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**The Short-Run Dynamics of Inflation: Estimating a "Hybrid  
New Keynesian Phillips Curve" for Argentina**

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**The Short –run Dynamics of Inflation:  
Estimating a “Hybrid New Keynesian Phillips Curve” for Argentina<sup>1</sup>**

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Based on recent developments in the empirical modeling of the short-run dynamics of inflation, we estimate a “Hybrid New Keynesian Phillips Curve” for Argentina over the period 1993-2003, which assumes that while a fraction of the firms are forward-looking, the others use a backward-looking rule to set prices. We extend the model to a small open economy, considering the influence of nominal devaluation and foreign inflation on domestic prices. Although we find a significant forward-looking behavior, backwardness seems to be more relevant for domestic prices setting. Finally, we cannot reject verticality of the Phillips Curve in the long run.

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<sup>1</sup> The views expressed here are those of the authors and do not necessarily reflect those of the BCRA.

## 1. Introduction

Assessing the short run dynamics of inflation is a relevant issue for monetary policy. A distinctive feature of recent theoretical developments in modeling inflation in the short-run is the introduction of some nominal rigidity in the context of inter-temporal optimizing behavior by non-competitive forward-looking firms. In these models, built on earlier work by Taylor (1980), Calvo (1983) and Fischer (1997), price stickiness could arise for different reasons. In Calvo's (1983) setting some sluggishness in price formation could be obtained by assuming that forward-looking firms face constraints on price adjustment. The resulting model is a New Keynesian, forward-looking version of the traditional Phillips Curve. The empirical relevance of inflation persistence, which imposes costs for disinflation policies has led to incorporate inflation inertia in these models, in spite of the theoretical difficulties to justify it. Galí and Gertler (1999) extend the Calvo's model, allowing for a portion of the firms to follow a backward-looking rule to set prices and obtain a "Hybrid New Keynesian Phillips Curve".

Based on these theoretical grounds, an empirical literature has developed and many issues related to theoretical and empirical aspects of these models are currently under debate. Models based on Calvo's (1983) setting have been subject to the critique of being quite unrealistic in assuming that firms should not expect to adjust prices in a finite horizon and it has been suggested that some truncation should be introduced to add them a quote of realism. The use of the output gap as a measure of marginal costs has also been questioned for both theoretical and empirical reasons. Galí and Gertler (1999) suggest using the aggregate labor income share as a a measure of marginal cost instead of the output gap.

We study here how well the so-called "Hybrid New Keynesian Phillips Curve" approximates the dynamics of inflation in Argentina over the period 1993-2003. The standard model is modified to capture the role played by the nominal exchange rate and foreign prices in domestic prices dynamics in a small open economy. This is a difficult task in the case of Argentina, because the economy went into structural changes after the devaluation of the peso that followed the financial and currency crises of 2001. In this context, it is highly probable that the dynamics of price setting has changed after the abandonment of the currency board regime and the adoption of a dirty float.

To estimate this New Keynesian version of the Phillips Curve we use the Generalized Method of Moments (GMM), which seems to be the appropriate method under rational expectations, since it is based on the assumption that the error in forecasting inflation by firms is orthogonal to the available information.

The paper is organized as follows: in section 2 we briefly present some recent theoretical developments in modeling inflation dynamics. Section 3 describes the estimation methodology. In section 4, we present the empirical results and, finally, section 5 concludes.

