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Estimation of a Time Varying Natural Interest Rate for Peru

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Abstract

Following the approach of Mésonnier and Renne (2007), we estimate a Natural Rate of Interest (NRI) using quarterly Peruvian data for the period 1996:3-2008:3. The model has six equations and it is estimated using the Kalman filter with output gap and NRI as unobservable variables. Estimation results indicate a more stable NRI in period 2001:3-2008:3 than in period 1996:3-2001:2 and also more stable than the observed real interest rate. Real interest rate gap (difference between real and natural rates), which measures monetary policy stance, indicates a restrictive policy for 1996-2001. Results also show a negative interest rate gap onwards, suggesting a less restrictive policy.

Keywords: Interest Rate, Natural Interest Rate, Kalman Filter, Output Gap, Unobserved Components.

JEL: C32, E32, E43, E52.

Resumen

Utilizando la metodología de Mésonnier y Renne (2007) se estima una Tasa Natural de Interés (TNI) utilizando datos peruanos de frecuencia trimestral para el periodo 1996:3-2008:3. El modelo consta de seis ecuaciones y es estimado usando el filtro de Kalman con la TNI y la brecha de producto como variables no observables. Los resultados empíricos indican una TNI más estable para el periodo 2001:3-2008:3 en comparación con el periodo 1996:3-2011:2 y también más estable que la tasa de interés real observada. La brecha de tasa de interés (diferencia entre las tasas de interés natural y real), lo cual mide la postura monetaria, indica una política monetaria restrictiva para el periodo 1996-2011. Los resultados también indican una política monetaria menos restrictiva en el resto del periodo bajo análisis

Palabras Claves: Tasa de Interés, Tasa Natural de Interés, Filtro de Kalman, Brecha de Producto, Componentes No Observables

Classificación JEL: C32, E32, E43, E52.

Estimation of a Time Varying Natural Interest Rate for Peru[1]

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1 Introduction

The natural rate of interest (hereafter NRI) is defined as the real interest rate for macroeconomic equilibrium. It is also known as the neutral interest rate. In more formal terms, NRI is a real short-term interest rate that is consistent with potential output and with stable inflation. Historically, the concept of a *natural* real rate of interest and its use for monetary policy is associated with Wicksell (1898, 1907). In recent years, the *neo-wicksellian* framework for monetary policy analysis advocated by Woodford (2003) has emphasized its relevance for monetary authorities.

An important measure derived from the NRI is the real interest rate gap (IRG). It is calculated as the difference between the real short-term interest rate and NRI. Naturally, this indicator is a relevant candidate for assessing monetary policy stance. Actually, central banks and central banks economists pay significant attention to theoretical developments and empirical strategies for estimating the NRI and the IRG. Examples at this respect are Archibald and Hunter (2001); Christensen (2002); Crespo-Cuaresma, Gnan, and Ritzberger-Grünewald (2004); ECB (2004); Neiss and Nelson (2003); and Williams (2003). For Peru, Castillo, Montoro and Tuesta (2006) estimate both NRI and IRG to asses monetary policy stance.

There is an enormous literature concerning the modeling and estimation of NRI.[4] Two characteristics may guide in distinguishing models inside

[1] We thank participants to the XXV Economists Meeting at the Central Bank of Peru (December 2007) and to the XIII Annual Meeting at CEMLA in Mexico (November 2008), as well as Carlos Montoro, for useful comments. The views expressed herein are those of the authors and do not necessarily reflect those of the Central Reserve Bank of Peru or the Pontificia Universidad Católica del Perú.

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[4] See Giammarioli and Valla (2004) for an excellent survey.

this vast literature. The first concerns whether the model focuses on the short-term or the medium to long-term implications of a non-zero gap. In this approach, the NRI estimates are obtained from within a microfounded *new Keynesian* model, the so called dynamic stochastic general equilibrium (DSGE) model; see Woodford (2003), Neiss and Nelson (2003), Giammarioli and Valla (2003), and Smets and Wouters (2003).[5]

The second feature relates to the degree of economic structure built into models to obtain NRI estimates. In this approach, simple macroeconomic models (from the monetary policy literature) are used along the Kalman filter to estimate the NRI, the natural rate of unemployment, and potential output all as unobserved variables. theoretical and empirical examples are Orphanides and Williams (2002); Crespo-Cuaresma, Gnan, and Ritzberger-Grünewald (2004); Basdevant, Björksten, and Karagedikli (2004); Larsen and McKeown (2004); Garnier and Wilhelmsen (2005); Brzoza-Brzezina (2006); and Mésonnier and Renne (2007).

The second strand of literature follows Laubach and Williams (2003). In this approach, simple macroeconomic models (from the monetary policy literature) are used along the Kalman filter to estimate the NRI, the natural rate of unemployment, and potential output all as unobserved variables.[6] Examples of this approach can be found in Orphanides and Williams (2002); Crespo-Cuaresma, Gnan, and Ritzberger-Grünewald (2004); Basdevant, Björksten, and Karagedikli (2004); Larsen and McKeown (2004); Garnier and Wilhelmsen (2005); Brzoza-Brzezina (2006); and Mésonnier and Renne (2007).

