The Statistical Persistence of Inflation in Colombia

Juan José Echavarría S., Enrique López E. and Martha Misas A.*

1. INTRODUCTION

Inflation persistence is an analogue concept to that of inertia in physics: the more inertia has a body, the greater the force required for its motion to return to its pre shock state (Fuhrer, 2009). In the same way, the greater the inflation persistence, the larger the decrease in GDP and employment required for inflation to return to its previous level. A high degree of persistence means authorities have to act in advance to stave off the lasting effects of shocks, as well as raise interest rates further and for longer periods in order to reduce inflation. Low persistence, on the other hand, allows for modest responses to cost shocks and the adoption of fast disinflationary policies.[1]

Furthermore, variations in inflation persistence can explain changes in the capacity of the yield curve to predict the business cycle, implying that high inflation persistence leads to greater reductions in GDP when contractionary monetary policy is adopted.[2] Finally, similar levels of persistence facilitate monetary integration between countries because they mean common shocks have similar effects (Franta, Saza, and Smidkova, 2007).

* J. J. Echavarría S., and E. López E. are researchers at Banco de la República, Colombia, and M. Misas A. is associate professor at Pontificia Universidad Javeriana. The points of view expressed in this paper are not necessarily shared by Banco de la República or its Executive Board. The authors would like to thank Leonardo Bonilla M., Andrés Giraldo P., Norberto Rodríguez N. and Luis Eduardo Rojas D. for their collaboration.

[1] See Altissimo, Ehrmann and Smets (2006) and Rudd (2005).

[2] Bordo and Haubrich (2004) and Kang, Kim and Morley (2009).

Statistical, or *reduced*, *persistence* is related to certain empirical regularities of inflation and occurs when inflation remains far from its mean after a shock,[3] while structural persistence includes *structural* economic factors which produce statistical persistence. A large body of recent research on inflation persistence has been focused on the relation between statistical persistence and the economic –structural factors determining them.

Proper measurement of *statistical persistence* is a first step towards understanding the phenomenon. It also allows authorities to make accurate forecasts of future inflation, an important factor in an inflation targeting scheme (named inflation-forecast targeting by Svensson, 2005). A high level of uncertainty regarding statistical persistence would make it recommendable to avoid any abrupt changes in economic policy instruments (Brainard, 1967) unless this was going to adversely affect inflation expectations.

However, the discussion on persistence must go beyond this and question the economic reasons producing the patterns observed in statistical persistence. Can a microfounded Phillips curve produce inflation persistence when there are rational expectations? What is the relative importance of the Phillips curve and the Taylor rule for explaining persistence? And how important is central bank credibility and the evolution of inflation targets? What monetary policy characteristics produce persistence?

Section 2 of this paper analyzes the *structural* factors possibly associated with statistical persistence. Section 3 discusses methodological aspects related to its measurement and presents a brief summary of international empirical evidence. Section 4 applies different methodologies to the case of Colombia. In particular, it evaluates the level of integration and the sum of autoregressive coefficients in determined subperiods using a Markov-Switching methodology, estimating the degree persistence changes over time for the spread between observed inflation and the inflation target. Section 5 gives the conclusions.

2. *STRUCTURAL* FACTORS. A RESEARCH PROGRAM FOR COLOMBIA

Although the main objective of this paper is the measurement of statistical persistence (sections 3 and 4), it is still important to show the economic

[3] When the series is stationary. If the series were not stationary then the shock would be permanent. See 3.1.

factors which determine it. As mentioned previously, a large amount of recent research on inflation persistence has referred to the relation between *statistical persistence* and *structural persistence*. The questions posed suggest a long term research program for Colombia.

2.1 Structural Factors Explaining Persistence

Before beginning it is important to emphasize the difficulties involved in evaluating the relative importance of different *structural* factors, given that they interact with general equilibrium and their relative importance can depend on the monetary regime (Angeloni et al., 2005). Such factors could also be surrounded by wide ranging uncertainty, in which case it might be necessary to evaluate the costs and benefits of employing the *incorrect* model.[4]

If we start from the version of the economy shown in equations (1) to (4) with two alternative Phillips curve models:

New Keynesian Phillips curve

(1) $$\pi_t = \beta E_t \pi_{t+1} + \phi_x x_t + u_t \quad \text{with } \beta \approx 1 .$$

Hybrid Phillips curve

(2) $$\pi_t = (1-\beta)\pi_{t-1} + \beta E_t \pi_{t+1} + \phi_x x_t + u_t .$$

IS

(3) $$x_t = \sigma_{x-1} x_{t-1} + (1-\sigma_{x-1}) E_t x_{t+1} - \sigma_r (R_t - E_t \pi_{t+1}) + \varepsilon_t .$$

Taylor rule

(4) $$R_t = \rho(L) R_{t-1} + (1-\rho)\left[r^* - (\tau_\pi - 1)\pi^* + \tau_\pi \pi_t + \tau_x x_t \right],$$

where π_t is the inflation rate; β, the discount factor; x_t, the output gap; u_t and ε_t correspond to supply (i.e., an international oil price shock) and demand shocks; R_t is the nominal interest rate and r the real interest rate; ρ is a smoothing parameter in the fixing of nominal interest rates by the central bank; super index * indicates the variable's target, which in literature mostly coincides with its *natural* equilibrium or long-term steady-state.[5]

[4] For the case of the Phillips curve see Sbordone (2007).

[5] More precisely, in several cases it concerns the deviation between the variable and its stationary position. See section 2.3.1.

Equation (1) corresponds to the so-called New Keynesian Phillips curve with rational agents that intertemporally maximize, and with a random proportion $(1-\theta)$ of firms who can adjust prices in each period (Calvo, 1983).[6] It is also assumed that there is a constant relation between real marginal costs and output gap, that the markup is constant throughout the cycle and that steady-state inflation equals zero $(\pi^{*}=0)$.

As will be seen, there is no inflation persistence (or it is very low) when the Phillips curve is as in (1), indicating that price rigidities (implicit in Calvo's model) do not explain inflation persistence.[7] The alternative Phillips curve represented in equation (2) is known as *hybrid* and adds lagged inflation π_{t-1}. Empirical evidence places significant weight on this variable, even though it is not easy to explain its inclusion in theoretical models where agents have rational expectations.

Equation (3) corresponds to the curve IS and (4) to a Taylor rule with interest rate smoothing by the Central Bank (Clarida, Galí and Gertler, 2000). The so-called Taylor principle $(\tau_{\pi}>1)$ is a necessary condition for the system's stability. It means that when inflation grows the authorities must raise nominal interest rates more than proportionally. This guarantees an increase in the real interest rate, a decrease in the output gap (in the IS) and a reduction of inflation (in the Phillips curve) to its previous level. The Taylor principle guarantees that the inflation series is $I(0)$ given that the authorities make it return to its previous level and the shock dissipates after some time.[8]

What is the relation between the parameters of equations (1)-(4) and *statistical persistence*? In order to understand the effect of some of the main parameters in the above system Fuhrer (2009) reduces them to a *minimum* model shown by equations (5)-(7):

Phillips curve

$$\pi_t=\pi_{t-1}+\phi_x x_t\ , \tag{5}$$

[6] Empirical evidence tends to support Calvo's model above other rigid price models such as Taylor's (1979). See Angeloni et al. (2005).

[7] Formally, Calvo's model sustains that $p_t=\theta p_{t-1}+(1-\theta)p_t^{*}$, where p_t^{*} is the optimum price fixed by firms which are able to re-optimize. There are rigid prices, with p_{t-1} on the right hand side.

[8] Formally, the *Taylor principle* guarantees the existence of a unique stationary equilibrium in the system (Walsh, 2004, pp. 247). In their classic paper, Clarida, Galí, and Gertler (2000) suggest that the Taylor principle was not followed in the US during pre-Volcker administrations but was applied in the Volcker-Greenspan administrations.

IS

(6) $$x_t = -\sigma_r r_t \,,$$

Taylor rule

(7) $$r_t = \tau_\pi \pi_t \,.$$

Inflation expectations and supply shocks in the Phillips curve disappear in this *minimum* model, as do lagged GDP and demand shocks in the IS, while it is assumed that the authorities' only objective is to control inflation with $\pi^* = 0$. Substituting (6) and (7) in (5) gives $\pi_t = \pi_{t-1} + \phi_x(-\sigma_r)(\tau_\pi \pi_t)$. From which one can deduce:

(8) $$\pi_t = a\pi_{t-1} \quad \text{with } a = \frac{1}{1+\tau_\pi \sigma_r \phi_x}.$$

Equation (8) shows that inflation persistence is low for high values of τ_π, σ_r y ϕ_x. Furthermore, the particular shape of the Phillips curve (5) suggests that variable π_{t-1} is important in explaining persistence (see below). Intuitively, in order for inflation persistence to be low the authorities must raise interest rates in the event of an inflation shock (*Taylor principle*, $\tau_\pi > 1$),[9] this increase in interest rates reduces the output gap in (6), which depends on σ_x in the IS curve, and this fall in x then reduces inflation in the Phillips curve through parameter ϕ_x.

The previous model allows identification of some of the main characteristics which lead to inflation persistence. Fuhrer (1995) sets forth a slightly more complex model which requires numerical solutions, although some of its results are similar to those of the simplified model. The exercise also shows the evolution of the output gap and the sacrifice ratio for different scenarios.[10] The sacrifice ration (SR) is defined as the cost society must pay in terms of GDP loss –unemployment in order to reduce inflation by one point.

[9] Besides, Section 2.5 argues that a low value of τ_π (i.e. a high value of τ_x) leads to higher persistence through expectations when these are not rational. An active central bank, overly concerned about the output gap can delay agents' process of learning and increase inflation persistence. Beeche and Osterholm (2009) suggest some of the reasons that could lead the authorities to high τ_x. The relative weight of new members with this vision on the Central Bank's Board, political pressure or empirical evidence on the high costs of reducing inflation.

[10] See also the calibration exercises presented by Beechey and Osterholm (2009).

The author compares the level of persistence produced by the Phillips curves (1) and (2). The Taylor rule with and without interest rate smoothing and the Taylor rule when parameter τ_x is increased (parameter τ_π is reduced). In addition, the numerical exercises assume that $\tau_\pi = 1.5$ y $\tau_x = 0.5$, a standard assumption in Taylor rule empirical evaluations. It also gives equal weight to π_{t-1} and $E_t\pi_{t+1}$ in the *hybrid* Phillips curve. Its shows that the Phillips curve plays an important role and that it is impossible to explain the persistence of equations' system without including π_{t-1} in said curve.

The author also shows that the New Keynesian Phillips curve (1) leads to immediate disinflation, without persistence, and to disinflation with a little persistence when there is simultaneous smoothing of nominal interest rates in Taylor rule. This therefore suggests that monetary policy persistence (rate smoothing) is not sufficient to explain high values of inflation persistence.

Little inflation persistence is observed for the New Keynesian Phillips curve with rational expectations (1) because expectations are totally flexible and π_t can be modified immediately in response to changes in output gap. Such flexibility is also observed in *stock* type models, useful for explaining the behavior of the US dollar or shares on the stock Exchange, in which future expectations play an important role. On the other hand, when the output gap changes and the Phillips curve is *hybrid*, π_t cannot fluctuate freely because it partly depends on π_{t-1}, a variable which has already happened.