## 2. Recent developments in modeling inflation dynamics

In the hybrid version of the Phillips Curve proposed by Galí and Gertler (1999) inflation follows the process

$$p_t = f p_{t-1} + (1-f) E_t(p_{t+1}) + d m c_t + e_t \quad (1)$$

Where  $\pi_t$  is the inflation rate at time  $t$ ,  $E_t$  is the expectation of inflation on  $t+1$  at time  $t$ ,  $m c_t$  is the marginal cost and  $e_t$  is a random shock. The assumption that  $0 < f < 1$ , implies a vertical Phillips curve in the long run. The lagged term in inflation introduces some backwardness in price setting, an observable feature of inflation dynamics, which is quite difficult to justify from a theoretical point of view. In Calvo's framework, firms operate in a monopolistically competitive environment and face some constraints in prices setting in the form of a time dependent rule of adjustment. More specifically each firm faces a constant probability  $(1-q)$  of adjusting prices in period  $t$  and a corresponding constant probability  $q$  of maintaining its prices unchanged.

$$p_t = (1-q) \sum_{j=0}^{\infty} q^j p_{t-j}^* = q p_{t-1} + (1-q) p_t^* \quad (2)$$

This implies that the price level in  $t$  is a convex combination of prices optimally set in previous periods  $p_{t-j}$  and prices optimally set in  $t$   $p_t^*$  according to

$$p_t^* = (1-bq) \sum_{j=0}^{\infty} (bq)^j E_t \{ m c_{t+j} \} \quad (3)$$

Which assumes that firms are identical and choose the same  $p_t^*$  according to their expected marginal costs for future periods  $mc_{t+j}$ , discounted at the subjective factor  $b$ .

Combining (2) and (3) an inflation equation can be written as

$$p_t = I mc_t + b E_t p_{t+1} \quad (4)$$

Where  $p_t = p_t - p_{t-1}$  and  $I = (1-q)(1-bq)/q$ .

Galí and Gertler (1999) introduce backwardness in the Calvo's price setting model (1983) and use the labor income share as a measure of marginal cost instead of the output gap, as suggested by the theoretical literature. They assume that while a fraction  $(1-w)$  of the firms that adjusts prices in  $t$  follows the optimizing behavior described by (3) a proportion  $w$  uses a rule of thumb based on past prices to adjust prices in  $t$ . Thus, prices adjusted in  $t$ , now referred as  $\bar{p}_t^*$  are set according to

$$\bar{p}_t^* = (1-w) p_t^f + w p_t^b \quad (5)$$

While the fraction  $(1-w)$  of the firms behaves according to (3)

$$p_t^f = (1-bq) \sum_{j=0}^{\infty} (bq)^j E_t \{ mc_{t+j} \} \quad (3')$$

the proportion  $w$  behaves according to

$$p_t^b = \bar{p}_{t-1}^* + p_{t-1} \quad (6)$$

where  $p_t^f$  indicates prices set according to (3) and  $p_t^b$  prices adjusted following a backward looking rule.

Combining equations (2), (5), (3') and (6) a Hybrid Phillips Curve is obtained

$$\mathbf{p}_t = \mathbf{I}m\mathbf{c}_t + \mathbf{g}_f E_t \{\mathbf{p}_{t+1}\} + \mathbf{g}_b \mathbf{p}_{t-1} \quad (7)$$

Where

$$\begin{aligned} \mathbf{I} &\equiv (1-\mathbf{w})(1-\mathbf{q})(1-\mathbf{bq})\mathbf{f}^{-1}, \\ \mathbf{g}_f &\equiv \mathbf{bqf}^{-1}, \\ \mathbf{g}_b &\equiv \mathbf{wf}^{-1}, \end{aligned} \quad (7')$$

$$\text{with } \mathbf{f} \equiv \mathbf{q} + \mathbf{w}[1-\mathbf{q}(1-\mathbf{b})] \quad (7'')$$

We adapt Galí and Gertler specification to the case of a small open economy. As pointed out by Svensson (1998) changes in the nominal exchange rate and imported goods prices have, in this context, a direct effect on domestic inflation. In addition, since the nominal exchange rate is the price of an asset, it is inherently a forward-looking variable. Thus, as a determinant of domestic inflation it contributes to make expectations play an essential role in domestic prices formation.

We then estimate an open economy version of the “Hybrid New Keynesian Phillips Curve” that modifies equation (1) in two directions: (i) introducing measures of nominal devaluation and imported inflation and (ii) using a measure of the output gap as a proxy for marginal costs rather than the labor income share.