There are, of course, other simpler procedures to estimate NRI such as the application of statistical filters. Some of the more common filters are Hodrick and Prescott (1997), Baxter and King (1999), and Christiano and Fitzgerald (2003). The use of these filters, however, may be subject to critics since it lacks support from economics for its results. As Larsen and McKeown (2004) and Mésonnier and Renne (2007) suggest, the approach in the second brand of literature represents a convenient compromise between the costly DSGE modeling from the first approach and the purely statistics approach from the filters.

In this paper, we follow the approach suggested by Mésonnier and Renne

[5] In this framework, the NRI is the real short-term interest rate that equates aggregate demand with potential output throughout time.

[6] Within this context, the NRI is the real short-term rate of interest consistent with output at its potential level and inflation at an stable rate in the medium run. It means the effects from demand and supply shocks upon the output gap and inflation, respectively, vanish completely.

(2007), which in turn is derived from Laubach and Williams (2003). The approach of Mésonnier and Renne (2007) has two advantages with respect to the method proposed by Laubach and Williams (2003). First, unlike Laubach and Williams (2003), we allow for stationarity (but high persistency) in the unobservable component that drives the low-frequency common fluctuations of the NRI and potential output growth. Second, the real interest rate is calculated as a model-consistent ex-ante real rate of interest using inflation expectations provided by the model.

We apply this approach to quarterly Peruvian data for the period 1996:3-2008:3. Our results are relatively sensible to the calibration of two parameters. However, in most cases, the NRI estimates are very stable. The gap on the real interest rate indicates a restrictive monetary policy for the period 1996-2001. Monetary policy appears to be relatively expansionary from 2002 onwards. The gap behavior is much less volatile than in the previous period.

This paper is organized as follow. In Section 2, the model is described. Section 3 briefly describes data and Peru's economic background. Section 4 presents and discusses the econometric results. Section 5 concludes.

2 The Model

Our specification follows closely Mésonnier and Renne (2007), which in turn is based in Laubach and Williams (2003). The model consists of six backward-looking linear equations which are still widely used for monetary policy analysis and they also appear to be robust empirically. Some examples at this respect are Rudebusch and Svensson (1998, 2002), Onatski and Stock (2002), Smets (2002), Fagan, Henry, and Mestre (2001), Fabiani and Mestre (2004), Rudebusch (2005), Bernanke and Mihov (1998), Estrella and Fuhrer (1999), Leeper and Zha (2002).

The approach of Mesonnier and Renne (2007) is preferred here firstly because, unlike Laubach and Williams (2003), the output is treated as an I(1) stochastic process. Secondly, productivity is considered a very correlated process but not necessarily an I(1) process. Finally, there is no application of the kind of approach to a developing country such as Peru, in which a low- inflation scenario resulted from a hyperinflation-fighting economic policy (in the first half of the 1990s) and a inflation targeting regime followed monetary discipline (from 2002 onwards).

The model consists of the following six equations:

$$\pi_t = \alpha(L)\pi_t + \beta(L)z_t + \epsilon_t^{\pi}, \quad (1)$$
$$z_t = \phi(L)z_t + \lambda(L)(i_t - \pi_{t+1|t} - r_t^*) + \epsilon_t^z, \quad (2)$$
$$r_t^* = \mu_r + \theta a_t, \quad (3)$$
$$\Delta y_t^* = \mu_y + a_t + \epsilon_t^y, \quad (4)$$
$$a_t = \psi a_{t-1} + \epsilon_t^a, \quad (5)$$
$$y_t = y_t^* + z_t, \quad (6)$$

where the four shocks are independently and normally distributed with variances σ_π^2, σ_z^2, σ_y^2 and σ_a^2, respectively.

The first equation may be interpreted as an aggregate supply equation or Phillips curve. It specifies that consumer price inflation relates to its own lags and output gap lags. The second equation is a reduced form of an aggregate demand equation, or IS curve, relating the output gap to its own lags and to real interest gap (IRG) lags. The IRG is defined as the difference between the real short-term interest rate and NRI. Stable inflation is consistent with a zero output gap and zero IRG. In this sense, NRI may be named non-accelerating-inflation rate of interest. In this model, monetary policy affects the inflation rate through its influence on the output gap. Furthermore, the nominal short-term interest rate is assumed exogenous, which implies an implicit reaction function.

In this approach, NRI is assumed to follow a highly autoregressive process as specified by (3) and (5).[7],[8] Even though the random walk assumption may be advantageous from some perspective[9], it render economic interpretation of the model very difficult. This is the case, in particular, if we assume that potential growth (Δy_t^*) shares common fluctuations with r_t^*.[10] NRI estimates (see next section) show that this process is highly persistent, but not an I(1) process, which is consistent with the purpose of capturing large

[7] In the literature a common NRI specification is a random walk. Nonstationarity is also specified for the potential output growth rate. Some examples are Laubach and Williams (2003), Orphanides and Williams (2002), Larsen and McKeown (2004), and Fabiani and Mestre (2004).