Price and wage rigidities increase the *impact* of monetary policy on production, but do not explain inflation persistence or the persistent effects of monetary policy on production. Mankiw (2001) makes an analogy with the relation between the behavior of capital stock and capital investment in growth models. In Calvo's (1983) model, higher θ, corresponding to greater price rigidity only produces lower ϕ_x.[11] Thus, in a less steep Phillips curve: when there are few opportunities for changing prices, firms cease to be interested in current demand and focus their attention more on future inflation as a determinant of current inflation.

[11] Fulfilling that $\phi_x = \frac{(1-\theta)(1-\theta\beta)}{\theta}$. Higher θ, corresponding to greater rigidity, produces a lower value ϕ_x. Sbordone (2007) shows that the coefficient ϕ_x declines even further when there are *strategic complementarities* among firms. Cogley and Sbordone (2005) also consider the case where capital cannot be reassigned instantaneously among firms.

Second, disinflation overshooting is produced when the Phillips curve is as in (1) and, even further, when there is smoothing of interest rates in Taylor rule. If the Central Bank raises interest rates in order to reduce inflation a negative gap is produced in (1) with $\pi_t < E_t\pi_{t+1}$ (not exactly a disinflation). The only way to avoid this is if inflation jumps downwards immediately and then reaches its long term level (0%) from below. Disinflation produces *bonanzas* in some subperiods. In such case there is a negative correlation between inflation and output gap, a paradoxical result, because disinflation produces *bonanzas* in some subperiods.[12]

The costs of disinflation are null or very low for Phillips curve (1), with a sacrifice ratio (SR) equal to zero if there is no interest rate smoothing,[13] and 0.7 when smoothing exists. On the other hand, the *hybrid* Phillips curve gives sacrifice ratios of 2.0 and 4.1 (with and without rate smoothing, respectively), closer to those observed in reality. Ball (1993) for instance finds a sacrifice ratio of 2.93 in Germany and 2.39 in the United States.[14]

A large amount of recent discussion on the topic analyzes the importance of the different components on the right hand side of equation (2). What is the role of output gap x_t (*inherited* or *intrinsic* persistence), or that of inflation expectations ($E_t\pi_{t+1}$), of π_{t-1} (*intrinsic* persistence), and supply shocks (persistence in the *error*)? The main conclusion is that the *hybrid* Phillips curve plays the determining role.

Finally, Fuhrer (2009) puts forward a general dynamic and stochastic equilibrium model with which it is possible to obtain more accurate conclusions, many of them coinciding with those given by the previous exercises. Among these are:

[12] The phenomenon of *disinflationary overshooting* is produced by the assumption of rational expectations and does not occur when expectations exhibit persistence. One way to understand the negative relation between inflation and output gap is as follows: lagging equation (1) with the assumption that $\beta = 1$ and adding π_t on both sides would give that $\pi_t = \pi_{t-1} - kx_{t-1} - E_{t-1}\pi_t + \pi_t$. This implies that: $\pi_t - \pi_{t-1} = -kx_{t-1} + \varepsilon_t$, where $\varepsilon_t = \pi_1 - E_{t-1}\pi_t$. Thus, the negative output gap will lead to growing inflation. Ball (1992) and Mankiw (2001) explain it simply. If announced disinflation is credible, firms who can adjust their prices will reduce the size of increases, even before money supply dynamics are reduced. Real balances (M/P) and output will grow.

[13] Calvo's model assumes rational expectations and includes a Phillips curve as in (1). It shows that the authorities can keep inflation under control, without costs, sustaining output close to its potential.

[14] Although it is much lower in France (0.75) or the UK (0.79). See also Cecchetti and Ric (2001). Gómez (2002) finds an average sacrifice ratio of 1.34 for Colombia during the 1990s.

- As mentioned above, inflationary inertia is shown to have a close relation with the presence of variable π_{t-1} in the Phillips curve (*intrinsic* persistence). Inflation falls immediately and inflationary inertia is minimal when $\phi_{\pi-1} = 1 - \beta = 0$ in (2).
- *Inherited* persistence, stemming from x_t in the Phillips curve is unlikely to play an important role. The pattern of inflation is relatively similar when ϕ_x varies from 0.10 to 0.25.[15] Furthermore, the volatility of supply shocks u_t decreases the persistence generated by x_t.[16] Finally, the persistence of x_t *has not decreased* over time, making it difficult to explain the reductions in inflation persistence (under discussion) from the behavior of x_t (Fuhrer, 2009, p. 39).
- The pattern of inflation is relatively similar when the variance of u_t changes (the supply shock in the Phillips curve) from 0.5 to 0.1, or when parameter σ_{x-1} changes in the IS curve from 0.5 to zero.
- The characteristics of monetary policy difficulty explain observed inflation persistence (see Section 3.2). Not even a value of τ_π equal to five in the Taylor rule manages to reduce inflation persistence slightly.

2.2 Including π_{t-1} in the Phillips curve

It is difficult to explain inflation's high *statistical persistence* (an ongoing debate) or obtain a successful empirical adjustment in the Phillips curve if π_{t-1} is not included. Thus, for the *tripod* model (Gordon, 1997), in which the oil price is added to the equation (2), including π_{t-1} raises the coefficient R^2 from 0.24 to 0.74 during the period 1966Q1-1984Q4, from 0.79 in the period 1985Q1-2008Q4, from 0.39 to 0.77 in 1996Q1 to 1984Q4, and from 0.16 to 0.72 in 1985Q1 to 2008Q4 (Fuhrer, 2009). In the same direction, Rudd and Whelan (2005) find that only a small percentage of

[15] Besides, some authors such as Williams (2006) and Mishkin (2007) state that ϕ_x has declined over time. Meanwhile, Dupuis (2004) and Linde (2005) find relatively stable parameters in the Phillips curve.

[16] Even with high persistence of x_t (i.e. between 0.9 and 0.95) and a high ϕ_x parameter (i.e. close to 0.01), inflation persistence is below 0.3 when the variance of supply shocks is high. Persistence values in real activity are in any case very high. The first-order autocorrelation coefficient varies between 0.80 and 0.92 for different subperiods, while that of the output gap varies between 0.80 and 0.92. The sum of autoregressive coefficients fluctuates between 0.78 and 0.96 (different periods) for the real marginal cost, and between 0.77 and 0.97 for the output gap.

the good adjustment of the *hybrid* Phillips curve comes from future inflation expectations or the output gap. Meanwhile, Estrella and Fuhrer (2002) conclude that that models including π_{t-1} tend to be more stable over time than those only using inflation expectations.[17]

Based on models which allow some *irrationality*, Smets (2004) and Galí and Gertler (2000) find a weight of 0.52 and 0.25 for π_{t-1}, respectively, while Paloviita (2004) finds that π_{t-1} significantly contributes to explaining π_t when the Organisation for Economic Co-operation and Development (OECD) inflation expectations are used as a proxy for expectations.

It is not necessary to assume adaptive expectations in order to explain the importance of π_{t-1} in the Phillips curve. For some authors the importance of π_{t-1} is spurious because it detaches from Calvo's model with rational expectations but with inflation targets different from zero or with non-random hazard functions, while for others it obeys the central bank's learning processes and lack of credibility. Empirical works show that the importance of π_{t-1} in the Phillips curve is low when inflation expectations are anchored (Altissimo, Ehrmann and Smets, 2006). For the same reason the impact of shocks other than Mishkin's (2007) output gap would seem to be lower nowadays.

2.3 Modifications to Calvo's Model (with Rational Expectations)

2.3.1 Inflation Target Different to Zero

For some authors it is not necessary to sacrifice the hypothesis of rational expectations or the policy implications caused by a microfounded Phillips curve (1). It is enough to eliminate the assumption that the inflation target is equal to zero in order to produce the alternative Phillips curve shown in (9).[18]

$$(9)\qquad \hat{\pi}_t = \phi_{\pi_{-1},t}\left(\hat{\pi}_{t-1} - \hat{g}_t^{\pi^*}\right) + \phi_{x,t}\hat{x}_t + \phi_{\pi_{+1},t}\tilde{E}_t\hat{\pi}_{t+1} + b_{\pi_{+j}}\tilde{E}_t\sum_{j=2}^{\infty}\phi_t^{j-1}\hat{\pi}_{+j} + u_t\,.$$

where π^* is the inflation target (or trend inflation), $\tilde{\pi}_t = \frac{\pi_t}{\pi^*}$ is the relation between inflation and the target, equal to one in its steady-state, and

[17] See also Rudebusch (2002).
[18] See Cogley and Sbordone (2006) and Cecchetti et al. (2007).

$\hat{g}_t^{\pi^*} = \frac{\pi_t^*}{\pi_{t-1}^*}$ corresponds to the target growth rate; finally $\hat{\pi}_t = \ln\left(\frac{\pi_t}{\pi_t^*}\right)$. The New Keynesian equation (1) coincides with (9) when $\pi_t^* = 0$ or when $\phi_{\pi_{-1},t} = 1$ (complete indexation). The assumption of an inflation target equal to zero is even less appropriate for a country like Colombia than for the US or Europe. As figure 1 shows, inflation targets in Colombia have been high and have decreased only gradually.

Equation (9) has three radically different characteristics from equation (1). First, the coefficients are now variable over time, even for parameters that are mainly constant in Calvo's model. Second, parameter $\phi_{x,t}$ is low (the sacrifice ratio) when the inflation target is high. In other words, a high inflation target makes reducing inflation more costly and could cause the authorities not to do so. Finally, the expected value for future inflation in (9) could be correlated with π_{t-1}, meaning the *successful* inclusion of the latter variable in empirical calculations could be erroneous (it obeys omitted variables). In fact, Altissimo, Ehrmann and Smets (2006) and Cogley and Sbordone (2006) show that *intrinsic* persistence (due to π_{t-1}) is reduced when long-term values for inflation are included. Given all the aforementioned, the microfounded Phillips curve (1) could be a good approach for designing optimum monetary policy.

2.3.2 Functions of Hazard Variables

Calvo's model assumes that changes in prices are random, but Gooodfriend and King (1999) and Wolman (1999) work with a more realistic assumption according to which the probability of changes in prices is higher when they have remained unchanged for a long period of time. Woodford (2007) shows that this case leads to the following equation for the Phillips curve:

$$\pi_t - \gamma\pi_{t-1} = \beta E\left[\pi_{t+1} - \gamma\pi_t\right] + \phi_x E_t\left[\left(1 - L^{-1}\right)^{-1} x_t\right]. \tag{10}$$

Where $0 < \gamma < 1$ in the case of a growing hazard function ($\gamma = 0$ in Calvo's model). Again, the relevance of variable π_{t-1} is spurious, and optimum monetary policy coincides with that derived from the microfounded Phillips curve (1).[19]

[19] Notwithstanding, Rudd and Whelan (2006) state that the expected sign for π_{t-1} is negative in this model, the opposite of that obtained in empirical calculations.

2.4 Learning Processes

The assumption of adaptive expectations would adequately explain the existence of π_{t-1} in the Phillips curve in the way originally set forth in the inflation models suggested by Friedman (1968) and Phelps (1967), although it seems insufficient in light of Lucas's so-called criticism (Mankiw, 2001). In any case, several recent empirical studies have been forced to abandon the assumption of perfect rationalism.

