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New Keynesian NAIRU and the Okun Law: An application for Colombia

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New Keynesian NAIRU and the Okun Law: An application for Colombia

J. Sebastián Amador-Torres[*†]

Abstract

This paper proposes new monthly estimates for the non-accelerating inflation rate of unemployment (NAIRU) and the output gap for Colombia. These rely on a New Keynesian small open economy model following González et al (2013), augmented by an Okun's Law equation. The resulting output gap closely follows the business cycle, as identified by other estimates currently employed by the central bank. The unemployment gap is negatively correlated to the output gap, in a magnitude consistent with simple Okun Law's estimations. Unlike previous works, this paper presents shocks decompositions, which allow for some economic interpretation of the unemployment dynamics in terms of macroeconomic shocks. This framework might be well suited to evaluate the effects of monetary policy on the labor market, as suggested by an evaluation of forecasting accuracy.

JEL Classification: E23, E24, E27, E32.

Keywords: NAIRU, unemployment, output gap, New Keynesian model, monetary policy, emerging economy, monthly data.

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1. Introduction

Typically, monetary policy involves assessing deviations of key variables from their respective neutral levels. In this context, a variable at its neutral level would be consistent with stable inflation and a closed output gap in the medium term (Blinder, 1999). In the case of the short-term interest rate, these deviations indicate whether a given monetary policy is expansionary or contractionary. On the other hand, for output and unemployment they reflect the current state of the economy. As these neutral levels are unobservable, they must be inferred from available macroeconomic data.

This paper develops a semi-structural New Keynesian model of the Colombian economy to estimate neutral levels for some key macroeconomic variables, using data from March 2001 to November 2017. It employs five behavioral equations that characterize the economy in a simple and tractable way. This set of equations describes the behavior of inflation, output, the short-term interest rate, the real exchange rate, and the unemployment rate. Importantly, these equations endow economic structure, providing valuable information for the estimation of their respective neutral levels. Models of this kind are mainly used as a forecasting and policy analysis tool (Coats et al, 2003), and are useful to understand past economic developments (Carabenciov et al, 2008).

This formulation provides a useful framework to assess both the policy stance and its effects. Similar approaches have been widely used to estimate neutral levels of macroeconomic variables and to inform monetary policy (see for example Laubach and Williams, 2003, and González et al, 2013).

The main variable of interest is the unemployment rate, as the model departs previous works by including an Okun's Law equation. Thus, it is possible to simulate the effects of diverse macroeconomic shocks on the labor market. This represents a contribution to the literature on the dynamic relationship of the Colombian labor market with other macroeconomic variables.

In addition, this paper contributes to the existing literature for Colombia by exploiting the relatively new Economic Activity Tracking Index (ISE, for its acronym in Spanish), to yield monthly neutral levels estimates for all variables. This represents two advantages. First, by using monthly data, the model has a higher frequency than previous contributions. Although quarterly data is available for a longer period, the number of monthly observations is larger. This improves statistical accuracy and reduces estimates' variance. Second, up to the author's knowledge, this would be the first monthly monetary policy model for Colombia, which allows for higher frequency forecasting, policy simulation, and analysis.

2. Data

There are six observable variables in the model, which are employed to estimate parameters, unobservables, and shocks. All series are in monthly frequency, were seasonally adjusted (X-11) and cover the period from May 2001 to November 2017. These are; the natural logarithm of the seasonally adjusted Economic Monitoring Index (ISE, for its acronym in Spanish), CPI inflation excluding foods and regulated items (seasonally adjusted), the average interbank interest rate, the upper limit of the Federal Reserve funds rate target range, the real bilateral exchange rate between Colombia and the United States (using both countries CPI's), and the unemployment rate in the thirteen main cities.

Two important issues on the data arise. First, it must be noted that the ISE Index fits the methodology used by the quarterly national accounts. Thus, it can fulfill the role of GDP for the purposes of this paper. Second, regarding the unemployment rate, the national aggregate was not used, due to a trade-off between sample size and geographical coherence. As the Colombian statistical office (DANE) measures CPI inflation only in the main twenty-three cities, it is desirable to use a rate that covers that domain. Although a series for unemployment for these twenty-three cities exist, it only starts on January 2008. Thus, the closest relatively long time series is used; that is the main thirteen cities rate.

3. Model

This section describes the model and its structure. The following formulation depicts a small open economy in which output, unemployment, inflation, the short-term interest rate, and the real exchange rate are jointly determined. In essence, it is built on the premise that relationships between gaps (from each variable corresponding neutral level) determine dynamics in the economy. Neutral levels and structural shocks are computed according to those estimated relationships.