[8] Another exception in the stationary specification of NRI is Gerlach and Smets (1999). Furthermore, they assume that potential output is I(1).

[9] It combines persistent changes in the unobservable component with smooth accommodation of feasible but unspecified structural breaks in the actual interest rate series.

[10] A nonstationary specification for NRI and potential output growth would indeed imply that potential output is integrated of order two. In terms of the standard optimal growth model, it would mean a nonstationary path of output to the stock of capital.

and low frequency fluctuations in the level of the equilibrium real rate.[11]

Equation (5) is an autoregressive representation for a_t. It captures low-frequency variations in potential output growth assuming that these variations are common with those of NRI. Notice that equation (4) specifies the behavior of potential output growth. It states that potential output growth has another stationary component that may account for other sources of discrepancies with NRI (shocks to preferences or changes in fiscal policy, for example). A simple white noise is enough to model this second stationary component.

An acknowledged setback of the model is that it does not incorporate open-economy features. For instance, the model does not allow for an explicit influence of terms of trade variations in potential output. Thus, the effects of positive external shocks in growth would be attributable to productivity growth and, as such, would imply a larger NRI than otherwise in an open-economy representation of NRI. Therefore, interpretation of NRI estimates should be drawn carefully over periods of external turbulence. In these cases, NRI would feasibly be considered as an upper limit to the equilibrium rate (if positive shocks were in place). Nonetheless, this approach is useful in establishing a reasonable benchmark for monetary policy analysis, in the context of a very simple macroeconomic structure.[12]

3 Data and economic background

Peruvian quarterly data for the period 1996:3-2008:3 is used in estimations. The inflation rate is defined as the annualized quarterly growth rate of the CPI series. The ex-ante real short-term rate of interest is obtained by deducting from the current level of the nominal interest rate the one-quarter-ahead expectation of the (quarterly annualized) inflation rate. The data set is complete with the log of the real GDP. All variables have been seasonally adjusted using the procedure Tramo-Seats of Gómez and Maravall (1992). A depiction of the evolution of real GDP, inflation rate and nominal interest rate could be seen in Figure 1. Notice up, in particular, the large upsurge in economic growth, along with the break in the nominal interest rate dynamics, from 2002 onwards.

[11] All specifications are consistent with the hypothesis that potential output is an I(1) process. Application of simple unit root tests reject the null hypothesis of an I(2) log real output.

[12] The model falls short also in incorporating the dollarization of the Peruvian financial system. However, effects from such an omission are not conclusive as for NRI.

Sample size is determined in practical terms considering data availability for the interbank rate (as a measure of the short-term nominal rate) in the Peruvian financial system. More importantly, economic rationale for the estimation period responds to Peru's output and inflation dynamics. Peru suffered from hyperinflation until 1990 and the disinflation process lasted up until 1994. Business cycle fluctuations were large and highly volatile during most of the 1980's and the first half of the 1990's.

A number of structural economic reforms were introduced during the first part of the 1990's, namely financial system liberalization (including a previsional pension fund reform), trade openness, reinsertion in the international financial system, tax-system reform, sound and prudent monetary and fiscal policies, investments promotion and, in general, more market-oriented policies throughout the economy. With so many structural reforms at roughly the same time, volatility of the main macroeconomic variables was wide and time-varying. By the start of the second half of the 1990's, most of these first-generation reforms were well functioning and key relationships between monetary and real sector were reestablished soundly.

Building upon new trends in macroeconomic variables by the late 1990's (and despite holding-up effects from the international financial crises), Peru started to use money-aggregates targeting with explicit, though still not binding, preferred inflation rates (since 1994).[13] By 2002, Peru formally adopted a fully-fledged inflation-targeting regime. Indeed, as it would be seen in the results, overall sample estimation for 1996-2008 captures a time varying NRI that suggests an interpretable monetary policy stance, not different from other empirical estimations.[14]

4 Results

The six-equation model is written in its state-space form, and the parameters are estimated by maximization of the likelihood function provided by the Kalman filter which provides the best linear unbiased estimate of the state variables. This approach allows to obtain a filtered estimate of the state variables using information only up to time t, whereas a smoothed estimate uses information from the whole sample, that is, up to time T.

In th unconstrained maximum likelihood estimation, two difficult arise. The first one is the estimation of the parameter θ which appears to be

[13] Output, investment and other key macroeconomic variables reduced considerably their volatility from mid-1990s onwards.

[14] See, for instance, Castillo, Montoro and Tuesta (2006).

very instable and not statistically significant.[15] This parameter links two unobservable variables, which may render its estimation ambitious if we consider the sample size used in the estimations. The second difficulty found in the unconstrained estimation is an estimated value of zero for σ_y. In some cases, estimation of the parameter σ_z also renders a zero value.[16] It implies that idiosyncratic shocks to output are indistinguishable from transitory shocks to output. That is not surprising if we think in the high persistence of the output gap.