Thus, our equation is as follows:

$$\mathbf{p}_t = \mathbf{f} \mathbf{p}_{t-1} + (1-\mathbf{f})E_t(\mathbf{p}_{t+1}) + \mathbf{g}\pi_t^* + \mathbf{I}\Delta e_t + \mathbf{d}x_t + \mathbf{e}_t \quad (8)$$

where  $\pi_t$  is domestic inflation, measured by the change in the log of the Consumer Price Index,  $E_t(\pi_{t+1})$  is inflation expectation for  $t+1$  at time  $t$ ,  $\pi_t^*$  is foreign inflation, measured by the change in the log of the US Producer Price Index,  $\Delta e_t$  is nominal

devaluation calculated as the change in the log of the nominal exchange rate, and  $x_t$  is the output gap.<sup>2</sup>

### 3. The estimation methodology

Under rational expectations economic agents are supposed to use current and past information efficiently. In terms of equation (8) this implies that the error in forecasting future inflation ( $p_{t+1}$ ) is uncorrelated to the set of information  $z_t$  available at date  $t$ , that is

$$E \{ (p_t - f p_{t-1} - (1-f) p_{t+1} - g p_t^* - l \Delta e_t - d x_t) z_t \} = 0 \quad (9)$$

Where  $z_t$  is a vector of variables (instruments) dated at  $t$  and earlier. A natural way to deal with the estimation of equation (1) is to use the Generalized Method of Moments (GMM), developed by Hansen (1982) which is a generalization of the method of moments. In what follows we present a brief description of GMM and some methodological issues related to time series estimation using this method. We stress two main advantages of the GMM estimation: (i) it does not require imposing a certain probability distribution to the variables and (ii) it is consistent with the assessments of inter-temporal optimizing behavior by economic agents.

Suppose we have a set of observations of a random variable  $y$ , whose probability function depends on a vector of  $k$  unknown parameters denoted by  $\mathbf{q}$ . We can then define

$$E(g(y_t, \mathbf{q})) = 0 \quad \text{for } \mathbf{q} = \mathbf{q}_0 \quad (10)$$

as a vector of the moment conditions of  $y$ .

The sample counterpart of the population moment condition is

$$g_T(\mathbf{q}) = \frac{\sum_{t=1}^T g(y_t, \mathbf{q})}{T} \quad (11)$$

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<sup>2</sup> The nominal exchange rate corresponds to the multilateral exchange rate with the three main trade partners of Argentina. The output gap is calculated according to the Production Function methodology.

If the number of moment conditions is equal to the number of parameters to be estimated,  $a=k$ , we have a system of  $k$  equations and  $k$  unknowns, which can be perfectly identified.

The Method of Moments estimator  $\hat{\mathbf{q}}$  can be defined as that which equals the sample moment with the population moment.

$$g_t(\hat{\mathbf{q}}) = \frac{\sum_{t=1}^T g(y_t, \hat{\mathbf{q}})}{T} = 0 \quad (12)$$

If the number of moment conditions exceeds the number of unknown parameters,  $a > k$ , the system is over-identified, since there does not exist a unique  $\hat{\mathbf{q}}$  satisfying (12). The

Generalized Method of Moments proposes to use  $\hat{\mathbf{q}}$

$$\hat{\mathbf{q}}_{GMM} \equiv \arg \min g_t(\mathbf{q})' C_T g_t(\mathbf{q}) \quad (13)$$

where  $C_T$  is a symmetric positive definite matrix, known as the “weighting matrix” that weights the moment conditions as to solve (13).

Hansen (1982) proposes a method to chose  $C_T$  optimally, that is, to obtain the  $\hat{\mathbf{q}}$  with the minimum asymptotic variance

$$C_T \xrightarrow{p} \partial E[g_T(\mathbf{q}_0)g_T(\mathbf{q}_0)']$$

where  $\partial$  is constant.

