values are similar for the AR(q) model (0.7%) and the augmented model (0.8%), and both are similar to those estimated using the growth accounting methodology for Chile.[7]

The coefficients of the explanatory variables have the expected signs. The long-run effect of the terms of trade on growth rate is positive, while our proxy for distortions (government consumption) has a negative effect. On the other hand, the cumulative effect of macroeconomic stability and relative price of investment to consumption are both statistically equal to zero.

Figure 1 depicts the growth rate of actual GDP per worker and the series implied from the Kalman Filter estimate. The smoothed series closely follow the actual series, but having difficulties to match the extreme realizations of the growth rate. Given that TFP is not observable, figure 2 compares the implied growth rate from the state-space model with the one estimated by growth accounting. Although both series move closely together, they depart from each other at all the spikes in the series for TFP growth.

FIGURE 1 HERE

FIGURE 2 HERE

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[7] Fuentes *et al.* (2006) find a growth rate around 0.7% for the 1960-2005 period.

Figure 3 presents the level of TFP constructed using the growth rate estimated from the Solow residual and from the fitted value of the Kalman filter (smoothed). Both series tend to move together, but with some important differences. Compared to growth accounting TFP, the smoothed series goes below in the 1960s and 70s, above from the mid 1980s to the mid 90s and then below again. As our series is smoother, it doesn't exhibit spikes like the one in 1974, where the TFP was declining and the Solow residual-based series shows a spike that has little or no justification. According to the growth accounting methodology, TFP fell very hard in the 1982-83 crisis and did not begin to recover until 1987, while with the new estimation the recovery seems to have started slowly in 1984, right after the crisis.

FIGURE 3 HERE

Figures 4 and 5 present the comparison between the series estimated under the AR(q) model and the augmented model. Given the structure of the lags in the AR(q) model, the growth rate and the level of TFP have a peculiar evolution over time. The growth rates from the AR(q) model fluctuate a lot less and the level of the TFP goes always above the one obtained with the augmented model. The series from the AR(q) model does not follow the cycle and could be interpreted as a kind of technological progress plus a technology shock. On the other hand, the series from the augmented model follows the cycle better, since it includes variables like terms of trade that are very procyclical.

FIGURE 4 HERE

FIGURE 5 HERE

Tables 2 and 3 summarize the descriptive statistics of all the measures and the correlation for the growth rate. The mean and the median of the growth rate obtained with the Solow residual are higher than the other two, but also more volatile. Nevertheless, the variation coefficient of the Solow residual and the smoothed-augmented model are very similar, while the smoothed-AR(q) is lower.

TABLE 2 HERE

Table 3 shows the correlation coefficient for all possible pairs of series. It is interesting to note the high correlation between the growth rate estimated by the Solow residual and the smoothed-augmented model, compared to the correlation between these two series and the AR(q) series. This means that TFP is capturing the effect of those variables included in the state-space model. The estimation of TFP using the smoothed-AR(q) will be a misspecified model.

TABLE 3 HERE

Tables 4 and 5 present the decomposition of GDP growth, identifying the contribution of capital, labor, and total factor productivity implied by growth accounting versus the state-space augmented model proposed above.

It is important to mention that the reasons for the differences in alternative decompositions are twofold. First, the estimated elasticity of capital obtained from the Kalman filter (0.52) is larger than the one used for computing the Solow residual (0.4). The other relevant difference is that the state-space approach allows disentangling the TFP growth from the estimation residual.[8] With a larger estimated elasticity of capital, the contribution of this production factor to total growth becomes more important in relative terms. Moreover, the state-space model, by separating TFP growth from the residual term, provides an additional "source" of growth, which is really the unexplained part of growth. We could say that this methodology is reducing the "measurement of our ignorance."

Under the Kalman filter estimation, periods of high growth are also characterized by significant contributions from both capital and TFP. However, the contribution from the "ignorance factor" is also significant during those periods.

TABLE 4 HERE

TABLE 5 HERE

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[8] The use of this approach for estimating TFP is, for the authors, the main contribution of this paper.