Christiano, Eichenbaum, and Evans (2005), for instance, assume that firms which do not re-optimize in Calvo's (1983) model, index their prices to the preceding period's inflation. Formally, firms which do not re-optimize remain constant $p_t(i)-\gamma p_{t-1}$, where γ corresponds to the indexation level of such prices, where $p_t(i)$ is the logarithm of the good's price *i*, and p_{t-1} is the logarithm of the aggregate level of prices in *t*−*1*.This therefore leads to the following hybrid Phillips curve $\pi_1-\gamma\pi_{t-1}=\phi_x x_t+\beta E_t\left[\pi_{t+1}-\gamma\pi_t\right]$ (Woodford, 2007, pp. 204). The authors' assumption appears inconvenient in light of empirical evidence because agents are not changing prices all time.[20]

Meanwhile, Galí and Gertler (2000) justify including π_{t-1} in the Phillips curve by assuming that firms which randomly decide to re-optimize their prices in Calvo's (1983) model follow a rule of thumb, with prices representing average weighted optimum prices fixed in the preceding period plus an adjustment for past inflation.

Small deviations from the rational expectations assumption can drastically change the model's results. Angeloni et al. (2005) show two examples: imperfect information on the shock's characteristics (e.g., temporary versus permanent) can produce persistence and a gradual response from agents; something similar happens when there are agents' learning processes and the authorities hamper them by preferring a high value of τ_x (or a low value of τ_π) in the Taylor rule.[21] Collard and Dellas (2004), Erceg and Levin (2001), and Milani (2005) include learning dynamics with transitory differences in the rational expectations model. Again, as in previous cases, the importance of coefficient π_{t-1} in empirical estimations of the Phillips curve is spurious and results from the correlation between lagged inflation and *irrational- subjective* forecasts for inflation.

[20] See Woodford (2007) and Sbordone (2007). Regarding price fixing schemes see Blinder (1991) for the US and Julio, Zárate, and Hernández (2010) and Zárate (2010) for Colombia.

[21] See also Orphanides and Wiliams (2005).

2.5 Central Bank Credibility

Svensson (1999) mentions the uncertainty of the model (e.g., uncertainty concerning the natural interest rate or the process of interest rate smoothing by the central bank) as an additional factor which creates persistence, although recent literature on the subject has focused its efforts on the uncertainty related to current and future central bank policies.

The previous models assume that agents who take pricing decisions know the central bank is determined to decrease demand in order to reduce the rate of inflation and will remain committed to this. If agents expect real short-term interest rates to be high today and in the future, the long-term interest rate will be high and this will lead to a reduction in aggregate demand and inflation.

Thus, Fuhrer (1995) considers the inertia stemming from the imperfect credibility of the central bank as a third persistence factor, besides the inertia resulting from price and wage pacts or a slow adjustment in expectations. Agents basically do not believe the central bank will implement the monetary policy required to reduce inflation. Erceg and Levin (2001), for instance, show that agents' learning of central bank inflation targets can explain the gradual disinflation observed in the Volcker era. Mishkin (2007) associates the trend inflation observed before Volcker with unanchored long-term inflation expectations.

If persistence originates in the price and wage fixing process, the central bank will have to accept the costs of disinflation if it fosters it. On the other hand, if persistence originates in central bank credibility, it must decide how and when to increase its credibility. Central bank communication could be a main determining factor in said expectations and the way agents learn (Woodford, 2005).

3. *STATISTICAL PERSISTENCE.* METHODOLOGY AND INTERNATIONAL EMPIRICAL EVIDENCE

Literature on persistence measurement is usually divided into two large groups. The first group researches the level of integration of the series, while the second considers the evolution of different persistence measurements in autoregressive models for $I(0)$ series. Section 3.1 suggests that the sum of autoregressive coefficients and the impulse-response functions represent the *best* measurements in $I(0)$ series. Section 3.2 shows international empirical evidence for different indicators. Inflation persistence falls when the monetary regime (i.e. the gold standard or inflation targeting scheme) manages to anchor inflation expectations, although it is still being debated whether persistence levels in all developed nations are lower today than in the past.

3.1 Measurement Methodologies

For inflationary process $\pi_t = a\pi_{t-1} + \varepsilon_t$, in which ε_t represents a shock during period *t*, fulfills that $\pi_1 = \varepsilon_t + a\varepsilon_{t-1} + a^2\varepsilon_{t-2} + a^3\varepsilon_{t-3} + \ldots$. A high *a* coefficient equals more persistence because it reflects a higher relative impact of past shocks on π_t. Furthermore, when the series has unit root $(a=1)$ inflation variance is unlimited and persistence is infinite because all past shocks affect current inflation $(\pi_t = \sum_{i=0}^{\infty} \varepsilon_{t-i})$.

One the first steps in determining *statistical persistence* consists of establishing the level of integration of the inflation series, an area where the results of international literature have not been conclusive. A large amount of such literature finds that long term series are *I*(1), even though the unit root is rejected more frequently when short and recent periods are studied. An *I*(1) series which then becomes *I*(0) indicates that the inflationary process has become less persistent because the shock now disappears at some moment in time.

For some authors, the unit root observed in long term series (under discussion) is not due so much to inflation persistence as to the persistence of the targets implied or fixed by the central bank. Stock and Watson (2006), for instance, propose breaking down observed inflation into its permanent and transitory components, each one of these with its own variance changing over time. Meanwhile, the permanent component is associated with implicit or explicit inflation targets.[22]

For others, the series are neither *I*(1) nor *I*(0), but present intermediate levels of fractional integration.[23] This also explains the divergent results observed in practice when only two extreme possibilities are consid-

[22] The model is relatively similar to an integrated moving average process. See also Cecchetti et al. (2007).

[23] A stochastic process characterized by the presence of a fractional difference operator. Fractional integration, more commonly known as long memory, can make a series seem stationary although it has high autocorrelations which are too large to be identified by a parsimonious ARMA model. See Baillie, Chung and Tieslau (1996), Baum, Barkuolas, and Caglayan (2010) and Kumar and Okimoto (2007).

ered. It might also explain why inflation series in the US is $I(1)$ when using an AR(12) model, and $I(0)$ when using AR(3) and AR(6) models (Kumar and Okimoto, 2007).[24] Nevertheless, it is not easy to differentiate long memory processes with fractional integration from those in which the average changes (Altissimo, Ehrmann and Smets, 2006).[25]

Only when the series is not $I(1)$ does it make sense to ask questions about the levels and variations in indicators such as the autocorrelation coefficient, the largest autoregressive root, average life, the sum of autoregressive coefficients or the impulse-response function. Literature tends to favor the sum of autoregressive coefficients and the impulse-response function as persistence indicators, both of which are used in the empirical evaluation of Colombia's case shown in section 4.

Although the trend is to favor the sum of coefficients, it does not seem advantageous to ignore information provided by other roots or lags. All else being equal, an AR(2) process with 0.9 and 0.8 roots is more persistent than an AR(2) process with 0.9 and 0.1 roots.[26] The impulse-response function is also popular because it can discriminate between a process with a unit root subject to permanent variations and one subject to transitory variations (something that does not occur, for instance, with the maximum autoregressive root).[27] The two best indicators are related: the sum of autoregressive coefficients is the indicator recommended by Andrews and Chen (1994), partly because it is similar to the long term impulse-response function in the event of a unit shock. Average life has been widely used for evaluating purchasing power parity (PPP), but presents innumerable problems as a persistence indicator due, among other reasons, to the fact that there is no broad body of study on the statistical characteristics of its distribution.

[24] Rose (1988) is one of the few studies which find that the integration series is I(0) during the post war period (to be more specific the author actually studies the 1947-1986 period).

[25] Besides, Hassler and Wolters (2010) argue that in the presence of fractional integration the augmented Dickey Fuller test (1979) fails for rejecting the hypothesis that the series is I(1). Furthermore, if fractional integration exists it is possible that unit root tests and AR based persistence measurements lead to diverging conclusions (Kumar and Okimoto, 2007).

[26] See Andrews and Chen (1994). The sum of autoregressive coefficients is not without problems either. The sum is higher when inflation rises rapidly to high levels and abruptly returns to zero than when inflation initially increases slightly and returns slowly to zero. The latter process should appear more persistent (Pivetta and Reiss, 2007, pp. 3).

[27] See Kang, Kim and Morley (2009).

Stock and Watson (2006) propose a different measure of inflation persistence[28] based on coefficient R^2 of forecasts for different terms from the model employed. For example, for 1960-2006 they find that coefficient R^2 in their transitory and permanent component model shifted from 90% in the 1970s and 1980s to around 50% from the 1980s until the end of the sample, suggesting lower persistence. For four quarters onwards coefficient R^2 increased from 50%-75% in the former period to 15% in the latter, and for eight quarters onwards from 20%-35% to 10 percent.

3.2 International Empirical Evidence

Literature on persistence measurement can be divided into two main groups. The first researches the levels of integration in the series, while the second studies the evolution of different persistence measures from valid autoregressive models for $I(0)$ series. The following paragraphs discuss the case of the US with occasional references to other developed countries and Latin America. Review of international empirical evidence suggests a large degree of uncertainty regarding the level of persistence in the series. There is uncertainty concerning the precise value of estimators, the sensitivity of adopted periods and methodological approaches, and uncertainty over the advantages of different measures of persistence (Altissimo, Ehrmann and Smets, 2006). Different levels of persistence are frequently obtained for different price indexes during the same period and the statistical properties of the series mean persistence grows with the level of aggregation.[29]

3.2.1 Level of Inflation Integration

Original post war inflation series (i.e., without considering structural breaks) seem to have a unit root. Fuhrer (2009), for instance, shows that the augmented Dickey Fuller test (ADF) does not allow rejection of the unit root hypothesis in 1966-2008 for any of the three price indexes used.[30] Meanwhile, based on the confidence interval for the largest unit

[28] The non-parametric persistence indicator proposed by Robalo Marques (2004) is not considered here. This indicator is not affected by the model's misspecification problems.

[29] Idiosyncratic shocks to a series' subcomponents tend to cancel each other out; besides, the persistence of aggregate series gives greater weight to the most persistent subcomponent. See Altissimo, Ehrmann and Smerts (2006) and Angeloni et al. (2005).

[30] Results are not so clear when using the Phillips-Perron test (1988).

root, Stock and Watson (2006) do not reject the unit root hypothesis for the 1960-1983 or 1984-2004 periods. Using a similar methodology (including Bayesian *priors*) Pivetta and Reis (2007) do it neither, for whom inflation in the US can be associated to a constant unit root process. Levin and Piger (2004), Table 1, find that three out of the four price series studied for the US are $I(1)$ between 1984 and 2003.[31] The unit root hypothesis is not rejected either by the relatively recent Works of Bai and Ng (2004) and Henry and Shields (2004), as well as a broad sub-group of papers outlined in Murray, Nikolsko-Rzhevskyy and Papell (2008), Table 1.

Similarly, for the 1980m01-2006m06 period, Capistrán and Ramos-Francia (2007) find that the inflation series is $I(1)$ in seven of the ten major Latin American countries, only rejecting by 5% the unit root hypothesis for Chile, Peru and Venezuela.