Following the notation found in Carabenciov et al (2008), upper case letters denote raw variables, while lower case represents gaps from the respective neutral levels. Therefore, Y is defined as a hundred times the log of the ISE index, and $\bar{Y}$ its respective potential output. These two variables yield the output gap, $y = Y - \bar{Y}$. The unemployment rate is denoted by U, its respective non-accelerating inflation rate of unemployment (NAIRU) would be $\bar{U}$, and the gap between them u. Monthly annualized inflation excluding foods and regulated items is $\pi_t = 1200(\Delta \ln(CPI_t))$. . In turn, the year-over-year inflation rate is $\pi_t^{yoy} = 100(\ln(CPI_t) - \ln(CPI_{t-12}))$. The nominal interest rate is I, the real interest rate is R and the latter's neutral level $\bar{R}$. The log of the real exchange rate index is Z, its equilibrium level $\bar{Z}$ and their corresponding gap z. Output is defined as the sum of potential and the gap $Y = \bar{Y} + y$. Potential output is modeled as random walk with stochastic drift:

$$\bar{Y}_t = \bar{Y}_{t-1} + g_t^{\bar{Y}}/_{12} + \varepsilon_t^{\bar{Y}} \quad (1)$$

The drift term $g_t^{\bar{Y}}$ is the year-over-year potential output growth rate, whose behavior is given by:

$$g_t^{\bar{Y}} = \tau g_{ss}^{\bar{Y}} + (1-\tau) g_{t-1}^{\bar{Y}} + \varepsilon_t^{g^{\bar{Y}}} \quad (2)$$

This allows for both permanent shocks to the potential output level ($\varepsilon_t^{\bar{Y}}$) and transitory shocks to its growth rate $\left(\varepsilon_t^{g^{\bar{Y}}}\right)$. In the steady state, potential output growth is equal to its long run value, $g_{ss}^{\bar{Y}}$. However, $g_t^{\bar{Y}}$ can persistently deviate from $g_{ss}^{\bar{Y}}$ due to shocks in $\varepsilon_t^{g^{\bar{Y}}}$ and its convergence speed to $g_{ss}^{\bar{Y}}$ depends on τ.

The unemployment rate U follows a similar structure, and $\bar{U}$ also has level ($\varepsilon_t^{\bar{U}}$) and growth rate shocks $\left(\varepsilon_t^{g^{\bar{U}}}\right)$:

$$\bar{U}_t = \bar{U}_{t-1} + g_t^{\bar{U}} + \varepsilon_t^{\bar{U}} \quad (3)$$

$$g_t^{\bar{U}} = \alpha_3 g_{t-1}^{\bar{U}} + \varepsilon_t^{g^{\bar{U}}} \quad (4)$$

The real interest rate is defined as the difference between the nominal interest rate and year-over-year inflation expected twelve months ahead.

$$R_t = I_t - E\left[\pi_{t+12}^{yoy}\right] \tag{5}$$

The real interest rate gap is given by $r_t = R_t - \bar{R}_t$, where $\bar{R}_t$ is the neutral level of the real interest rate. This neutral level can differ from its steady state value in response to shocks:

$$\bar{R}_t = \rho\bar{R}^{ss} + (1-\rho)\bar{R}_{t-1} + \varepsilon_t^{\bar{R}} \tag{6}$$

The external interest rate is also included as $I_{US,t} = R_{US,t} + \pi_{US,t}^{yoy}$. The corresponding external equilibrium rate is given by a structure similar to that of equation 6.

$$\bar{R}_{US,t} = (1-\rho_{US})\bar{R}_{US}^{ss} + \rho_{US}\bar{R}_{US,t-1} + \varepsilon_t^{\bar{R}_{US}} \tag{7}$$

The external interest rate gap follows an autoregressive process subject to shocks:

$$R_{US,t} - \bar{R}_{US,t} = \kappa\left(R_{US,t-1} - \bar{R}_{US,t-1}\right) + \varepsilon_t^{R_{US}} \tag{8}$$

Similarly, the real exchange rate gap, $z = Z_t - \bar{Z}_t$, depends on the unobserved equilibrium exchange rate, which follows a random walk:

$$\bar{Z}_t = \bar{Z}_{t-1} + \varepsilon_t^{\bar{Z}} \tag{9}$$

Real exchange rate expectations are defined as a weighted average of the one period ahead model forecast of Z and its lagged value:

$$Z_{t+1}^e = \phi E[Z_{t+1}] + (1-\phi)Z_{t-1} \tag{10}$$

The investment-savings curve is given by equation 11. It relates the current output gap to its past and expected values, and to the lagged real interest rate and real exchange rate gaps. The term χ_t^y represents demand shocks.

$$y_t = \beta_1 y_{t-1} + \beta_2 E[y_{t+1}] - \beta_3 r_{t-1} + \beta_4 z_{t-1} + \chi_t^y \tag{11}$$

The process for demand shocks is modeled in a way that allows for persistence. This allows the output gap to deviate persistently from zero for reasons outside the systematic behavior of the model (for example, uncertainty shocks as in Leduc and Zheng, 2016). Thus χ_t^y is specified as follows:

$$\chi_t^y = \rho_y \chi_{t-1}^y + \varepsilon_t^y \tag{12}$$

Equation 13 characterizes the model Phillip's curve. In this specification, monthly-annualized inflation excluding foods and regulated items depends on expectations of year-over-year inflation 12 months ahead, lagged year-over-year inflation, lagged output gap, and the year-over-year real depreciation rate. Note that the inflation expectations term includes both rational and adaptative terms, in a structure similar to the hybrid model of González et al (2013). Supply shocks to the Phillip's curve are denoted by ψ_t^π.