4. Concluding remarks

Growth accounting methodology allows estimating TFP as a residual from the difference of growth in output and growth in inputs. The problem with this approach is that TFP includes omitted explanatory variables of growth, measurement error in the production factors, etc. This paper proposes the use of a state-space model to estimate the level of TFP, its long-term growth rate and other relevant parameters like the capital-output elasticity. The advantage of the proposed methodology is the depuration of TFP between observed factors and a “true” measure of our ignorance.

The methodology is applied to Chilean data available from previous studies. We find that capital share in total income is around 0.5, which is consistent with the National Accounts value. The decomposition of growth under this methodology—compared to the growth accounting results—shows that the importance of capital in explaining growth increases, the importance of TFP declines and a small part of the growth rate is due to an additional factor, which is the measure of our ignorance.

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Table 1: Results of Kalman Filter Estimation

	AR(q)	Augmented
Capital per Worker	0.463 (0.139)	0.520 (0.054)
Constant	0.002 (0.004)	0.011 (0.028)
$\Delta \ln Z_{t-1}$	0.483 (0.230)	0.247 (0.089)
$\Delta \ln Z_{t-2}$	-0.635 (0.118)	-0.667 (0.081)
$\Delta \ln Z_{t-3}$	0.855 (0.189)	
$\Delta \ln T_t$		0.179 (0.012)
$\Delta \ln T_{t-1}$		0.093 (0.030)
$\Delta \ln g_{t-1}$		-0.108 (0.044)
$\Delta \ln \inf_t$		-0.013 (0.009)
$\Delta \ln \inf_{t-1}$		0.020 (0.009)
$\Delta \ln p_{t-1}$		-0.522 (0.044)
$\Delta \ln p_{t-2}$		0.524 (0.016)

Note: Standard errors in parenthesis. The long-run coefficients for Δln(*inf*) and Δln(*p*) are not statistically significant.

Table 2: Descriptive Statistics for Estimated TFP Growth

	Solow Residual	Smoothed-Augmented	Smoothed-AR(q)
Mean	0.0086	0.0061	0.0078
Median	0.0135	0.0087	0.0075
Maximum	0.1008	0.0598	0.0372
Minimum	-0.1452	-0.0707	-0.0237
Std. dev.	0.0468	0.0345	0.0210
Variation coefficient	5.4419	5.6557	2.6923

Table 3: Correlation Matrix for Estimated TFP Growth

	Solow Residual	Smoothed-Augmented	Smoothed-AR(q)
Solow Residual	1	0.8574	0.5667
Smoothed-Augmented		1	0.4627
Smoothed-AR(q)			1

Table 4: Factor Contribution to Total Growth

	Growth Accounting				Augmented			
	GDP growth	Share of K	Share of Lh	Share of TFP	Share of K	Share of Lh	Share of TFP	Share of Rest
1963-2005	3.87%	1.47%	1.53%	0.86%	1.92%	1.23%	0.62%	0.11%

1963-1973	3.07%	1.46%	1.36%	0.25%	1.90%	1.09%	0.10%	-0.02%
1974-1989	2.90%	0.92%	2.49%	-0.51%	1.20%	1.99%	-0.11%	-0.18%
1990-2005	5.39%	2.04%	0.70%	2.66%	2.64%	0.56%	1.70%	0.49%
1990-1997	7.35%	2.12%	1.69%	3.54%	2.76%	1.35%	2.58%	0.66%
1998-2005	3.43%	1.95%	-0.28%	1.77%	2.53%	-0.23%	0.82%	0.31%
2003-2005	5.05%	1.93%	-0.30%	3.42%	2.51%	-0.24%	2.19%	0.60%

Table 5: Factor Contribution to Total Growth (in percent)

		Growth Accounting			Augmented			
	GDP growth	Share of K	Share of Lh	Share of TFP	Share of K	Share of Lh	Share of TFP	Share of Rest
1963-2005	3.87%	38.1	39.6	22.3	49.5	31.7	15.9	2.9
1963-1973	3.07%	47.7	44.2	8.1	61.9	35.4	3.2	-0.5
1974-1989	2.90%	31.8	85.8	-17.6	41.3	68.7	-3.9	-6.1
1990-2005	5.39%	37.7	13.0	49.3	49.0	10.4	31.5	9.1
1990-1997	7.35%	28.9	22.9	48.2	37.5	18.3	35.1	9.0
1998-2005	3.43%	56.7	-8.2	51.5	73.7	-6.6	23.8	9.1
2003-2005	5.05%	38.2	-5.9	67.7	49.6	-4.7	43.3	11.8