As mentioned above, for some authors the series are not $I(1)$ or $I(0)$, but instead possess intermediate levels of fractional integration. Baillie, Chung and Tieslau (1996), for instance, simultaneously apply the tests suggested by Phillips and Perron (1988) and by Kwiatkowski et al. (1992) in the 1948-1990 period in the US They find that it is possible to reject both the hypothesis that the series is $I(1)$ as well as that it is $I(0)$ for eight out of the 10 countries studied (excluding Germany and Japan).

Kumar and Okimoto (2007) and Baum, Barkuolas and Caglayan (2010) also find it appropriate to consider methodologies that allow fractional integration levels to be considered. Meanwhile, Kumar and Okimoto (2007) discover a permanent reduction in the level of integration (degree of persistence) in the US since the mid-1980s as well as in other G7 countries except Italy.

3.2.2 Level of Integration of the Series Including Structural Changes

After including structural changes in the series for 1984-2003, Levin and Piger (2004) reject the unit root hypothesis in all four of the inflation indexes studied, with an inflation shock which in most cases disappears within a few quarters. This result is in contrast to the unit root found for three of these when structural changes are not considered (see above). The authors note that structural changes occur in the inflation mean and not in the autoregressive coefficients.

[31] Altissimo, Ehrmann and Smets (2006) combine the evidence presented by Levin and Piger (2004) with other works and arrive at similar conclusions.

TABLE 1. UNIT ROOT TESTS AT 10%, 1960-2010

				ERS				*NG-PERON*								
		AIC lags		*DF_GLS*		*PT*		*MZA*		*MCB*		*MSB*		*MPT*		*KPSS (Newey-West)*
Variable	*Model*	*MAIC*	*ADF*	*AIC*	*MAIC*	*AIC*	*MAIC*	*AIC*	*MAIC*	*AIC*	*MAIC*	*AIC*	*MAIC*	*AIC*	*MAIC*	
Period: 1960m8-2010m6																
		12		−3.563	−3.563	4.05	4.05	−23.32	−23.32	−3.39	−3.39	0.145	0.145	4.04	4.04	0.628
PI	CT	12		Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:
				−1.61	−1.61	6.89	6.89	−14.2	−14.2	−2.62	−2.62	0.18	0.18	0.18	0.18	0.12
		12	−3.28	−3.038	−3.038	1.603	1.603	−18.00	−18.00	−2.90	−2.90	0.161	0.161	1.706	1.706	0.75
PI	C	12	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:
			2.56	1.61	1.61	4.48	4.48	−5.7	−5.7	−1.62	−1.62	0.27	0.27	4.45	4.45	0.34
Period: 1980m1-2009m12																
		12	−2.77	−2.76	−2.76	7.12	7.12	−12.73	−12.73	−2.52	−2.52	0.197	0.197	7.16	7.16	0.388
PI	CT	12	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:
			]3.13	−2.59	−2.59	6.88	6.88	−14.2	−14.2	−2.62	−2.62	0.19	0.19	6.67	6.67	0.12
Period: 1990m1-2010m6																
		12	−3.45	−3.47	−3.47	4.40	4.40	−20.57	−20.57	−3.20	−3.20	0.16	0.16	4.48	4.48	0.36
PI	CT	12	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:	Vc:
			3.13	−2.63	−2.63	6.86	6.86	−14.2	−14.2	−2.62	−2.62	0.19	0.19	6.67	6.67	0.12

Using information for 1948-1999, Kim (2000) presents evidence that the inflation series in the US shifted from being $I(0)$ before 1973 to $I(1)$ in later years. Using information for the 1959-2000 period, Leyburne et al. (2003) show evidence that inflation moved from having a unit root before 1982 to being stationary in the following years.

Persistence also falls significantly in Latin America when structural breaks are included in the analysis, and the series now becomes $I(0)$ in nine out of the ten countries studied by Capistrán and Ramos-Francia (2007). Paradoxically, it is not possible to reject the unit root hypothesis for Colombia, not even when structural breaks are considered. The authors attribute this result to the significant seasonal variations in monthly data, but they do not reject the unit root hypothesis either when this factor is explicitly included.

3.2.3 Sum of Autoregressive Coefficients

Just as occurred with the level of integration, persistence measurements for series $I(0)$ decrease slightly when structural changes are considered. Altissimo, Ehrmann and Smets (2006), Table 3.1, for instance, compare the sum of autoregressive coefficients for studies with long time series, whose average is close to 0.9, with those of other studies which consider short time periods or changes in the mean, whose average is close to 0.6.

On the other hand, persistence seems to be low when there is a well-established monetary anchor. Thus, Benati (2008) finds that inflation persistence has been low under the gold standard, with the adoption of the euro by some countries in the European Community and the adoption of inflation targeting regimes in the UK, Canada and Australia.

However, there is great controversy over the existence (or not) of lower inflation persistence during recent decades, presumably as a consequence of changes in monetary policy. On the one hand, Brainard and Perry (2000), Taylor (2000) and Kim, Nelson and Piger (2001) find that inflation persistence in the Volcker-Greenspan era has been substantially lower than during previous decades. Similar results are obtained by Evans and Wachtel (1993) and Kang, Kim ad Morley (2009) based Markov-switching estimates. Fuhrer (2009) and Mishkin (2007) also find significant decreases in the sum of autoregressive coefficients during recent periods.[32] Ravenna (2000) documents a strong fall in persistence for the post-1990 period in Canada.

Nonetheless, a large body of other work reaches opposite conclusions. Benatti (2008), Tables 7 and 8, present perhaps the most exhaustive research on the behavior of inflation persistence in the US since the colonial period. The author does not find any significant change in the sum of autoregressive coefficients between the period named *high inflation* and the post-Volcker period of stabilization.[33] For 12 industrialized countries in the 1984-2003 period (and four price indexes) Levin and Piger (2004) find important changes in the average, but not in the sum of autoregressive coefficients. O'Reilly and Whelan (2004) do not discover significant changes for the euro zone as a whole, concluding that the sum of autoregressive coefficients is around one,[34] while Batini (2002) does not find significant changes in persistence when different European countries are studied. As mentioned above, the major autoregressive root estimates made by Pivetta and Reiss (2007) and Stock and Watson (2006) do not identify any significant changes either.

For the ten main Latin American countries, Capistrán and Ramos Francia (2007) find that the sum of autoregressive coefficients are high between January 1980 and June 2006 in Uruguay and Venezuela, at medium levels in Argentina, Brazil, Colombia, and Ecuador and low in Chile, Mexico and Peru (with mixed results in Bolivia). Nevertheless, once again some of the results change when mean changes are taken into account, in this case persistence levels are relatively low (as compared to historic levels) in at least five out of the ten countries analyzed (Argentina, Brazil, Ecuador, Mexico and Peru); no significant declines are found in Chile, Colombia and Venezuela; with increases in Uruguay and mixed results in

[32] According to Fuhrer (2009), for the consumer price index the indicator shifted from 0.89 in 1966-2008 to values close to zero in 1995-2008 (the decline is lower for the GNP deflator and even less for indicators on core inflation). Evidence for significant changes in persistence for other indicators is also found. The average autocorrelation coefficient rose from 0.5 in the 1970s to 0.8 in 1975-1995, and values close to zero during recent years. Autocorrelograms show important reductions, with values oscillating between 0.75 and 0.5 for the first three lags in the 1966-1984 period, and values around 0.3 in 1995-2008 (decreases in persistence are not so clear when core inflation is considered).

[33] No important changes are found in persistence for the GNP deflator, the GNP deflator or the so-called PCE; the only significant change is that observed in the consumer price index.

[34] The authors do not find significant changes in the sum or the mean of coefficients once they correct the parameter stability test proposed by Andrews (1993).

Bolivia. Idiosyncratic factors dominate, particularly in Bolivia and Mexico, and slightly in Chile, Peru and Uruguay.[35]

According to the authors, Colombia has one of the highest autocorrelation coefficients for inflation in levels, both for the period as a whole (0.91), 1980-1989 (0.90), 1990-1999 (0.92) and 2000-2006 (0.85). The results are relatively more favorable (less persistence) when the sum of autoregressive coefficients is studied, giving values of 0.79 (whole period), 0.59 (1980-1989), 0.62 (1990-1999) and 0.67 (2000-2006) when breaks are not considered, and 0.58 (whole sample), 0.58 (1980-1989), 0.58 (1990-1999) and 0.68 (2000-2006) after including breaks.

3.2.4 Markov-switching

The Markov-switching methodology or regime switching model recognizes that the temporary series is state-dependent, i.e. its average, variance and historic relation depends on the economy's regime or state, said state being generated by a first order Markov process. The advantage of this methodology for studying inflation persistence as compared to other traditional models is that it allows endogenous recognition of regime changes in the behavior of the autoregressive process over time. In this case, persistence is defined as state-dependent and is measured using the sum of the autoregressive coefficients associated to each state.

Furthermore, applying the Markov-switching model to inflation allows analysis of persistence or the expected duration of inflation in each regime, as well as the frequency of change of private agents' rational expectations, assuming that these form their expectations following simple rules. If inflation is highly persistent, the rule employed by private agents for forming their inflation expectations would therefore not change frequently. The assumption of relatively sudden changes is particularly relevant given that inflation persistence is possibly linked to monetary regime changes and the central bank's reputation.[36] Murray, Nikolsko-Rzhevskyy and Papell (2008) employ Markov-switching methodology and find that

[35] In any case *common* factors explain between 15% and 30% (depending on the methodology) of persistence variations in the different countries. The authors suggest that during the 1980s fiscal dominance was relatively common in all the region's countries. The favorable behavior of inflation in the last decade possibly obeyed the impact of globalization and appropriate policies (Rogoff, 2003).

[36] See Cogley and Sbordone (2005), Benati (2008) and Kang, Kim and Morley (2009).

inflation has a unit root in most years between 1967 and 1981, while it is stationary before 1967 and after 1981.[37]

3.2.5 Inflation Targets

Robalo Marques (2004) emphasizes that any persistence indicator is conditional to the assumption made on medium and long term inflation, which can also vary over time. In the same way, a large body of recent literature tends to assign an important role to the high persistence of the inflation target as a determinant of persistence in observed inflation (Altissimo, Ehrmann and Smets, 2006).

As mentioned above, Stock and Watson (2006) consider that observed inflation results from the sum of a permanent component, modeled as a random walk, with unit root and associated with the inflation target implicit in the US as well as a transitory component. The authors find that the reduction in inflation variance observed during recent years is due to the reduction of the variance of this permanent component. In the same way, Cogley, Primiceri and Sargent (2009) find a significant reduction in the persistence of $\pi - \pi^*$, π^* being the inflation target, and Kang, Kim and Morley (2009) find that $\pi - \pi^*$ is stationary during the whole 1959Q1-2006Q2 period.

4. STATISTICAL PERSISTENCE IN COLOMBIA

As mentioned above, measuring statistical persistence is the first step in an analysis of inflation dynamics and should serve as the basis for later study on the behavior and dynamics of the *structural* variables which determine it. Questions on the IS, the Taylor rule and the Phillips curve (mainly) will be addressed by the authors in the future.