$$\pi_t = \lambda_1 \pi_{t+12}^{yoy} + (1-\lambda_1)\pi_{t-1}^{yoy} + \lambda_2 y_{t-1} + \lambda_3 \Delta_{12} Z_t + \psi_t^\pi \tag{13}$$

The process that describes supply shocks to the Phillips curve shocks also presents persistence (equation 14). This emulates the high degree of persistence observed in Colombian inflation in the sample (for a description, see Echavarria et al, 2011). Although persistence is partially captured by $(1-\lambda_1)$, equation 14 allows for episodes of non-systematically higher inflation, that could be the result of a non-linearity not explicitly modeled here (an example of this is described in González et al, 2010).

$$\psi_t^\pi = \rho_y \psi_{t-1}^\pi + \varepsilon_t^y \tag{14}$$

A Taylor-type mechanism is included in the model by equation 15. This relationship determines the short term nominal interest rate, and it depends of its own lag, the neutral real interest rate, expectations of year-over-year inflation twelve months ahead, expected deviations from the inflation target (π^{tar}) and the output gap.

$$I_t = \gamma_1 I_{t-1} + (1-\gamma_1)\left[\bar{R}_t + \pi_{t+12}^{yoy} + \gamma_2(\pi_{t+12}^{yoy} - \pi^{tar}) + \gamma_3 y_t\right] + \varepsilon_t^I \tag{15}$$

Equation 16 introduces the uncovered interest rate condition. The expected annualized monthly depreciation rate depends on the differentials between foreign and domestic real interest rates and real neutral rates.

$$12(Z_{t+1}^{e} - Z_t) = \left(R_t - R_{US,t}\right) - \left(\bar{R}_t - \bar{R}_{US,t}\right) + \varepsilon_t^{Z-Z^e} \tag{16}$$

Finally, equation 17 is a dynamic Okun's law, where the labor market gap is persistent. This relationship also depends on the contemporaneous output gap. As a result, the labor market gap is informed by the business cycle, via the estimated output gap.

$$u_t = \alpha_1 u_{t-1} + \alpha_2 y_t + \varepsilon_t^{u} \tag{17}$$

4. Results

The model outlined in the previous section was estimated employing Bayesian techniques. This method combines prior information with the model's likelihood function. It is usually employed for the estimation of dynamic stochastic general equilibrium models. As An and Schorfheide (2007) point out, this procedure exhibits important advantages for dealing with short time series and for parameter identification; issues common to semi-structural models. While most parameters were estimated, some had to be calibrated, for two different reasons. First, a subset of them determine long run values for some variables, thus the calibration intended to match those observed in historical Colombian data. Second, some were set to fixed values because available data did not allow for their identification.

These parameters were calibrated as follows. The long run output growth rate is given by $g_{ss}^{\bar{Y}} = 3.7$. This value was set using the average year-over-year GDP growth rate from 1978 to 2015. The long run inflation target is $\pi^{tar} = 3\%$, equal to the one published by Banco de la República's in its communiques. The long run real interest rate is supposed to be equal to the foreign interest rate $\bar{R}^{ss} = \bar{R}_{US}^{ss} = 2.5\%$, as in González et al (2013). This, together with the absence of drift in the real equilibrium exchange rate process, implies zero depreciation in the steady state. The parameters corresponding to the Taylor rule were set to those of González et al (2013) ($\gamma_1 = 0.7$ $\gamma_2 = 2.5$, and $\gamma_3 = 0.8$).

It must be noted that some priors were imposed on some variables to improve the model's fit. As the data starts after 1998-1999 Colombian financial crisis, priors for potential output and NAIRU were included at the beginning of the sample. This acknowledges the fact that the economy was operating significantly below capacity during that period. Additionally, to account for the decrease in national income that followed the 2015 drop in oil prices, some priors were also imposed on potential output for that episode. The inclusion of these priors also allows the identification of the parameters associated to potential output growth and the change in the NAIRU.

Estimated parameters were obtained by a Bayesian procedure, and the Kalman filter computed both shocks and unobservable variables[1]. Two chains of one hundred and fifty thousand draws were used to approximate posterior distributions for these parameters. As in González et al (2013), three set of priors were used in the estimation procedure. A beta distribution was employed for parameters bounded between zero and one, gamma distribution for unbounded parameters, and inverse gamma distribution for shock's variances. A summary of all estimated parameters is presented in Table 1.

4.1.The output gap

This subsection analyzes the dynamics of the output gap derived from the model's potential output estimate. First, to asses if the model reflects historical business cycle dynamics it is compared to a benchmark estimation used for policy analysis by the Colombian central bank (Banco de la República). This measure summarizes estimates from five different methodologies into a single indicator. As output gap assessments have policy implications, those actually used in practice are the only relevant yardstick (for comprehensive views on this issue, and a full description of the models see Amador-Torres; 2017, and Cobo; 2005).

Figure 1 presents the estimated the 12-month average of the output gap estimated in this paper (labeled as NK model gap), and the corresponding central bank benchmark. The benchmark series has a quarterly frequency, and it is relative to the quarterly GDP, so these comparisons require a grain of salt.