Figure 1: Growth of GDP per worker (Actual vs. Smoothed-Augmented)

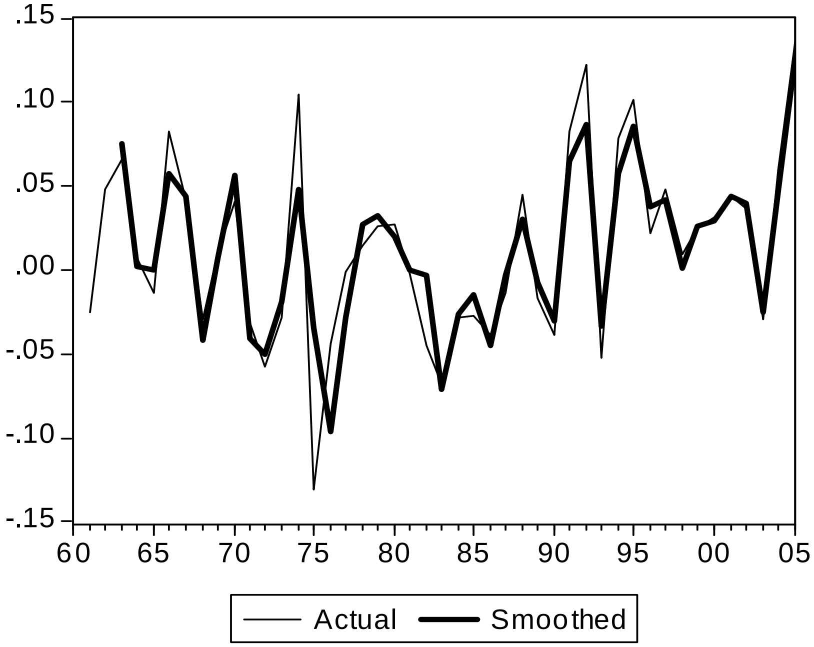


Figure 2: Estimated TFP Growth (Growth Accounting vs. Smoothed-Augmented)

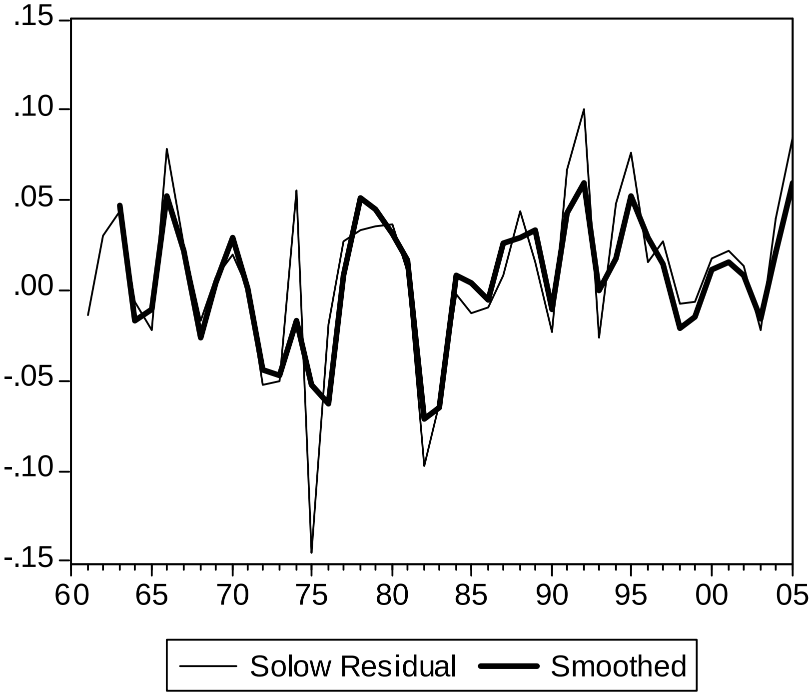


Figure 3: Estimated TFP Index (Growth Accounting vs. Smoothed-Augmented)