In this context, an analysis of the series' order of integration is of central importance. If inflation is integrated by first-order $I(1)$, it is said to be extremely persistent, because all shocks to it are permanent and there is no return to its previous behavior. If inflation is stationary, $I(0)$, all shocks dissipate and it is possible to determine the time necessary for it to revert to its mean. In such case it is advantageous to use the two *best* persistence indicators, the sum of autoregressive coefficients and the impulse-response function. Finally, as mentioned previously, it is not only im-

[37] Evans and Wachtel (1993) also.

portant to consider the dynamics of inflation but also those of differential $\pi - \pi_t^*$.

Sections 4.1 and 4.2 evaluate the order of integration of overall inflation in Colombia[38] during the periods: *i)* 1960m08-2010m06, *ii)* 1980m01-2010m06, and *iii)* 1990m06-2010m06. Evidence of the stationary behavior of the series in the latter period allows it to be examined to ascertain if it is governed (or not) by a Markov-switching autoregressive process, i.e. if the nature of inflation differs during said period. There are two regimes: the *previous regime*, between 1990m01 and 2000m01, and the *current regime* between 2000m02 and 2010m06. The behavior of the sum of autoregressive coefficients and the impulse-response function in each of these periods is researched. Section 4.3 studies the performance of the spread between inflation and its target ($\pi - \pi_t^*$, instead of π_t), constructing a persistence measurement which changes over time based on the combination of a Kalman filter and a non-linear optimization procedure.

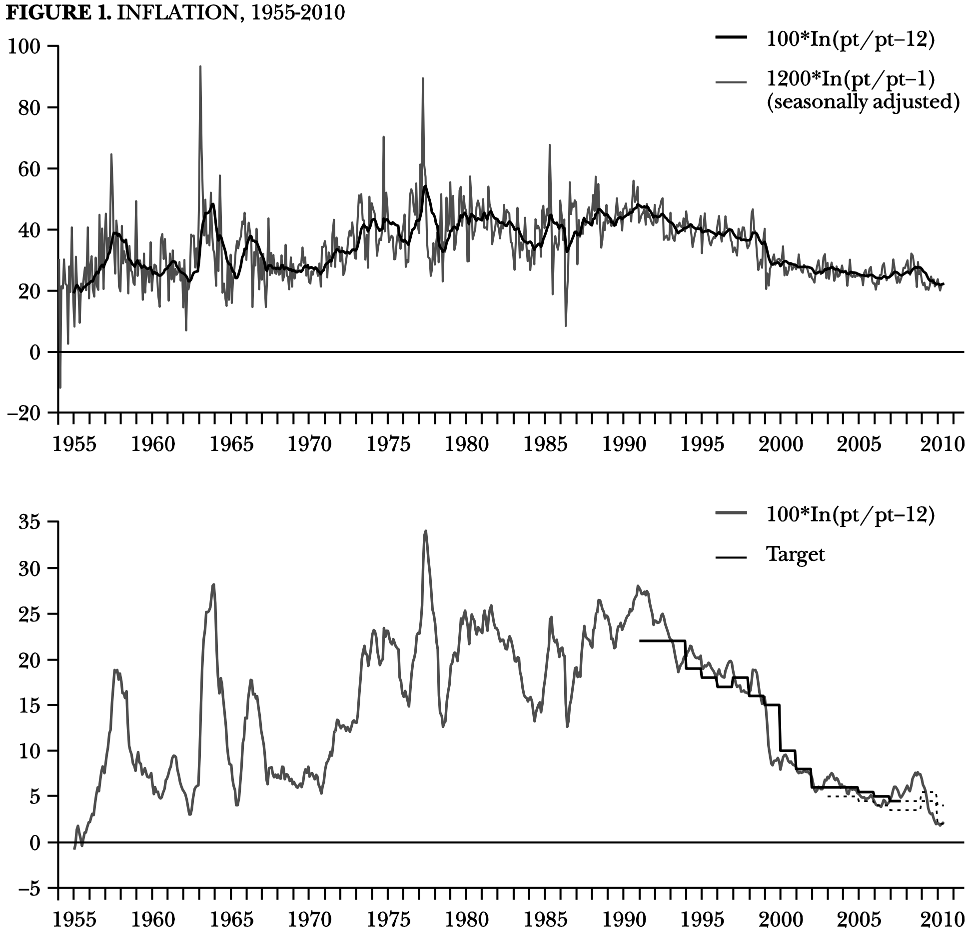
4.1 Series Order of Integration Test

The top of Figure 1 shows the evolution of annualized monthly inflation, defined by $1{,}200 * \ln(P_t / P_{t-1})$ and month-on-month annual inflation defined by $100 * 1\mathrm{n}(P_t / P_{t-12})$. As would be expected the former series exhibits greater volatility because the latter smooth shocks that dissipate in less than one year. The bottom of the figure again shows annual inflation and the inflation target set by the central bank each year. According to the bank's law, it aims to meet in December the inflation target established in November of the preceding year. Thus, the target set for 1991 was 22% but was not met because inflation observed in December of that year was 23.8%. The Executive Board established *punctual targets* during the period between 1991 and 2002, and *target ranges* in later years. Furthermore, since 2001 it announced a long term target range of 3% plus or minus 1 percentage point.

With the aim of examining the degree of integration of the inflation series, this paper employs unit root tests developed by Ng and Perron (2001), Elliot, Rothenberg and Stock (1996), and Hobijin, Franses and

[38] Employing annualized monthly inflation $1{,}200 * 1\mathrm{n}(P_t / P_{t-1})$ where P_t is the seasonally adjusted CPI. Seasonal adjustment is made using the X11 procedure. This series differs from that used in economic policy discussions in Colombia, defined as $100 * 1\mathrm{n}(P_t / P_{t-12})$, which smooths shocks lasting less than 12 moths and therefore shows greater persistence (Payaa, Duarteb and Holdene, 2010).

FIGURE 1. INFLATION, 1955-2010



Ooms (2004), who modified conventional tests in order to improve performance and power. Conventional tests such as that of Dickey-Fuller and augmented Dickey-Fuller (Dickey and Fuller, 1979), present particularly delicate problems when dealing with the case presented here.

Ng and Perron (2001) underline two main problems in conventional test construction.[39] The first concerns low explicative power when the autoregressive polynomial is smaller but very close to one. A correction for this problem is obtained with the ADF-GSL and Point Optimal tests proposed by Elliot, Rothenberg and Stock (1996) –ERS– who, using simulations based

[39] Taken from Betancourt, Misas and Bonilla (2008).

on finite samples, found a greater power as compared to traditional tests. The second problem occurs when the moving average polynomial of the first difference or the residuals has a large negative root, which induces a higher probability of rejecting the unit root hypothesis. In this regard, Ng and Perron (2001) propose modifications to the Phillips and Perron (1988) and ERS Point Optimal (1996) tests[40] and develop modified Akaike's information criterion (MAIC) to determine the optimal number of lags. Finally, there is the unit root test proposed by Kwiatkowski et al. (1992), KPSS, whose null hypothesis sets out series stationary. The test has been generalized for highly autoregressive processes by Hobijin, Franses and Ooms (2004), introducing automatic lag selection from a broadband in the Newey and West (1994) fashion.

Series testing is carried out for the periods: *i)* 1960m8-2010m6, *ii)* 1980m1-2010m6, and *iii)* 1990m1-2010m6. Table 1 shows results of the tests for unit root existence of Elliott, Rothenberg and Stock (1996), ADF-GSL and Point Optimal, Ng and Perron (2001) MZA, MZB, MSB and modified KPSS (1998), to a 10% level of significance. The maximum number of lags used is 12 in the first two periods and five in the last, which guarantees correlation absence of the residuals in each period. Lags were determined according to Akaike (AIC) and modified Akaike's (MAIC) selection criterion, after considering 18 lags in the first two sub periods and 12 lags in the last. The intercept, and the intercept and trend in auxiliary regressions are considered.

According to the results of Table 1 there is no conclusive evidence on the order of integration for the inflation series during the reference period. This is also open to debate for the US series (see section 3.2). Based on the results of the ADF test, which is high powered under the alternative hypothesis, and the ERS-DFGLS and MZA, and Ng and Perrron's MZB tests, in this paper annualized inflation is considered stationary $I(0)$ for the period between January 1990 and June 2010. Furthermore, as mentioned above, it is difficult to believe that an inflation targeting regime can move away permanently from its long-term level.[41]

[40] The Phillips and Perron (1988) tests transform DF statistics in order to make them compatible with the presence of autocorrelation and heteroskedasticity in disturbance terms, without altering test distribution.

[41] Section 3.2 mentioned that Stock and Watson (2006) and Cogley, Primiceri and Sargent(2009), among others, consider a different strategy. According to these authors, the inflation series can be $I(1)$ (several statistical tests do not allow reject this hypothesis for the US) thanks to the influence of long-term targets implicitly or explicitly adopted by the

It should be remembered that, the fact that a series is $I(0)$ implies that all shocks dissipate over time. An $I(1)$ variable will be persistent, meaning that shocks affecting it will be long lasting and prevent the series from returning to a previously defined level. It has been observed recently that macroeconomic variables –such as the rate of inflation– can have stationary or non-stationary characteristics within specific periods. Thus, some series can shift from $I(0)$ to $I(1)$ behaviors or vice versa. An important number of papers show that the current monetary regime has a significant impact on the properties of inflation persistence. This seems to have been the case for the inflation targeting scheme adopted by the monetary authority in Colombia.

4.2 Regime Switching Model (Markov-switching)

Given the stationarity of the annualized inflation series in the 1990-2010 period, this Section analyzes if the behavior of inflation during this period is regime-dependent. In particular, taking into account the adoption of an inflation targeting regime in Colombia in 1999 (Vargas, 2007), the possible existence of two regimes or natural states for inflation is studied.[42] The *current regime* could be characterized by a credible inflation target with expectations anchored to the targets, something which did not happen in the *previous regime*. The persistence index would therefore be expected to be lower in the *current regime*. The exercise uses the sum of autoregressive coefficients as an indicator of persistence.

Krolzig (1997) and Hamilton (1994) are followed in order to estimate the core inflation generation process in Colombia from 1990 to 2010 through a Markov regime switching model. It is found that the model shows inflation in Colombia as a process governed by two regimes or natural states, which switch among themselves according to a first order Markov process, i.e., the probability of being in a particular state or regime only depends on the state during the preceding period. The methodology explains inflation through an autoregressive scheme which allows parameters to change with the states.

The Markov-switching method employed asserts that all parameters depend on unobservable variable S_t, called state variable. This variable

central bank. For this reason the authors suggest analyzing statistical properties of the *spread* between inflation and the long term target.

[42] For details on the characteristics of monetary policy during the 1990s see Hernández and Tolosa (2001).

characterizes the state or regime during period t, and takes values 1, 2,..., K; K being the number of regimes included in the model. Each of the states describes a determined inflationary behavior. For instance, if $K = 2$, a state or regime will have a situation of low inflation and low volatility, while the other describes a situation of high inflation and high volatility. In this way the Markov-switching model employed allows each regime to be characterized by a determined average, variance and level of persistence.