[1] Computations performed using the Dynare software (Adjemian et al, 2011)

However, judging by its similarity to the benchmark, the NK model gap captures the dynamics of the Colombian business cycle well. At the start, both gaps reflect the recovery from the 1998-1999 financial crisis, the mid-2000s boom, the 2008-2009 international financial crisis, and the deceleration due to the 2014-2015 commodities prices drop. Although the two variables are relative to different economic activity indicators (GDP and the ISE index), they follow each other quite closely.

4.2. The NAIRU

Before describing the NAIRU estimate, is important to remark on the α_2 parameter. First, judging its posterior mean value of 0.08, it appears to be rather low. As it relates the output and unemployment gaps, α_2 should roughly compare with previous Okun Law estimates, which are much higher. However, as equation 17 has an unemployment gap persistence term, it does not correspond to the traditional gaps version of Okun's Law, which would be:

$$u_t = \theta y_t + \epsilon_t \tag{18}$$

A regression using y_t and u_t from the NK model yields an θ equal to -0,51 and an R^2 of 0,68. Recently, Ball et al (2016) analyzed θ and R^2 for a set of 71 advanced and emerging economies. Results for Colombia were broadly consistent with those presented here.

Consequently, although α_2 appears to be low, Okun's Law as implied by the model allows for an economically significant relationship between output and unemployment (Figure 2). Judging by the unemployment gap inverse correlation with the output gap, it is clear that both variables follow the business cycle well.

Figure 3 shows the observed unemployment rate and the estimated NAIRU. Both variables show a downward trend, as in other studies (see for example, Arango and Posada, 2006, or Arango and Flórez, 2016). After the 1998-1999 financial crisis, unemployment rose nearly to 20%. Although, it is not possible to account for the estimated drop in the NAIRU within the model presented here, other works provide some information on the matter. Institutional changes and a general improvement in economic conditions made the NAIRU fell slowly from 2001 onwards (Arango and Flórez, 2016).

4.3. Model accuracy

Two exercises were performed in order to assess the model's goodness of fit. First, forecasts were calculated and evaluated for several observed variables. Second, to judge the extent to which the variables included provide information to the dynamics of the labor market, a counterfactual unemployment rate was computed, and compared to observed data, for the period from January 2016 to November 2017.

For the first exercise, forecasts were computed for the unemployment rate, year-over-year inflation excluding foods, the short-term interest rate and ISE index output growth. These were rolling recursive forecasts, starting with data up to December 2011 and ending with data up to November 2017. Overall, the best forecasts at all horizons were those for the unemployment rate (Table 2). Also, forecast accuracy appears to fall less as the horizon increases for the unemployment rate.

The second exercise answers the question: are unemployment dynamics sufficiently explained by other variables observed by the model? To answer it, all observables are included in the estimation except for the unemployment rate during the period from January 2016 to November 2017. An alternative rate is calculated using the Kalman filter for that period. If observed unemployment were significantly different from this alternative rate, the model structure and variables would be insufficient to explain labor marked dynamics. Figure 4 shows that, although the observed and alternative rates deviate during some shorts periods both estimates follow each other closely, at least on trend.

4.4 Shock decomposition

An interesting exercise is to analyze the model's historical shock decompositions. Figures from 5 to 7 show decomposition for several key variables. The black lines show deviations from their respective steady states. The colored bars depict the contribution of shocks to the deviation of each endogenous variable. This exercise allows identifying which shocks affected each variable, by using the model's structure and the observed macroeconomic series.

Figure 5 shows the historical shock decomposition for the output gap. It can be easily seen that, as in Gonzalez et al (2013), most of the output gap movements are related to demand and Phillips curve shocks. There is also some contribution due to shocks to the real equilibrium exchange rate and the neutral real rate of interest. As expected, the initial values of the filter affected negatively the output gap at the beginning of the series. Thus, the model reflects the fact that before the start of the data there was an unidentified negative shock, in the form of the 1998-1999 financial crisis. Like in other similar models, this effect dissipates relatively quickly.

Figure 6 shows the inflation rate (excluding foods and regulated items) shock decomposition. Most of the behavior of this variable is explained by shocks to the Phillips curve. As inflation is modeled in a relatively simple fashion, these shocks account for several mechanisms not explicitly modeled here. For example, they probably reflect indexation processes. Inflation also appears to have been affected by shocks to the real equilibrium exchange rate, in accordance to the low estimated pass-through parameter λ_3. These results are similar to those reported in the Colombian pass-through literature (see for example, Rincón and Rodríguez, 2014).

The unemployment gap shock decomposition (Figure 7) is largely consistent with the output gap results. Initial values play a significant role at the beginning of the series, indicating some unidentified effects due to the 1998-1999 crisis. Again, demand and Phillips curve shocks determine most of the gap evolution. Labor market shocks do not appear to play a significant role, as they probably reflect non-systematic movements in unemployment, not related to other macroeconomic variables.

For example, in the first half of 2016, unemployment fell, only to jump back a couple months after. At the time, this behavior was considered an outlier attributed to a temporary shock to the labor force participation. The model identifies these as temporary labor market shocks, not related to the underlying Okun's law relationship, which adequately explains unemployment dynamics in most periods. It is important to note that deviations in Figure 4 match large labor market shocks in figure 7. This result suggest that the model presented here can explain broad cyclical movements in the unemployment rate.