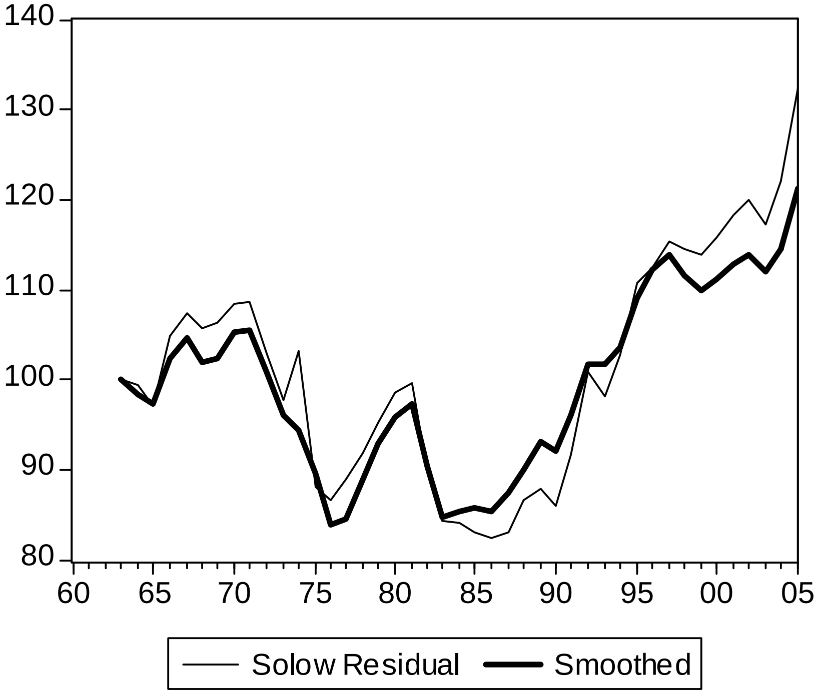


Figure 4: Estimated TFP Growth (Smoothed-AR(q) vs. Smoothed-Augmented)

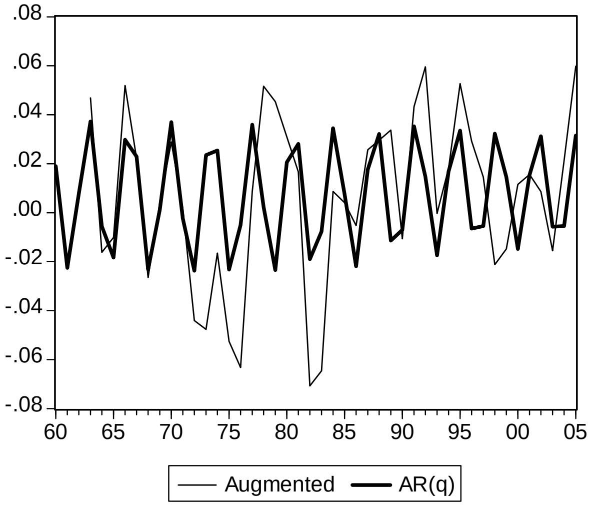
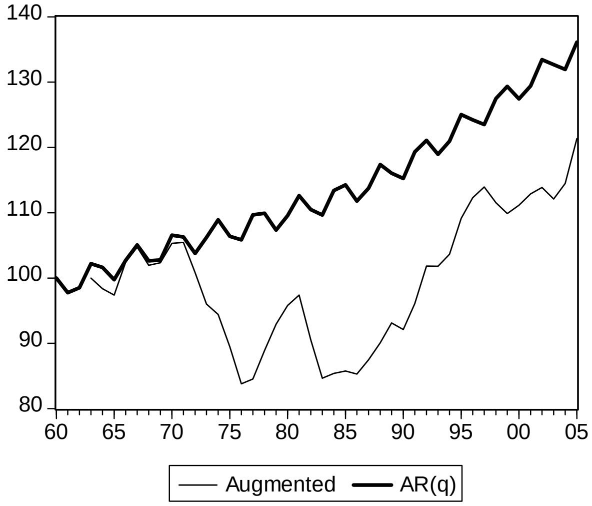


Figure 5: Estimated TFP Index (Smoothed-AR(q) vs. Smoothed-Augmented)



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