The results of different statistical tests show that the specification best describing the process of changing inflation regimes in Colombia is that found in the MSIAH model.[43] This acronym is taken from Krolzig (1997) and means that both intercept (I), as well as autoregressive parameters (A) and the variance-covariance matrix (H) are regime dependent. Thus, it is considered that inflation follows a state-dependent autoregressive process in all the parameters included in equation (11).

$$\pi_t = \mu_{S(t)} + \phi_{1_{S(t)}} \pi_{t-1} + \ldots + \phi_{p_{S(t)}} \pi_{t-p} + \varepsilon_t . \tag{11}$$

Where π_t is inflation and $S_t \in \{0,1\}$ is an unobserved discrete variable representing the state of the economy. The behavior of this variable defines regime 1 or *current* when $S_t = 0$ and regime 2 or *previous* when $S_t = 1$. The end of shock ε_t follows a normal distribution with state-dependent variance:

$$\varepsilon_t \sim N\left(0, \sigma_{S_t}^2\right). \tag{12}$$

That is, variance depends on the natural state of the economy:

$$\begin{gathered} \sigma_{S_t}^2 = \sigma_0^2 \left(1 - S_t\right) + \sigma_1^2 S_t, \\ \sigma_0^2 > 0, \quad \sigma_1^2 > 0. \end{gathered} \tag{13}$$

Similar behavior is observed in the different autoregressive parameters of model:

$$\varphi_{jS_t} = \varphi_{j0}\left(1 - S_t\right) + \varphi_{j1} S_t, \qquad j = 1, \ldots, p \tag{14}$$

Equations (15) and (16) show regime switch or state transition probabilities.

[43] Markov Switching Intercept Autoregressive Parameters Heteroscadasticity

(15) $$P\left[s_t = 0 \middle| s_{t-1} = 0\right] = p \quad P\left[s_t = 1 \middle| s_{t-1} = 1\right] = q$$

(16) $$P\left[s_t = 1 \middle| s_{t-1} = 0\right] = 1 - p \quad P\left[s_t = 0 \middle| s_{t-1} = 1\right] = 1 - q$$

Persistence will be determined by the sum of the autoregressive coefficients in each regime:

(17) $$\alpha_{S(t)} = \sum_{i=1}^{p} \phi_{i_{S(t)}}$$

Table 2 shows the results of MSIAH model estimates for total inflation in Colombia during the 1990m01-2010m06 period when considering two natural states. Regime 1, or *current*, corresponds to the period between 2000m02 and 2010m06 and is characterized by low and slightly volatile

TABLE 2. MSIAH ESTIMATE: INFLATION

Current Regime_1 $(S_t = 0)$

	Coefficient	*Standard*	*t statistics*
Constant	11.035	2.063	5.34
Infla_1	0.332	0.083	4.02
Infla_2	0.061	0.075	0.82
Infla_3	−0.126	0.072	−1.76
Infla_4	−0.040	0.069	−0.58
Trend	−0.038	0.008	−4.75

Standard error: 1.936
Confidence interval for the variance: I = [3.46, 5.10]
Sum of autoregressive coefficients: 0.2267

Previous Regime_2 $(S_t = 1)$

	Coefficient	*Standard*	*t statistics*
Constant	16.75	3.339	5.02
Infla_1	0.425	0.100	4.25
Infla_2	−0.056	0.111	−0.51
Infla_3	0.234	0.113	2.10
Infla_4	−0.267	0.103	−2.59
Trend	−0.059	0.012	−4.61

Standard error: 3.68
$\sigma^2_{Regime2} \notin I$
p-values
Difference of intercepts: 0.120
Difference of trend: 0.116
Difference of sum of coefficients: 0.552

inflation, while regime 2, or *previous*, comprising the period between 1990m01 and 2000m01 is characterized by high and very volatile inflation.

In order to verify the existence of statistical changes in the model's parameters for each regime, tests are made on the difference of: *i)* intercepts, *ii)* coefficients associated to the deterministic trend and *iii)* level of inflation persistence or sum of the model's autoregressive coefficients. At a level of 12% significance the tests indicate that each natural state presents statistically different trend intercepts and parameters. The results also show the *previous regime* exhibits higher volatility and that the variance associated to the *previous regime* does not belong to the variance interval estimated for the *current regime*.

However, no differences in persistence between the two states are found. The sum of autoregressive coefficients decreases from 0.336 in the previous regime (1990m01-2000m01) to 0.226 in the current regime (2000m02 and 2010m06), but this difference is not statistically significant, with a p-value of 0.552 for the difference.

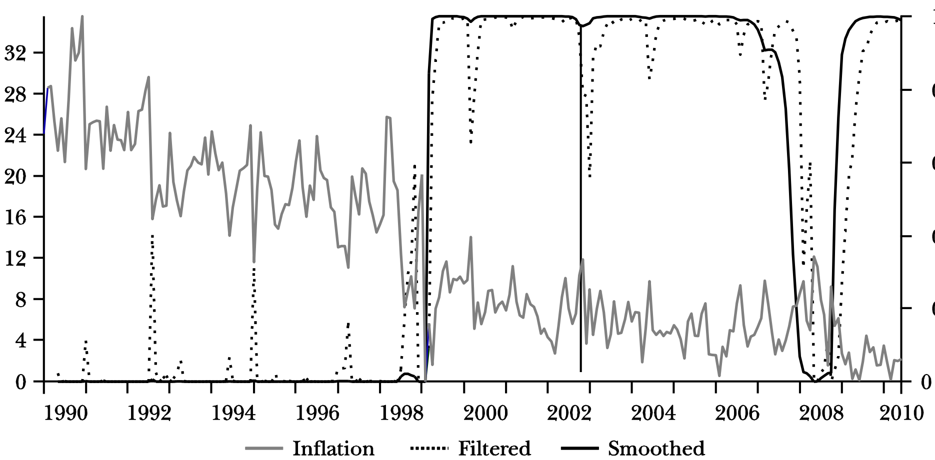
Finally, Table 3 shows the Markov transition matrix, illustrating that the two regimes are absorbent: after having entered a particular regime there is a very low probability of exiting it. In fact, the probability of remaining in the *previous regime* once already in it is 0.9824, and that of remaining in the *current regime* is 0.9905.

TABLE 3. TRANSITION MATRIX

	Current-regime 1	*Previous-regime 2*
Current-regime 1	0.9905	0.0095
Previous-regime 2	0.0176	0.9824

Nevertheless, the high probability of remaining in the current regime is no guarantee of not returning to the past. Figure 2 represents the probability that inflation during a determined period of time t is governed by the *current regime*. It can be seen that during the months from November 2007 to October 2008 inflation temporarily changed to the *previous regime*, characterized by high inflation and volatility. During said period Colombia's economy was affected by an international shock in the prices of foods and energy, which could have had serious consequences for inflation. Luckily, the response of the authorities and a new fall in international prices mitigated its impact and returned the economy to the regime of low inflation and volatility achieved since 2000.

FIGURE 2. PROBABILITY OF REGIME ONE, OR CURRENT, 1990-2010

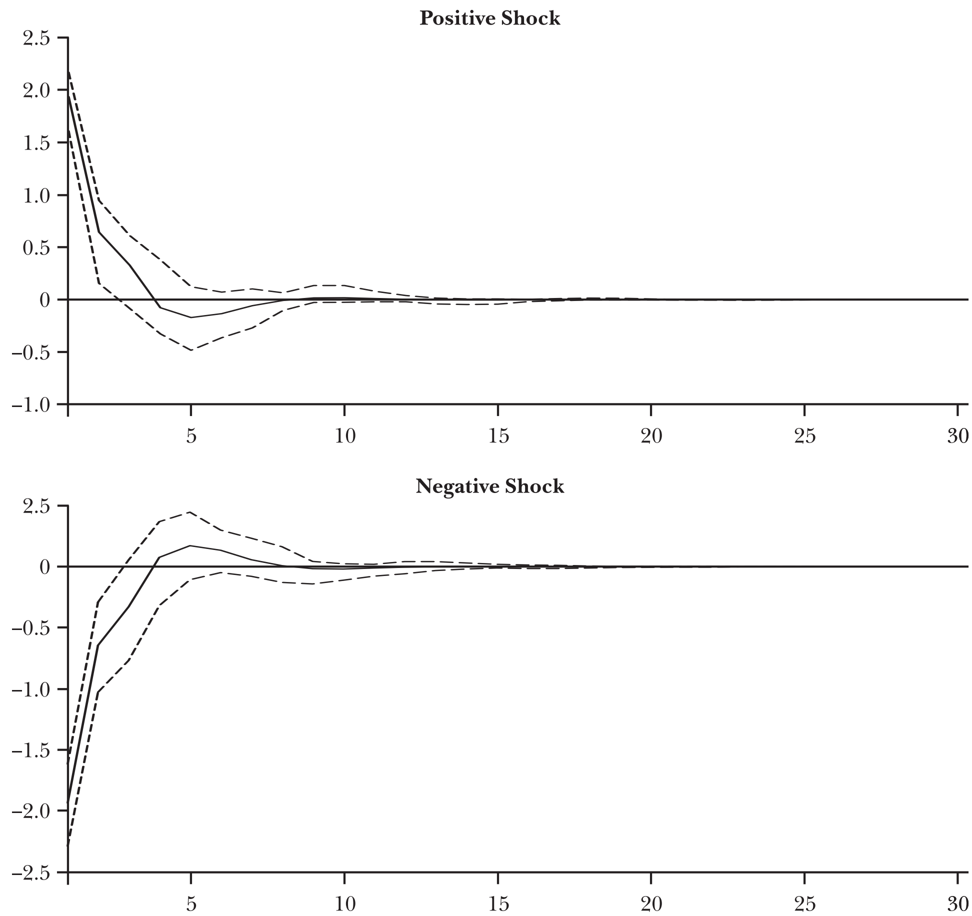


The functions shown in Figures 3 and 4 suggest that a positive shock on inflation dissipates in four months under the *current regime* and in five months under the *previous regime*. In other words, as mentioned above, when the sum of autoregressive coefficients is compared inflation persistence seems to have declined very slightly in Colombia during the last two decades. Furthermore, the non-asymmetrical behavior between states in the event of positive and negative shocks is due to the fact that the system in each regime is lineal and the transition matrix has an absorbent main diagonal.

Although inflation persistence has fallen only slightly during the last two decades (previous section), this could result from the fact that central bank inflation targets were highly persistent in both periods (lower part of Figure 1). For this reason, following, among others, Cogley, Primiceri and Sargent (2009), this Section analyzes persistence of the variable $\pi_t - \pi_t^*$ (instead of π_t), where π_t^* is the inflation target established by the central bank each year. The variable π_t^* also corresponds to the long-term trend when the central bank's targets are totally credible. As mentioned above, Stock and Watson (2006) propose an alternative strategy in which the long-term stochastic trend is estimated (and a stationary component), associating this trend with what agents estimate to be the implicit and explicit target of the central bank (see footnote 41).

A model allowing changes in persistence to be observed over time is employed as shown in equation (18).