In order to deal with these difficulties, two calibrations are used. The first one is calibration of the ratio σ_y/σ_z. Basis to calibrate this ratio is difficult to find. Even for the US and economies of the European Union (EU), evidence does not suggest basis for a consensus calibration. Fabiani and Mestre (2004) find a ratio of 0.94 for their Euro area model. Peersman and Smets (1999) find a value of 0.42 for a model including five countries of the Europe. For the US some estimates are due to Peersman and Smets (1999), Smets (2002) and Laubach and Williams (2003) and the range of values is from 1.7 to 3.3.

The second calibration is for parameter θ. Reasonable values for this parameter should be consistent with the order of magnitude of empirical estimates of the inverse of intertemporal elasticities of substitution found in the literature. Hall (1988) finds a small parameter that is non-statistically different from zero. It corresponds to an infinite risk aversion coefficient. Other estimates of the intertemporal elasticity of substitution (ranging from 0.27 to 0.77) are due to Ogaki and Reinhart (1998a,b). For Peru, Castillo, Montoro and Tuesta (2006) find a value of 4.00 for the risk aversion coefficient.[17] Given the aforesaid discussion, we consider the range $[0.5, 4]$ as a reasonable interval for plausible values of the ratio σ_y/σ_z and the range $[0, 20]$ for values of the risk aversion parameter θ.

Equations (1) and (2) need selection of lag lengths. Based on the statistical significance, equation (1) uses three lags for inflation and one lag

[15] Similar difficulties have been found by Larsen and McKeown (2004) applying the methodology of Laubach and Williams (2003) to UK data. Because they interpret the problem as a dimensionality issue, they decide to reduce the number of parameter using a calibration similar to Mésonnier and Renne (2007), which is also applied here. Further instability determines to calibrate another parameter.

[16] See the last two columns of Table 1 in which this is the case (despite the estimated parameters being statistically significant) for a calibrated and an unconstrained estimation of the model.

[17] Castillo, Montoro and Tuesta (2006) consider habits in the utility function. Using a habit coefficient of 0.75, the intertemporal elasticity of substitution corresponds to 0.25. Therefore, it implies a risk aversion coefficient of 4 in quarter terms.

for output gap. In equation (2), one lag for output gap and the second lag for the IRG have been selected. Furthermore, the null hypothesis that the coefficients of inflation sum to unity is not rejected. Therefore, we impose this condition, implying that an accelerationist form of the Phillips curve is adopted. In other words, inflation depends only on nominal factors in the long run.

Table 1 reports parameter estimates under alternative estimation scenarios that differ on the values for the calibrated parameters. Last column presents the unrestricted estimates. Most parameter estimates are statistically significant. Our preferred scenario is $\theta = 4$ and $\sigma_y/\sigma_z = 0.5$. Adopting this calibration, most of estimated parameters have the expected sign and are significant (see first column of Table 1). Notice, however, that the scenario $\theta = 4$ and $\sigma_y/\sigma_z = 4$ (second column of Table 1) presents very similar results in terms of significance but the size of some estimates are different.

There are basically two parameters related to the monetary policy transmission. The first parameter is β which is the slope of the Phillips curve. The second parameter is λ, which is the IRG semi-elasticity of the output gap. The estimates of β are very sensitive to the calibrated values according to the columns of the Table 1. In our preferred scenario, $\beta = 0.15$ which is in agreement with other calculations performed for Peru. For example, in a recent research, Salas (2009) uses Bayesian tools to estimate a semi-structural model with around 31 equations and he concludes that slope of the Phillips curve is between 0.05-0.20. Furthermore, Canales et al. (2008) find estimates close to our results and Rodríguez (2010) find a slope of the Phillips curve of 0.08, in the range suggested by Salas (2009). Notice that this coefficient rises to 0.80 and 0.76 (last two columns of Table 1) but is not significant even at 10.0%. The IRG semi-elasticity fluctuates between -0.06 and -0.13 in Table 1. Our preferred scenario indicates a highly significant value of -0.13. Last two columns of Table 1 show estimates which are smaller in absolute values but not significant at 5.0%.

According to the first three columns of Table 1, the estimates of the parameter ψ indicate strong persistence in the productivity process. Our preferred scenario indicates an estimate of 0.92. Second and third columns show very similar values and they are highly significant. These results are opposite to those in the last two columns where estimates indicate a very slow persistent process. However, results in the last two columns are not selected because there are more statistically non-significant parameters. It is important that the productivity process appears persistent but that it does not turn up to be an I(1) process, as Laubach and Williams (2003) suggested. In our preferred scenario, the output gap is also persistent and output gap volatility is larger than total output volatility (indicating smoothing of potential output). Opposite results are found in the second column of Table 1. Another interesting result is the estimate of μ_r. This coefficient is very significant and relatively stable except at the third column of Table 1. Depending on the scenarios, this estimate lies between 4.7 (unrestricted estimation) and 5.4 (preferred scenario). If there is no productivity in the model, this value indicates some kind of average (or middle value) for NRI. From this value, NRI moves with productivity fluctuations.