5. Conclusions

This paper presented a simple New Keynesian model for the Colombian economy. Importantly this new methodology exploits newly available data to yield monthly estimates of the output gap and the NAIRU. As a result, the model produces forecasts and policy simulations at a higher frequency than previous contributions.

Results follow the Colombian business cycle well, as evidenced by their similarity with output gap estimates from the Colombian central bank. Additionally, the model appears to account for most of the cyclical behavior of unemployment. Finally, the fact that the model's best forecast are those of the unemployment rate, suggest that its purpose might be simulating the effects of monetary policy on the labor market.

Although this paper represents a key contribution for Colombian macroeconomic modeling and policy analysis, it falls short on some counts. Including the labor market only through the Okun's Law probably is too simplistic. Future works should include, for example, the relationship between labor market slack, wages and inflation. In addition, explicitly accounting for the informal sector may be of importance in an emerging market such as Colombia.

Additionally, the model does not explain the dynamics governing the behavior of the NAIRU, as it is derived using only a statistical trend. This leaves an important blind spot, as it is unable to explain the economics behind changes in the NAIRU. A recent contribution in this regard can be found in Arango y Flórez (2016). Although they study the structural unemployment rate instead of the NAIRU, their results suggests that production costs, sectoral shifts and demographic factors appear to affect unemployment in the long run. Future research should point in this direction, lending economic interpretation to movements in the NAIRU.

However, this paper suggests that a relatively simple model can explain the interplay between macroeconomic variables and the unemployment rate in Colombia. The main piece of evidence that supports this view is the strong relationship found between the unemployment and output gaps. Even after accounting for the model's shortcomings, results indicate that this specification can be used successfully as a forecasting and policy analysis tool.

Table 1: Estimated Model Parameters

	Prior mean	Posterior mean	90% HDP Interval		Prior distribution	Prior standard deviation
$\boldsymbol{\alpha_1}$	0.7	0.8695	0.8244	0.9152	Beta	0.1
$\boldsymbol{\alpha_2}$	0.2	0.0896	0.0668	0.1133	Beta	0.05
$\boldsymbol{\alpha_3}$	0.8	0.7709	0.7009	0.8495	Beta	0.05
$\boldsymbol{\beta_1}$	0.75	0.6393	0.5794	0.6979	Beta	0.05
$\boldsymbol{\beta_2}$	0.25	0.1964	0.1371	0.2545	Gamma	0.05
$\boldsymbol{\beta_3}$	0.075	0.0833	0.0651	0.1003	Gamma	0.01
$\boldsymbol{\beta_4}$	0.1	0.0684	0.014	0.1189	Gamma	0.05
$\boldsymbol{\kappa}$	0.5	0.5043	0.2578	0.7565	Beta	0.15
$\boldsymbol{\lambda_1}$	0.3	0.8156	0.7683	0.8608	Beta	0.1
$\boldsymbol{\lambda_2}$	0.2	0.091	0.0528	0.1257	Gamma	0.05
$\boldsymbol{\lambda_3}$	0.1	0.0314	0.0199	0.0432	Gamma	0.025
$\boldsymbol{\phi}$	0.5	0.862	0.8169	0.9084	Beta	0.1
$\boldsymbol{\rho}$	0.5	0.1082	0.0787	0.1358	Beta	0.1
$\boldsymbol{\rho_y}$	0.5	0.247	0.166	0.3239	Beta	0.075
$\boldsymbol{\rho_\pi}$	0.5	0.3118	0.2503	0.3727	Beta	0.075
$\boldsymbol{\rho_{US}}$	0.8	0.9482	0.9317	0.9653	Beta	0.05
$\boldsymbol{\tau}$	0.05	0.048	0.0335	0.0622	Beta	0.01
$\sigma\ \varepsilon_t^{g^{\bar{Y}}}$	0.25	0.3227	0.2337	0.4079	Inverse gamma	0.050
$\sigma\ \varepsilon_t^{\bar{Y}}$	0.001	0.0012	0.0003	0.0024	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{y}$	0.001	0.7296	0.6478	0.8152	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{\bar{R}}$	0.001	1.124	1.0175	1.2237	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{\pi}$	0.001	1.138	1.0393	1.2353	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{\bar{Z}}$	0.001	0.7274	0.6305	0.8206	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{\bar{R}US}$	0.001	0.4996	0.4601	0.5424	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{RUS}$	0.001	0.0013	0.0003	0.0028	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{Z-Z^e}$	0.001	0.0011	0.0003	0.0021	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{I}$	0.001	0.0011	0.0003	0.0023	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{u}$	0.001	0.1902	0.1717	0.2099	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{\bar{U}}$	0.001	0.001	0.0003	0.0018	Inverse gamma	Inf
$\sigma\ \varepsilon_t^{g^{\bar{U}}}$	0.05	0.0515	0.0361	0.0663	Inverse gamma	0.010