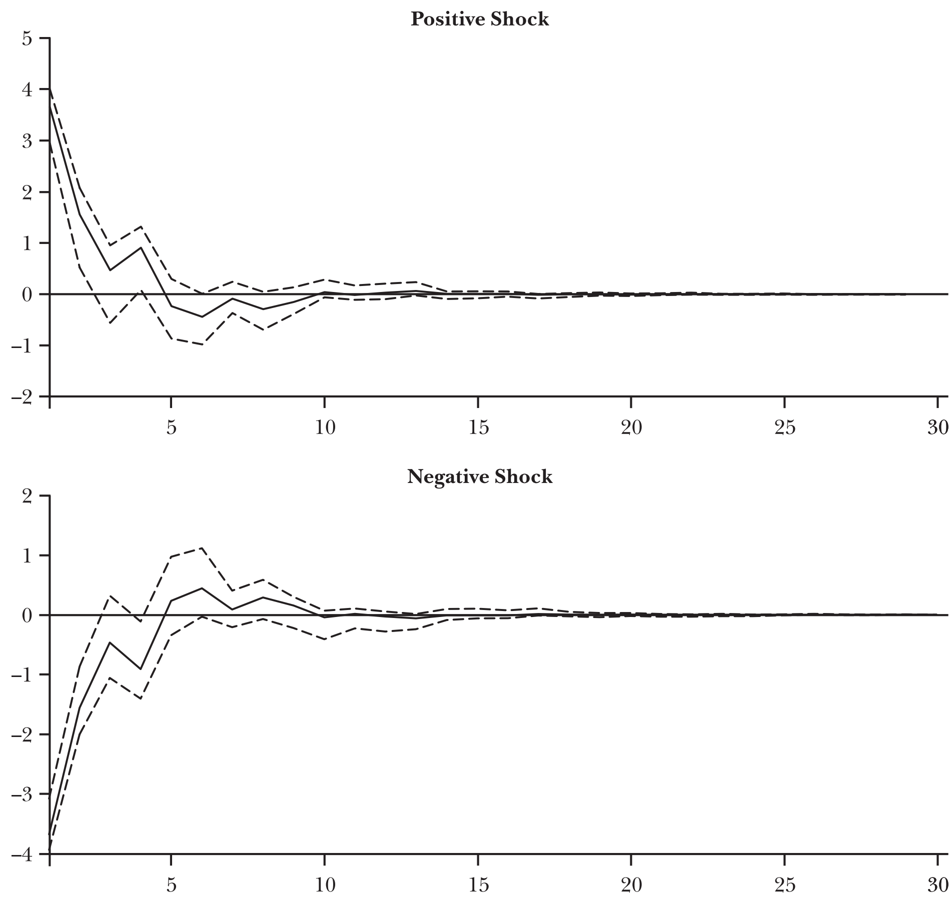
FIGURE 3. IMPULSE-RESPONSE ANALYSIS. TOTAL INFLATION. CURRENT REGIME



$$\pi_t = \pi_t^* + \rho_t \pi_t \left(\pi_{t-1} - \pi_{t-1}^*\right) + u_t + \sum_{i=1}^{11} \theta_i u_{t-1} \,, \tag{18}$$

where ρ_t is the series persistence parameter changing over time and π_{t-1}^* is the inflation target from the preceding period. In this case annual inflation π_t is defined as $100^*\ln(P_t/P_{t-12})$, more comparable with the annual inflation target set by the central bank than the annualized monthly inflation employed in the previous exercises. However, the end of the Section presents some comments allowing persistence values in both exercises to be compared. Modeling through a first order autoregressive process in this case introduces an MA(11) structure in the disturbance term.

FIGURE 4. IMPULSE-RESPONSE ANALYSIS. ANNUALIZED TOTAL INFLATION. PREVIOUS REGIME



In addition, equation (19) shows the law of evolution for parameter ρ_t:

(19) $$\rho_t = \rho_{t-1} + w_t .$$

Equations (18) and (19) show a state-space representation formulated from measurement and transition equations (20) and (21):

(20) $$\pi_t = H_t'\xi_t + A_t ,$$

(21) $$\xi_t = F\xi_{t-1} + v_t .$$

With R and Q in (24) and (25) being the variance-covariance matrices of the measurement and transition equation, and ξ_0 the initial state vector, which must satisfy $E[v_t, \xi_0] = 0$.

Equations (20) and (21) correspond to the measurement and transition equations of the state-space representation in matrix form, and equations (22) and (23) to the corresponding variance-covariance matrices.

$$\pi_t = \begin{bmatrix} \pi_{t-1} & -\pi^*_{t-1} & 1 & \theta_1 & \theta_2 & \theta_3 & \theta_4 & \theta_5 & \theta_6 & \theta_7 & \theta_8 & \theta_9 & \theta_{10} & \theta_{11} \end{bmatrix} \begin{bmatrix} \rho_t \\ u_t \\ u_{t-1} \\ u_{t-2} \\ u_{t-3} \\ u_{t-5} \\ u_{t-6} \\ u_{t-7} \\ u_{t-8} \\ u_{t-9} \\ u_{t-10} \\ u_{t-11} \end{bmatrix} + \begin{bmatrix} \pi^*_t \end{bmatrix} \tag{22}$$

$$\begin{bmatrix} \rho_t \\ u_t \\ u_{t-1} \\ u_{t-2} \\ u_{t-3} \\ u_{t-4} \\ u_{t-5} \\ u_{t-6} \\ u_{t-7} \\ u_{t-8} \\ u_{t-9} \\ u_{t-10} \\ u_{t-11} \end{bmatrix} = \begin{bmatrix}
1 & 0 & \cdots & & & & \cdots & & & & \cdots & & 0 \\
0 & 0 & \cdots & & & & \cdots & & & & \cdots & & 0 \\
0 & 1 & 0 & & & & \cdots & & & & \cdots & & 0 \\
0 & & 1 & 0 & & & & & & & \cdots & & 0 \\
0 & & 0 & 1 & 0 & & & & & & \cdots & & 0 \\
0 & & \cdots & 0 & 1 & 0 & \cdots & & & & \cdots & & 0 \\
0 & & \cdots & & 0 & 1 & 0 & & & & \cdots & & 0 \\
0 & & \cdots & & & 0 & 1 & 0 & & & \cdots & & 0 \\
0 & & \cdots & & & & 0 & 1 & 0 & & \cdots & & 0 \\
0 & & \cdots & & & & & 0 & 1 & 0 & \cdots & & 0 \\
0 & & \cdots & & & & & & 0 & 1 & 0 & & 0 \\
0 & & \cdots & & & & & & & 0 & 1 & 0 & 0 \\
0 & & \cdots & & & & \cdots & & & & 0 & 1 & 0
\end{bmatrix} \begin{bmatrix} \rho_{t-1} \\ u_{t-1} \\ u_{t-2} \\ u_{t-3} \\ u_{t-4} \\ u_{t-5} \\ u_{t-6} \\ u_{t-7} \\ u_{t-8} \\ u_{t-9} \\ u_{t-10} \\ u_{t-11} \\ u_{t-12} \end{bmatrix} + \begin{bmatrix} \eta_\rho \\ u_t \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \tag{23}$$

$$R = 0 \tag{24}$$

(25)
$$Q=\begin{bmatrix} \sigma_w^2 & 0 & & \cdots & 0 \\ 0 & \sigma_u^2 & 0 & & 0 \\ & 0 & 0 & & 0 \\ \vdots & & 0 & 0 & 0 \\ & & & 0 & 0 \\ 0 & 0 & & 0 & 0 \end{bmatrix}_{13\times 13}$$

The estimation process is carried out through the work of both an optimization algorithm and a Kalman filter on the previously shown representation, a procedure which enables estimation of unobserved variables and parameters such as coefficient ρ_t (persistence). Table 4 shows the results of state-space representation estimates for equations (22) and (23).

The results can be seen in Figure 5.[44] Parameter ρ_t increased in the 1992-1995 period, rising from levels below 0.72 to values above one by the end of the period, and remaining stable at *high* levels between 1999 and 2007 (0.88 on average). After a sharp but short lasting fall during some months of 2008, it increased in the second half of the year to its highest level for the period as a whole. The increase observed at the end of the exercise corresponds to the increase in inflation which took place during the referred period as a consequence of the supply shock caused by increases in international prices of foodstuffs.

The results are consistent with those in the preceding section, in that the value of ρ_t does not seem to have fallen significantly with the adoption of an inflation targeting regime. On the other hand, they tended to increase worryingly during all of 2009 and part of 2010. Although our exercise ends in March 2010, a preliminary study with new information seems to suggest that persistence has again declined to past levels, partly because the authorities responded to the external shocks by considerably raising their reference interest rates and because the international shock weakened during the remainder of the year. Inflation reached surprisingly low levels for the rest of 2010 and might end the year at below 2.7%.

Values of *persistence* ρ_t obtained in this Section for $\pi_t-\pi_t^*$ are not directly comparable with those in the preceding Section, partly because different inflation series are employed. This Section uses the series $100*\ln(P_t/P_{t-12})$ which allows a direct comparison with the central bank's

[44] It is important to point out that the path of persistence is strong in initial parameter values and the state vector.

annual inflation targets, while the preceding Section employs the series 1,200*ln(P_t/P_{t-1}) (see footnote 38).

Nevertheless, as would be expected, and as Robalo Marques (2004) suggests, the persistence obtained when medium-term inflation is *discounted* (this Section) should be much lower than when it is not *discounted* (preceding Section).[45] This also occurs in our case if it is taken into account that series 1,200*ln(P_t/P_{t-1}) can be expressed as: $\pi_t = \ln(p_t/p_{t-1}) + \ln(p_{t-1}/p_{t-2}) + \ldots + \ln(p_{t-11}/p_{t-12}) = \pi_t^{month} + \pi_{t-1}^{month} + \ldots + \pi_{t-11}^{month}$. For this reason the original model can be written as:

$$(26)\quad \pi_t^{month} = \left(\pi_t^* - \rho\pi_{t-1}^*\right) + (\rho_t - 1)\pi_{t-1}^{month} + (\rho_t - 1)\pi_{t-2}^{month} + \ldots + (\rho_t - 1)\pi_{t-11}^{month} + (\rho_t - 1)\pi_{t-12}^{month} + u_t$$

Equation (26) corresponds to an AR(12) with trend given by $\pi_t^* - \rho_t\pi_{t-1}^*$, with stationary component $\rho_t\pi_{t-12}^{month}$, and persistence $(\rho_t - 1)\pi_{t-j}^{month}$. The sum of coefficients will therefore be $13\rho_t - 12$, whose minimum occurs when $\rho = 0.92$, a value relatively close to those shown in Figure 5.

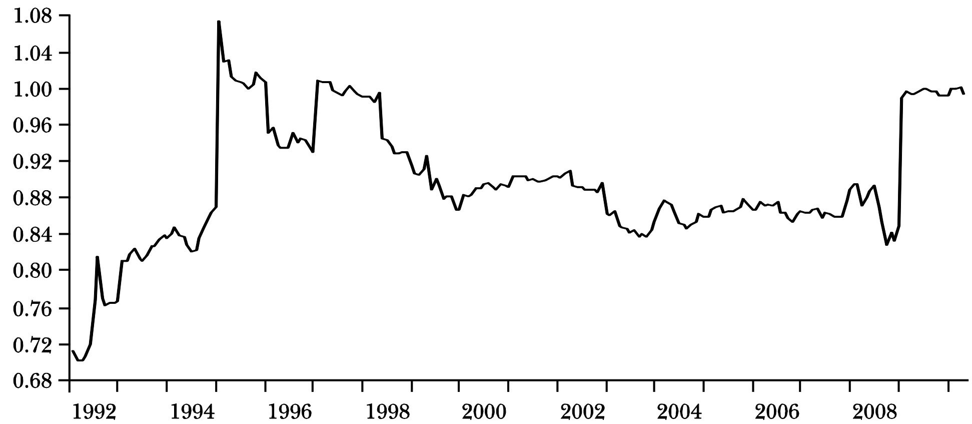
TABLE 4. STATE-SPACE REPRESENTATION ESTIMATE

Optimization Process Results		
Parameter	*Estimate*	*Gradient function*
θ_1	0.7367	0.00128
θ_2	0.6311	−0.00016
θ_3	0.7135	−0.00061
θ_4	0.5445	−0.00134
θ_5	0.4131	−0.00087
θ_6	0.5095	0.000009
θ_7	0.5214	−0.00017
θ_8	0.5621	0.00077
θ_9	0.7133	−0.00041
θ_{10}	0.6786	0.00034
θ_{11}	0.5465	0.00076
θ_u^2	0.00020	0.00164
θ_w^2	0.1548	−0.00064

Objective function value: −429.67

[45] Special thanks to Luis Eduardo Rojas for his suggestions regarding this exercise.