Figure 2 shows output gap, the productivity measure a_t, NRI versus the observed real short-term interest rate, and the monetary position implied by the IRG (with 90% confidence bands in all cases) for our preferred scenario with $\theta = 4$ and $\sigma_y/\sigma_z = 0.5$. Picture of the output gap indicates excess supply until 2002-2003. Thereafter, the output gap is positive and displays a significant and pronounced upward trend. In comparison with the observed real short-term interest rate, NRI appears much more stable during the last part of the 1990s but with a significant upward trend from 2004 onwards, consistent with the increasing productivity during the same period. Notice up that despite the actual real interest rate being more stable after the adoption of the inflation targeting regime, the rising NRI shows clearly the effects from a growing economy (both in output gap and in productivity). Inflation rate and the nominal interest rate were relatively low and stable from 2002 till 2005, while that NRI was responding to the rise in output and productivity. Correspondingly, the IRG indicates a tight monetary policy for the period 1996-2001, a loose monetary policy from 2004 onwards, and a more neutral stance of policy for 2002-2003. There seems to be a trend reversion in the output gap, productivity, NRI and IRG that might capture real effects from the 2007-2009 international crisis.

Figures 3 to 6 show alternative estimation scenarios. Noticeably, both NRI and IRG estimates appear to be much more stable and similar throughout all cases. For Figures 5 ($\sigma_y/\sigma_z = 0.5$ and $\theta = 1$) and 6 (unrestricted), confidence bands end up coinciding with estimates, apparently reflecting precise estimations. However, as we mentioned above, problems with distinguishing idiosyncratic and transitory shocks to output might render incorrect initial values and, therefore, the code would not performed the required iterations. Interestingly, calibration implied in Figure 4 renders a NRI with a less-pronounced upward trend in recent years. However, the lack of confidence bands and a lightly more volatile NRI (than in the other calibrated cases) prevent us from preferring it as our case scenario.

As we discussed in previous pages, there are, of course, other methods to identify the NRI and consequently the IRG. In order to compare with our results, we have used three approaches. The first approach is a simple statistical filter due to Hodrick and Prescott (1997). The second approach is an adequacy of the unobserved components model of Clark (1987). The last approach is the dynamic linear model with Markov-Switching specification proposed by Kim (1994). The results show evidence of important differences between all these estimations and our calculations. The difference is explained because in the three approaches, the estimated natural rate follows closely the actual real interest rate, without capturing the strong upsurge in economic growth and its corresponding raise in productivity. It renders our estimates more consistent with the performance of the Peruvian economy during the period under study.

5 Conclusions

This paper uses a semi-structural model to estimate the natural rate of interest (NRI) for Peru in the period 1996:3 - 2008:3. We follow closely the approach suggested by Mésonnier and Renne (2007). Some scenarios with two calibrated parameters, along with a model without restrictions, are estimated. Our results are relatively sensible to the calibration of these two parameters. However, in most cases, NRI estimates are very stable in comparison to the actual real interest rate. The interest rate gap, the diference between the real interest rate and NRI, indicates a restrictive monetary policy for the period 1996-2001. Monetary policy appears to be neutral during the period 2002-2003 and relatively expansionary from the end of 2003 onwards.

These results are related to a strong upsurge in economic growth and productivity from 2004 onwards. Indeed, the output gap become positive and with a significant and pronounced upward trend since that year. Correspondingly, NRI would have followed a significant upward trend from 2004 onwards, consistent with increasing productivity during the same period. There seems to be a trend reversion for productivity and NRI for 2008 due to the real effects from the 2007-2009 international crisis.

Other statistical procedures to estimate the NRI have been used to compare with those from our model. The results indicate strong differences between both set of estimates. It suggests that care should be taken when we use simple statistical procedures to estimate the NRI or the gap of the interest rate.

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Table 1. Parameter Estimates

	σ_y/σ_z= 0.5 $\theta = 4$	σ_y/σ_z= 4 $\theta = 4$	σ_y/σ_z= 0.5 $\theta = 16$	σ_y/σ_z= 0.5 $\theta = 1$	No Restrictions
	Value (p-value)	Value (p-value)	Value (p-value)	Value (p-value)	Value (p-value)
α_1	0.85 (0.00)	0.83 (0.00)	0.84 (0.00)	0.90 (0.00)	0.89 (0.00)
α_2	-0.02 (0.89)	-0.05 (0.77)	-0.03 (0.86)	-0.08 (0.60)	-0.08 (0.66)
α_3	0.17 (0.17)	0.21 (0.08)	0.19 (0.14)	0.19 (0.12)	0.19 (0.16)
β	0.15 (0.09)	0.48 (0.11)	0.13 (0.07)	0.80 (0.11)	0.76 (0.11)
σ_π	0.78 (0.00)	0.71 (0.00)	0.78 (0.00)	0.72 (0.00)	0.72 (0.00)
ϕ	0.73 (0.00)	0.53 (0.02)	0.67 (0.01)	0.51 (0.02)	0.51 (0.03)
λ	-0.13 (0.01)	-0.08 (0.05)	-0.11 (0.04)	-0.06 (0.08)	-0.06 (0.10)
σ_z	0.94 (0.00)	0.28 (0.00)	0.90 (0.00)	0.00 (0.99)	0.00 (0.99)
σ_a	0.25 (0.14)	0.20 (0.31)	-0.17 (0.13)	1.28 (0.00)	1.28 (0.00)
ψ	0.92 (0.00)	0.94 (0.00)	0.95 (0.00)	0.30 (0.02)	0.30 (0.07)
μ_r	5.44 (0.03)	5.05 (0.06)	6.93 (0.35)	4.72 (0.00)	4.70 (0.00)
μ_y	1.08 (0.01)	1.14 (0.05)	1.06 (0.01)	1.09 (0.00)	1.09 (0.00)
θ	4.00	4.00	16.00	1.00	0.66 (0.60)
σ_y	0.47	1.13	0.45	0.00	0.00 (0.99)