Hansen shows that given S

$$S = \lim_{T \rightarrow \infty} T.E[g_T(\mathbf{q}_0)g_T(\mathbf{q}_0)']$$

the optimum value of the matrix  $C_T$  is given by  $S^{-1}$ , the inverse of the asymptotic variance covariance matrix. Then, the minimum variance estimator of  $\theta$  is obtained by

choosing  $\hat{\mathbf{q}}$  as to minimize



$$Q(\mathbf{q}) = [g_T(\mathbf{q})]' S^{-1} [g_T(\mathbf{q})] \quad (14)$$

Assuming that  $g_T(\mathbf{q}_0)$  is not serially correlated,  $\hat{\mathbf{q}}$  is a consistent estimator of  $\mathbf{q}_0$ .

$$\hat{S} \equiv (1/T) \sum_{t=1}^T g_t(\hat{\mathbf{q}}) g_t(\hat{\mathbf{q}})' \xrightarrow{p} S \quad (15)$$

The estimation of  $\hat{S}$  requires having a previous estimation of  $\hat{\mathbf{q}}$ . Thus, substituting  $C_T$  in (13) by the identity matrix  $I$ , an initial estimation of  $\hat{\mathbf{q}}$  is obtained and then used in (15) to obtain an initial  $\hat{S}_0$ . The expression (14) is minimized using  $S^{-1} = \hat{S}_0^{-1}$ , to obtain a new estimation of  $\hat{\mathbf{q}}$ . The process can be repeated until  $\hat{\mathbf{q}}^j \equiv \hat{\mathbf{q}}^{j+1}$ .

If the vector  $g_T(\mathbf{q}_0)$  is serially correlated, the matrix  $\hat{S}$  will have the following structure

$$\hat{\Omega}_{HAC} = \hat{\Gamma}(0) + \left( \sum_{j=1}^{T-1} k(j, q) (\hat{\Gamma}(j) + \hat{\Gamma}'(-j)) \right) \quad (16)$$

where

$$\hat{\Gamma}(0) = \frac{1}{T} \left( \sum_{t=1}^T g_t(\hat{\mathbf{q}}) g_t(\hat{\mathbf{q}})' \right)$$

is White's heteroskedasticity consistent covariance matrix and

$$\hat{\Gamma}(j) = \frac{1}{T} \left( \sum_{t=j+1}^T g_t(\hat{\mathbf{q}}) g_{t-j}(\hat{\mathbf{q}})' \right)$$

describes the autocovariances and  $k(j, q)$  is a kernel

The matrix  $\hat{\Omega}_{HAC}$  is known as the Heteroskedasticity and Autocorrelation Consistent (HAC) Covariance Matrix. The estimation of  $\hat{\Omega}_{HAC}$  needs to specify a kernel, used to weight the covariances so that  $\hat{\Omega}_{HAC}$  is positive semi-definite and a bandwidth which is a lag truncation parameter for the autocovariances.

Two type of kernel are commonly used in the estimation of  $\hat{\Omega}_{HAC}$ , Barlett and quadratic spectral.<sup>3</sup>

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<sup>3</sup> See E-Views User's Guide for specific functional forms (pgs. 498, 499).

With regards to the bandwidth selection, different methods have been developed. The E-View program provides three methods: Fixed Newey-West, Variable Newey-West (1994) and Andrews (1991).

The use of the GMM estimator implies that number of orthogonality conditions exceeds the number of parameters to be estimated, thus the model is overidentified, since more orthogonality conditions than needed are being used to estimate the parameters. Hansen (1982) suggests a test of whether all of the sample moments are close to zero as would be expected if the corresponding population moments were truly zero.

Hansen's test of over-identifying restrictions can be conducted using the *J-statistic* reported in E-Views and using it to construct the following statistic:

$$T.J - statistic \sim \chi^2(p - q)$$

where  $p$  represents the number of orthogonality conditions and  $q$  the number of parameter to be estimated.