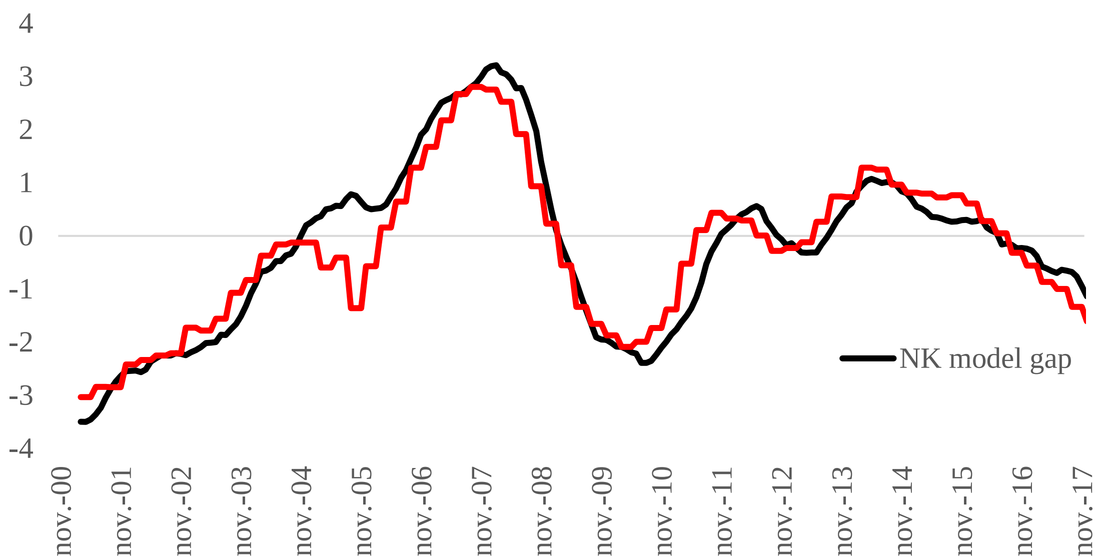
Source: Author's calculations

Table 2: Unemployment rate forecasts root mean squared error (RMSE)

Horizon	Unemployment Rate	Inflation (YoY)	Short Term Interest Rate	Output Growth
1	0.14	0.81	0.37	0.55
2	0.24	0.85	0.37	0.62
3	0.28	0.89	0.36	0.65
4	0.28	0.95	0.41	0.78
5	0.28	1.02	0.45	0.82
6	0.33	1.08	0.54	0.90
7	0.37	1.15	0.62	0.96
8	0.39	1.23	0.71	1.03
9	0.37	1.32	0.82	1.07
10	0.40	1.42	0.90	1.11
11	0.44	1.52	0.98	1.16
12	0.48	1.62	1.05	1.25

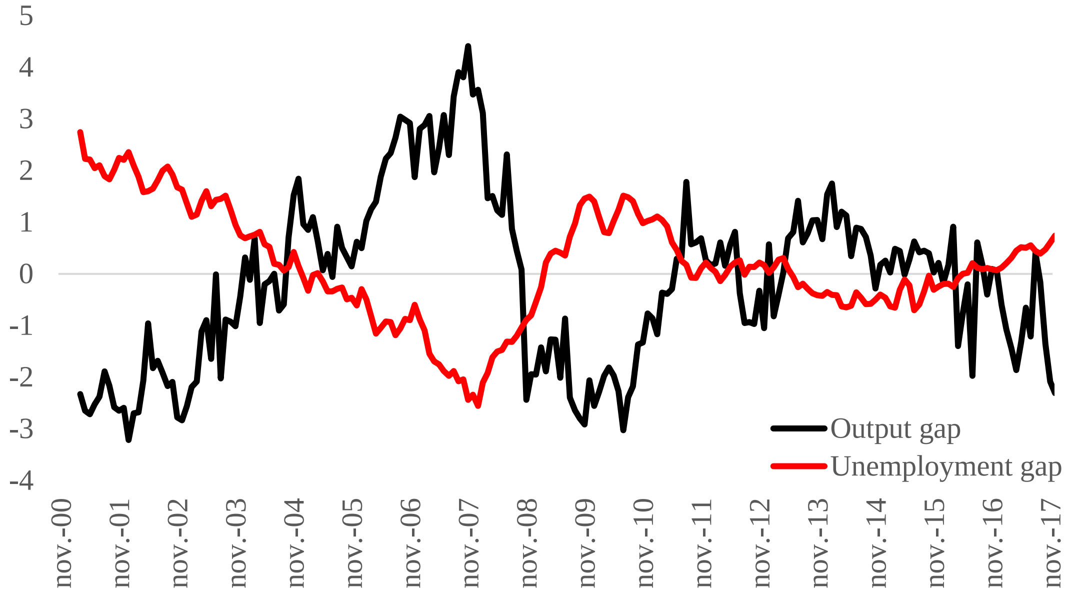
Source: Author's calculations.