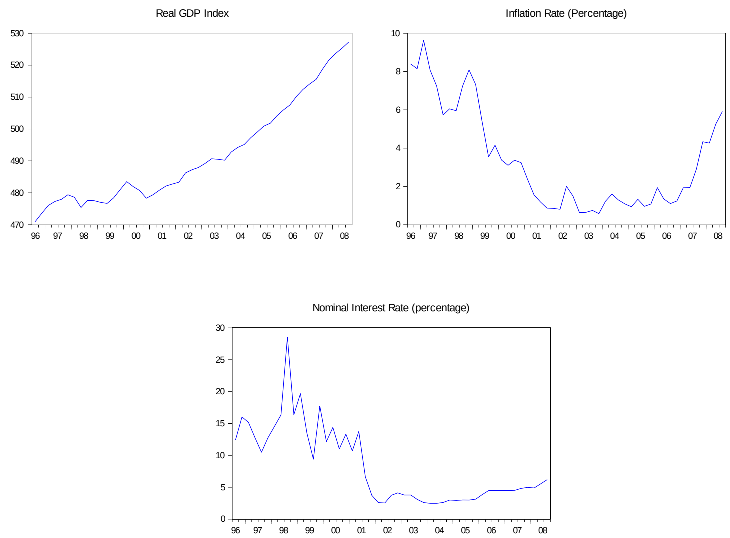

Figure 1. Real Output, Inflation, and Nominal Interest Rate

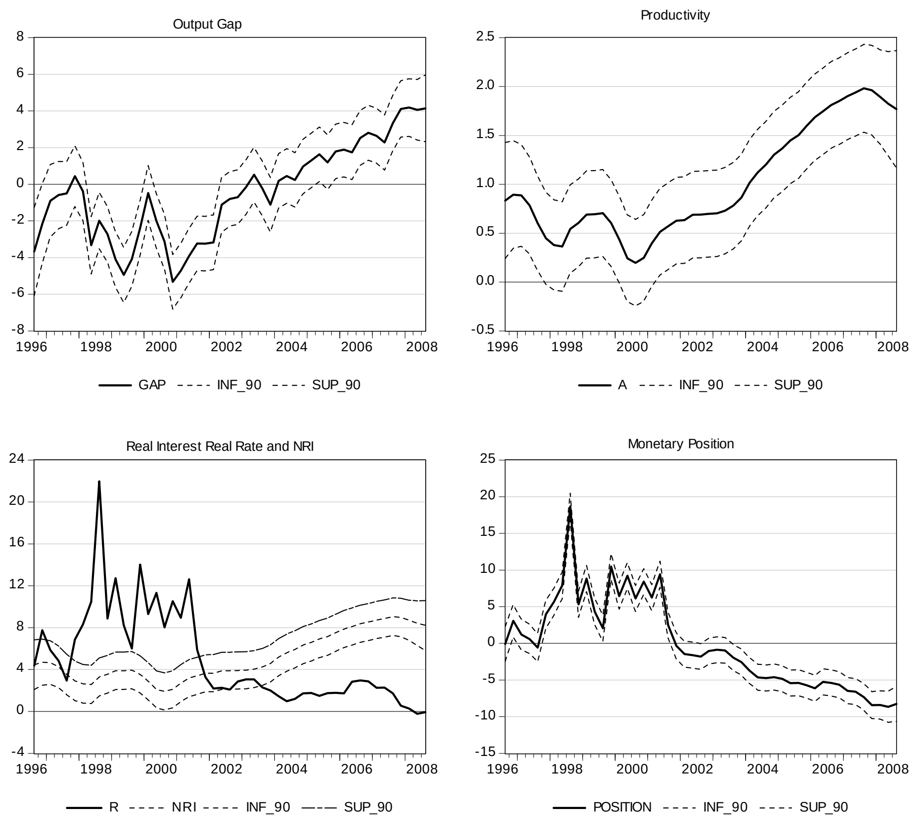

Figure 2. Estimates with $\sigma_y/\sigma_z = 0.5$ and $\theta = 4$