## **4. Empirical results**

### **4.1. A brief descriptive analysis**

We estimate equation (8) for the period 1993.1-2003.12, using monthly information. This period includes two very different exchange and monetary regimes: a currency board, known as the "Convertibilidad", at place between 1993 and 2001 and a dirty float from then on. Inflation was stable and low under the "Convertibilidad" period. There was even a deflationary period during the prolonged recession that unchained in the third quarter of 1998. This recession ended in a financial crisis at the end of 2001. In January 2002 the currency board regime was abandoned, the peso was devalued, and a dirty float scheme was adopted since then. An interesting phenomenon was that, in spite of strong expectations of an acceleration of inflation after the abandonment of the currency board, inflation reached a peak of 18.4% (annual) in April 2002 and then decelerated significantly, remaining stable and low. There are still quite few observations of the new regime, part of which belong to a turbulent period of financial distress. This makes difficult to model inflation and puts some warnings on the stability

of these results as long as more observations of the new regime were added to the sample. Figures 1 to 3 illustrate the relationship between domestic inflation and its main determinants over the period of analysis.

Figure 1: Domestic Inflation and nominal devaluation

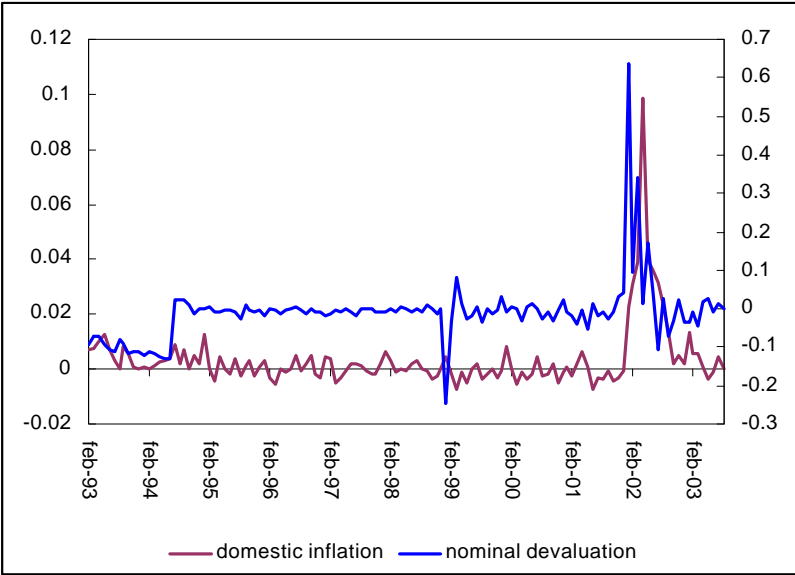


Figure 2: Domestic and Foreign Inflation

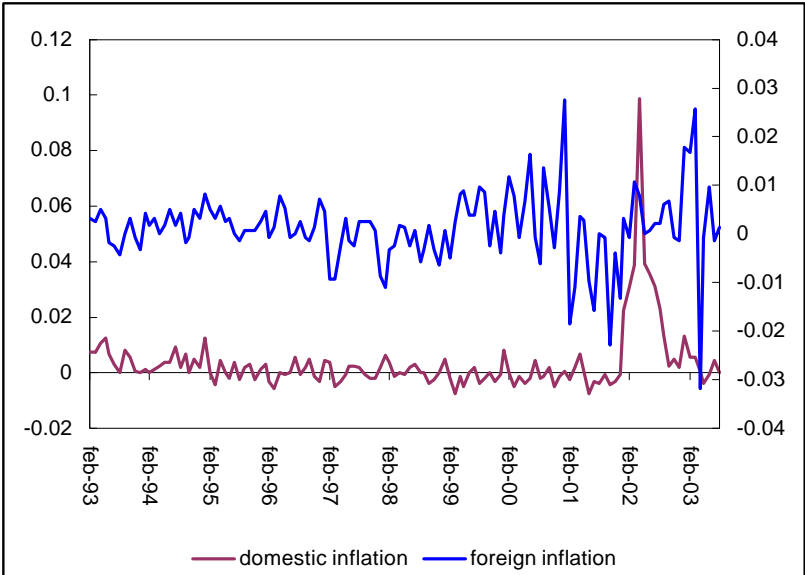


Figure 3: Domestic Inflation and the Output Gap

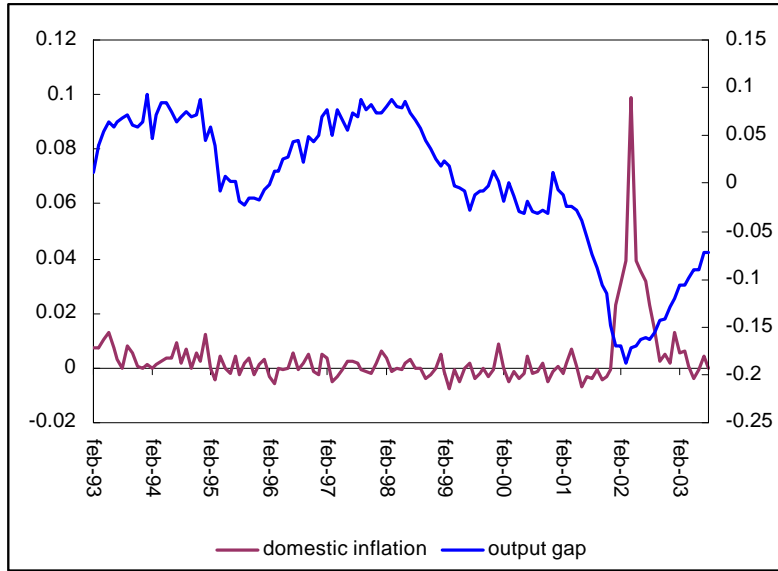