Figure 1: Output gap estimates



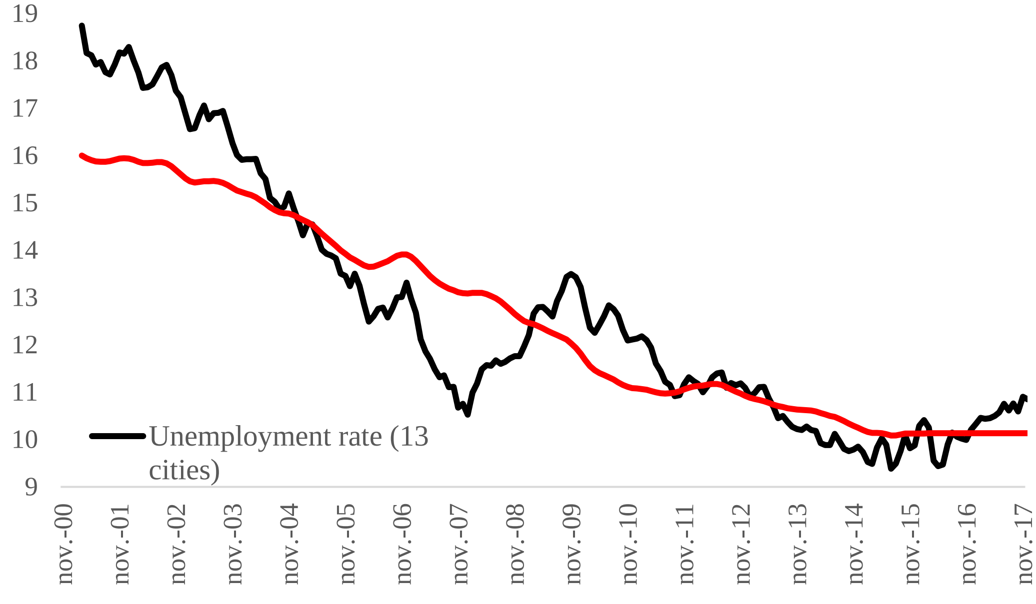
Source: Author's calculations and Banco de la República

Figure 2: Output and Unemployment Gap



Source: Author's calculations and Banco de la República

Figure 3: Output and Unemployment Gap

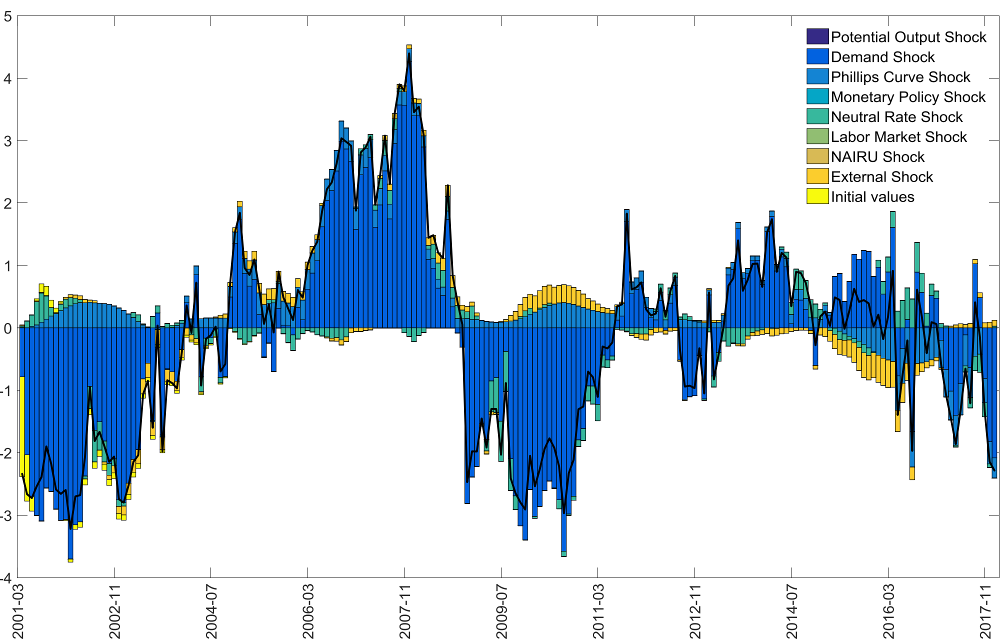


Source: Author's calculations and Banco de la República

Figure 4: Observed and Estimated Unemployment

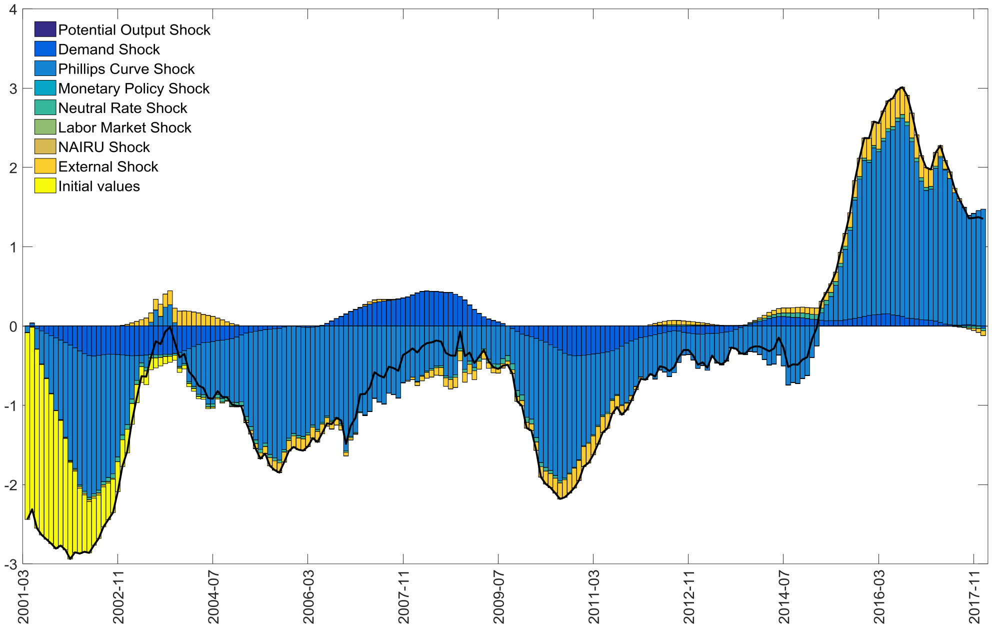
Source: Author's calculations and Banco de la República