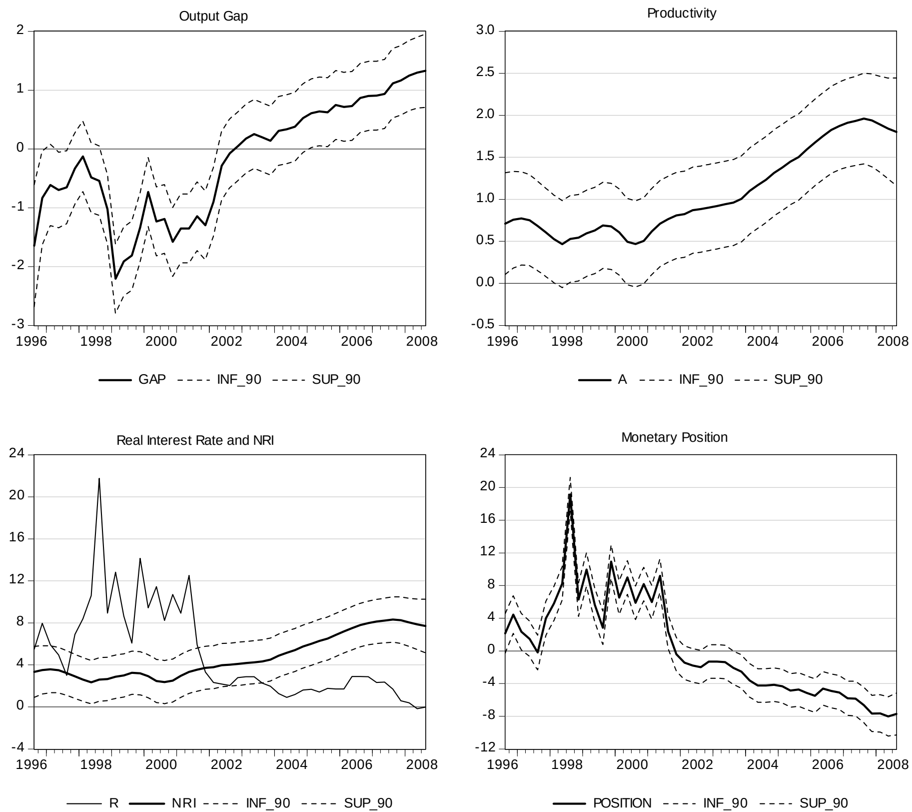

Figure 3. Estimates with $\sigma_y/\sigma_z = 4$ and $\theta = 4$

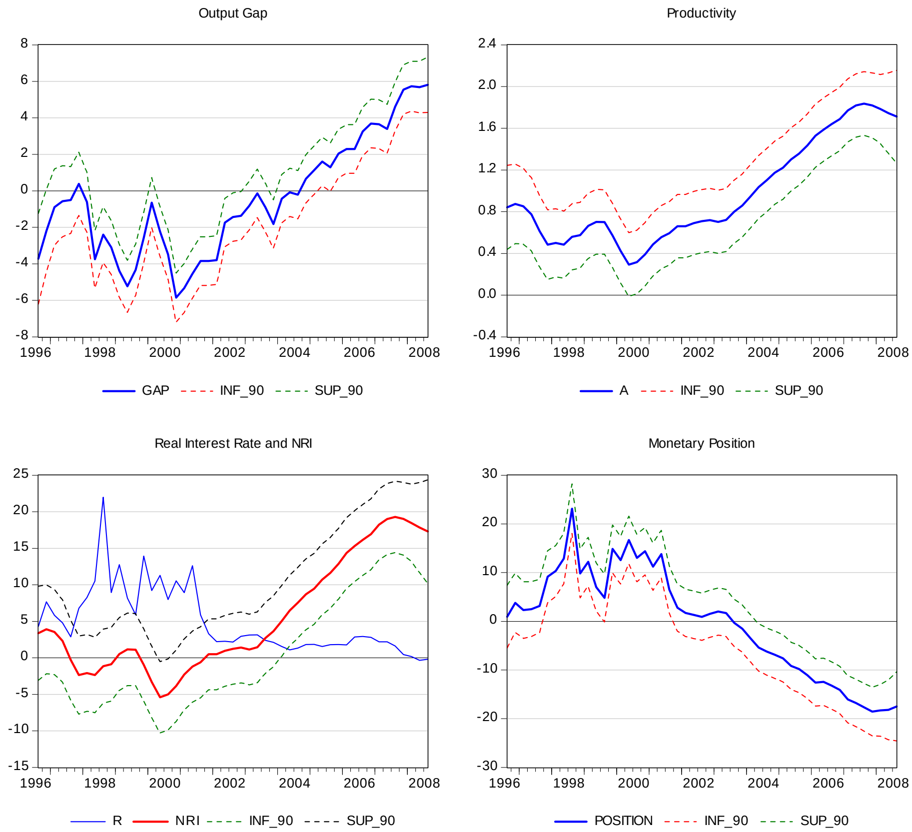

Figure 4. Estimates with $\sigma_y/\sigma_z = 0.5$ and $\theta = 16$