Figure 1 shows the weak response of domestic inflation to the sharp nominal devaluation and also how rapid it decelerated, following the stabilization of the nominal exchange rate converging to its average during Convertibility. Figure 3 depicts the relationship between the output gap and domestic inflation, showing the persistent negative values of the output gap since April 1999, reaching a trough in February 2002, after the devaluation in January of the same year. Inflation had a weak response to the deep and lasting decay in economic activity and prices even showed a deflationary tendency. Although there was a positive response to the nominal devaluation of January 2002, as said before, inflation rapidly slowed down, probably due to the high levels of unemployment and capacity utilization.

#### 4.2. Estimation results

We estimate a reduced form of the “Hybrid New Keynesian Phillips Curve”, given by equation (8), which provides interesting information about the dynamics of inflation. In particular the relevance of forwardness in price setting behavior by firms is an issue that has not been investigated yet for Argentina. Rather than imposing the verticality of the Phillips Curve in the long run, we test for it, specifying (8) as follows

$$\mathbf{p}_t = \mathbf{f}_1 \mathbf{p}_{t-1} + \mathbf{f}_2 E_t(\mathbf{p}_{t+1}) + \mathbf{g} \mathbf{p}_t^* + \mathbf{l} \Delta e_t + \mathbf{d} x_t + \mathbf{e}_t \quad (8')$$

We then estimate equation (8') using GMM. Nine lags of all variables are used as instruments. To test for the robustness of our results, we conducted several estimations of (8') using the different specifications for matrix  $\hat{\Omega}_{HAC}$  described in section 3. As can be seen from *Table 1* the estimations are quite robust to changes in the specification of  $\hat{\Omega}_{HAC}$ . For this reason, our preferred form for  $\hat{\Omega}_{HAC}$  is Variable Newey – West, which selects the band-width based on the autocorrelation in the data and thus is the more flexible one. Tests for over-identifying restrictions, applied to each of the estimations confirm that the instruments are valid in all cases.