Figure 5: Output gap shock decomposition



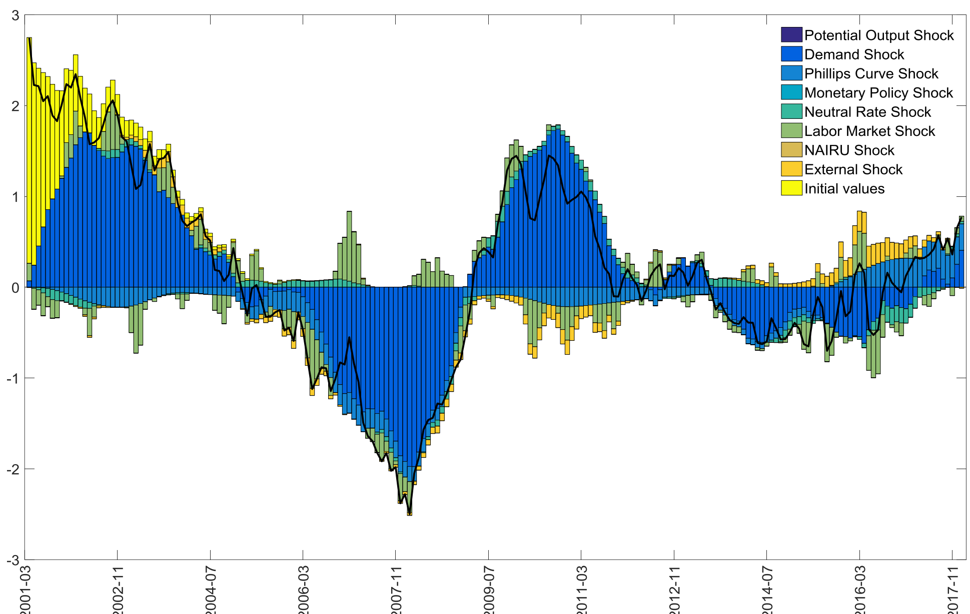
Note: Shocks are added to simplify interpretation. Potential output shock corresponds to $\varepsilon_t^{y} + \varepsilon_t^{g^{\bar{Y}}}$. Demand shock is ε_t^{y}. Phillips curve shock is ε_t^{π}. External shock is $\varepsilon_t^{\bar{Z}} + \varepsilon_t^{\bar{R}_{US}} + \varepsilon_t^{R_{US}} + \varepsilon_t^{Z-Z^e}$. The interest rate shock is given by ε_t^{I} and the neutral rate shock by $\varepsilon_t^{\bar{R}}$. Labor market shock is ε_t^{u}. Finally NAIRU shock corresponds to $\varepsilon_t^{\bar{U}} + \varepsilon_t^{g^{\bar{U}}}$.
Source: Author's calculations.

Figure 6: Inflation (year-over-year) shock decomposition



Note: Shocks are added to simplify interpretation. Potential output shock corresponds to $\varepsilon_t^{y} + \varepsilon_t^{g^{\bar{Y}}}$. Demand shock is ε_t^{y}. Phillips curve shock is ε_t^{π}. External shock is $\varepsilon_t^{\bar{z}} + \varepsilon_t^{\bar{R}US} + \varepsilon_t^{RUS} + \varepsilon_t^{z-z^e}$. The interest rate shock is given by ε_t^{I} and the neutral rate shock by $\varepsilon_t^{\bar{R}}$. Labor market shock is ε_t^{u}. Finally NAIRU shock corresponds to $\varepsilon_t^{\bar{U}} + \varepsilon_t^{g^{\bar{U}}}$.
Source: Author's calculations.

Figure 7: Unemployment gap shock decomposition



Note: Shocks are added to simplify interpretation. Potential output shock corresponds to $\varepsilon_t^{y} + \varepsilon_t^{g^{\bar{Y}}}$. Demand shock is ε_t^{y}. Phillips curve shock is ε_t^{π}. External shock is $\varepsilon_t^{\bar{z}} + \varepsilon_t^{\bar{R}US} + \varepsilon_t^{RUS} + \varepsilon_t^{z-z^e}$. The interest rate shock is given by ε_t^{I} and the neutral rate shock by $\varepsilon_t^{\bar{R}}$. Labor market shock is ε_t^{u}. Finally NAIRU shock corresponds to $\varepsilon_t^{\bar{U}} + \varepsilon_t^{g^{\bar{U}}}$.
Source: Author's calculations.

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