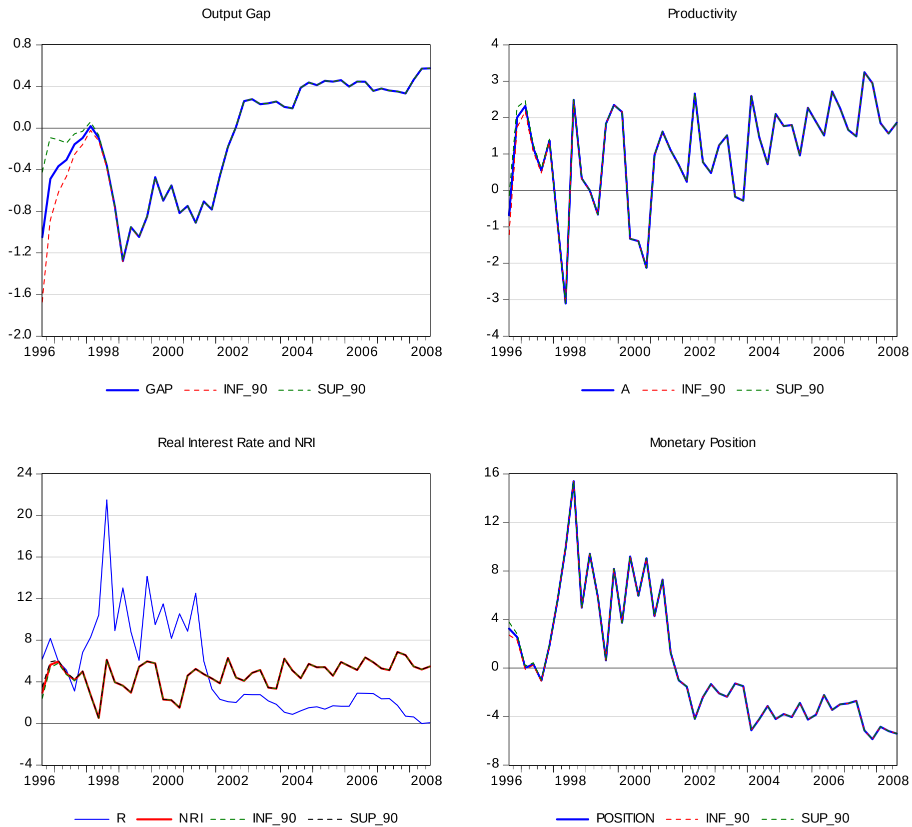

Figure 5. Estimates with $\sigma_y/\sigma_z = 0.5$ and $\theta = 1$

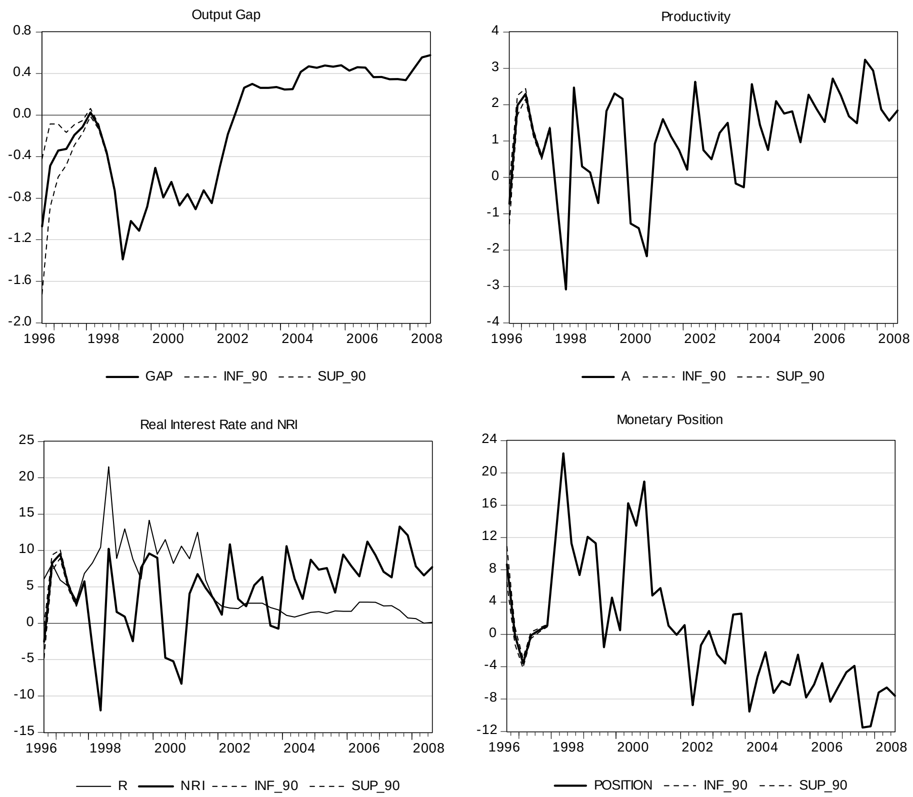

Figure 6. Estimates without restrictions

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