*Table 1. Estimation results*

<i>GMM estimates</i>	<i>Newey-West (nw) Fixed (4)</i>	<i>Andrews (2.88)</i>	<i>Variable Newey-West (9)</i>
$f_1$	0.561700	0.560719	0.450607
<i>Std. Error</i>	0.0493	0.0654	0.0337
$f_2$	0.160795	0.135870	0.207878
<i>Std. Error</i>	0.0358	0.0598	0.0252
$d^*$	0.015912	0.017891	0.016610
<i>Std. Error</i>	0.0049	0.0058	0.0028
$g^*$	0.38148	0.373438	0.325374
<i>Std. Error</i>	0.0930	0.1047	0.0546
$l^*$	0.028426	0.033837	0.025128
<i>Std. Error</i>	0.0059	0.0075	0.0041
<i>J-statistic</i>	0.117078	0.140565	0.094189

\* These coefficients correspond to the first lag of foreign inflation and nominal devaluation respectively.

As said before, we concentrate on the results of the model using the Variable Newey-West specification, which is also the one that yields the better estimation in terms of the individual significance of variables and the overidentifying restrictions test. A first important finding is that there is a significant forward-looking component in price formation. The backward looking component is also relevant, but the relative values of  $f_1$  and  $f_2$  indicate more weight of the backward looking component.<sup>4</sup> We checked for the validity of imposing verticality in the long run, and we couldn't reject the null (see *Table 2*).

<sup>4</sup> We tested for equal weights of the backward and forward looking components and the hypothesis was strongly rejected at the conventional significance levels.

Table 2: Testing for linear restrictions

<i>Linear Restriction:</i>			
$f_1 + f_2 + g + 1 = 1$			
<i>Test Statistic</i>	<i>Value</i>	<i>df</i>	<i>Probability</i>
<i>F-statistic</i>	0.0241	(1, 115)	0.8769
<i>Chi-square</i>	0.0241	1	0.8766

Given that we are extending the model to the case of a small open economy it is interesting to observe that changes in foreign inflation and nominal devaluation have a significant effect on domestic inflation. Inflation responds to lagged values of both, nominal devaluation and foreign inflation. While the response of domestic prices to changes in foreign inflation is quite important, of around 0.33, its response to nominal devaluation, although significant, is much weaker. These results have to be taken cautiously, since most part of the sample we are considering here corresponds to the “Convertibilidad” period over which the peso was fixed to the dollar. We also find a weak response of domestic inflation to changes in the output gap. This is frequent empirical finding in the literature on short-run inflation dynamics.

Summing up, our results suggest that a hybrid representation of the “New Keynesian Phillips Curve” adequately describes inflation dynamics in Argentina over the period 1993-2003. The estimates indicate that both components, forward and backward-looking appear to be significant in price formation decisions. Finally, we find strong evidence of verticality in the long run.

## 5. Conclusions

Recent developments in the empirical modeling of short-run dynamics of inflation assume inter-temporal optimizing behavior by non-competitive firms. The empirical relevance of persistence in inflation dynamics has led to introduce backwardness in these models by assuming that a portion of the firms could follow a backward-looking rule. The resulting model is known as the “Hybrid New Keynesian Phillips Curve”. Using GMM, we estimate a “Hybrid New Keynesian Phillips Curve” for Argentina over the period 1993-2003. We extend the basic model to the case of a small open economy, allowing nominal devaluation and foreign inflation to play a role in domestic prices setting. We find that both components, forward and backward are relevant to explain the dynamics of domestic prices, although the backward-looking component weights more in determining inflation dynamics. Nominal devaluation and foreign

inflation are also significant to explain domestic inflation behavior, being the response of inflation to the second more intense. The output gap, although weak, has a significant effect on inflation. We cannot reject verticality of the Phillips Curve in the long run.

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