FIGURE 5. PERSISTENCE EVOLUTION, 1992-2008



5. POLICY IMPLICATIONS AND CONCLUSIONS

Reduced or statistical measurement of persistence is an essential step for understanding the *structural* factors governing it. One of this paper's first findings is that the annual inflation series is stationary around a deterministic trend during the period from January 1990 to June 2010. This implies that the shocks to inflation dissipated over time.

Second, employing a Markov-switching method for an autoregressive process finds two natural states. Inflation was high and very volatile in the 1990m01-2000m01 period (*previous state*), while inflation was low and less volatile during the 2000m01-2010m06 period (*current state*). This suggests that the inflation targeting scheme adopted at the end of the 1990s had an impact on some of the characteristics of inflation.

Nevertheless, there is no statistically significant reduction in persistence. Although the sum of autoregressive coefficients declined from 0.336 during the *previous regime* to 0.226 in the *current regime*, such difference is not statistically significant. In the same way, impulse-response functions for each period show that the positive shock disappears in five months during the *previous regime* and in four months in the *current regime*, while the negative shock disappears in one month in both regimes.

Third, there is little room for complacency among economic authorities given the return of inflation persistence from 2007-2008 during the *previous regime* characterized by high and volatile inflation. Fortunately, international prices of foods declined rapidly and the authorities reacted quickly and strongly.

Fourth, and in line with previous results, no significant decline in persistence is seen since 1999 when working with the spread between observed inflation and the target.

A large amount of recent research on inflation persistence has been focused on the relation between *statistical persistence* and *structural persistence*, which suggests a long-term research program for Colombia. Inflation persistence is closely related to parameters τ_π in the Taylor rule, σ_r in the IS and ϕ_x in the Phillips curve, but above all to the existence (or not) of lagged inflation π_{t-1} in the Phillips curve. This has perhaps been the central debate in macroeconomics for the last 30 years and it continues to be so.

References

Altissimo, F., M. Ehrmann, and F. Smets (2006), *Inflation Persistence and Price-setting Behaviour in the Euro Area: A Summary of the Evidence*, Occasional Paper Series, No. 46, European Central Bank.

Andrews, D. W. K. (1993), "Test for Parameter Instability and Structural Change with Unknown Change Point", *Econometrica*, Vol. 61-4, pp. 821-856.

Andrews, D. W. K., and H.-Y. Chen (1994), "Approximately Median-unbiased Estimation of Autoregressive Models with Applications to US Macroeconomic and Financial Time Series", *Journal of Business and Economic Statistics*, Vol. 12, pp. 187-204.

Angeloni, I., L. Aucremanne, M. Ehrmann, J. Galí, A. T. Levin, and F. Smets (2005), *New Evidence on Inflation Persistence and Price Stickiness in the Euro Area: Implications for Macro Modelling*, Economics Working Papers, No. 910, Department of Economics and Business, Universitat Pompeu Fabra.

Bai, J., and S. Ng (2004), "A Panic Attack on Unit Roots and Cointegration", *Econometrica*, Vol. 72, pp. 1127-1177.

Baillie, R. T., C.-F. Chung, and M. A. Tieslau (1996), "Analysing Inflation by the Fractionally Integrated ARFINA-GARCH Model", *Journal of Applied Econometrics*, Vol.11, pp. 23-40.

Ball, L. M. (1992), *Disinflation with Imperfect Credibility*, NBER Working Paper, No. 3983.

Ball, L. M. (1993), *What Determines the Sacrifice Ratio?*, NBER Working Paper, No. 4306.

Batini, N. (2002), *Euro Area Inflation Persistence,* Working Paper, No. 201, European Central Bank.

Baum, C. F., J. T. Barkuolas and M. Caglayan (2010), *Persistence in International Inflation Rates,* mimeo.

Beechey, M., and P. Osterholm (2009), *The Rise and Fall of US Inflation Persistence,* Working Paper, No. 2007-18, Upsala University.

Benati, L. (2008), *Investigating Inflation Persistence across Monetary Regimes,* Working Papers Series, No. 85, European Central Bank.

Betancourt, Y. R., M. Misas, and L. Bonilla (2008), "*Pass-through" de las tasas de interés en Colombia: un enfoque multivariado con cambio de régimen,* Borradores de Economía, No. 535, Banco de la República, de Colombia.

Blinder, A. S. (1991), "Why Are Prices Sticky? Preliminary Evidence from an Interview Survey", *American Economic Review*, Vol. 81, No. 2, pp. 89-96.

Bordo, M. D., and J. G. Haubrich (2004), *The Yield Curve, Recessions, and the Credibility of the Monetary Regime: Long-Run Evidence, 1875-1997,* NBER Working Paper, No. 10431.

Brainard, W. (1967), "Uncertainly and the Effectiveness of Policy", *American Economic Review*, Vol. 57, No. 2, pp. 411-425.

Brainard, W., and G. Perry (2000), "Making Policy in a Changing World", en G. Perry and J. Tobin (eds.), *Economic Events, Ideas, and Policies: The 1960s and After*, Brookings Institution.

Calvo, G. A. (1983), "Staggered Prices in a Utility-Maximizing Framework", *Journal of Monetary Economics*, Vol. 12, pp. 383-398.

Capistrán, C., and M. Ramos-Francia (2007), *Inflation Dynamics in Latin America,* Banco de México.

Cecchetti, S., *et al.* (2007), *Understanding the Evolving Inflation Process,* US Monetary Policy Forum.

Cecchetti, S., and R. W. Rich (2001), "Structural Estimates of the US Sacrifice Ratio", *Journal of Business and Economic Statistics*, Vol. 19, No. 4, pp. 416-427.

Christiano, L., M. Eichenbaum, and C. Evans (2005), "Nominal Rigidities and the Dynamic

Effects of a Shock to Monetary Policy", *Journal of Political Economy*, Vol. 113, pp. 1-45.

Clarida, R. H., J. Galí, and M. Gertler (2000), "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory", *The Quarterly Journal of Economics*, Vol. 115, No. 1, pp. 147-180.

Cogley, T., G. E. Primiceri, and T. J. Sargent (2009*), Inflation-gap Persistence in the US,* NBER Working Paper Series, No. 13749.

Cogley, T., and A. M. Sbordone (2005), *A Search for a Structural Phillips curve,* Staff Reports, No. 203, Federal Reserve Bank of New York.

Cogley, T., and A. M. Sbordone (2006), *Trend Inflation and Inflation Persistence in the New Keynesian Phillips curve,* Staff Report, No. 270, Federal Reserve Bank of New York.

Collard, F., and H. Dellas (2004), *The New Keynesian Model with Imperfect Information and Learning,* Working Paper, University of Toulouse.

Dickey, D. A., and W. A. Fuller (1979), "Distribution of the Estimators for Time Series. Regressions with a Unit Root", *Journal of the American Statistical Association*, Vol. 74, pp. 427-431.

Dupuis, D. (2004), *The New Keynesian Hybrid Phillips curve: An Assessment of Competing Specifications for the United States,* Working Paper, No. 2004-31, Bank of Canada.

Elliott, G., T. J. Rothenberg, and J. H. Stock (1996), "Efficient Tests for an Autoregressive Unit Root", *Econometrica*, Vol. 64, No. 4, pp. 813-836.

Erceg, C. J., and A. T. Levin (2001), *Imperfect Credibility and Inflation Persistence,* Federal Reserve Board.

Estrella, A., and J. Fuhrer (2002), "Dynamic Inconsistencies: Counterfactual Implications of a Class of Rational-expectations Models", *American Economic Review*, Vol. 92, No. 4, pp. 1013-1028.

Evans, M. D., and P. Wachtel (1993), "Inflation Regimes and the Sources of Inflation Uncertainty", *Journal of Money, Credit and Banking*, Vol. 25, No. 3, pp. 475-511.

Franta, M., B. Saza, and K. Smidkova (2007), *Inflation Persistence: Euro Area and New EU Member States,* Working Paper Series, No. 810, European Central Bank.

Friedman, M. (1968), "The Role of Monetary Policy", *American Economic Review*, Vol. 58, pp. 1-17.

Fuhrer, J. (1995), "The Persistence of Inflation and the Cost of Disinflation", *New England Economic Review*, 3-16.

Fuhrer, J. (2009), *Inflation Persistence,* mimeo.

Galí, J., and M. Gertler (2000), *Inflation Dynamics: A Structural Econometric Analysis,* NBER Working Paper, No. 7551.

Gómez, J. (2002), *Wage Indexation, Inflation Inertia and the Cost of Disinflation,* Borradores de Economía, No. 198, Banco de la República, Colombia.

Goodfriend, M., and R. King (1997), "The New Neoclassical Synthesis and the Role of Monetary Policy", mimeo.

Gordon, R. J. (1997), "The Time-varying NAIRU and its Implications for Economic Policy", *Journal of Economic Perspectives*, Vol. 11.

Hamilton, J. D. (1994), *Time Series Analysis*, Princeton University Press, Princeton.

Hassler, U., and J. Wolters (2010), "Long Memory in Inflation Rates: International Evidence", *Journal of Business & Economic Statistics*, Vol. 13, No. 1, pp. 37-45.

Henry, Ó. T., and K. Shields (2004), "Is There a Unit Root in Inflation", *Journal of Macroeconomics*, pp. 481-500.

Hernández, A., and J. Tolosa (2001), *La política monetaria en Colombia en la segunda mitad de los años noventa,* Borradores de Economía, No. 172, Banco de la República, Colombia.

Hobijn, B., P. H. Franses, and M. Ooms (2004), "Generalizations of the KPSS-test for Stationarity", *Statistica Neerlandica*, Vol. 58, No. 4, pp. 483-502.

Julio, J. M., H. Zárate and M. Hernández (2010), "Rigideces de precios al consumidor en Colombia", mimeo.

Kang, K. H., C.-J. Kim, and J. Morley (2009), "Changes in US Inflation Persistence", *Studies in Nonlinear Dynamics & Econometrics*, Vol. 13, No. 4, pp. 1-21.

Kim, C.-J., C. R. Nelson, and J. M. Piger (2001), "The Less-volatile US Economy: A Bayesian Investigation of Timing, Breadth, and Potential Explanations", *Journal of Business and Economic Statistics*, Vol. 22, No. 1.

Kim, J.-Y. (2000), "Detection of Change in Persistence of a Linear Time Series", *Journal of Econometrics*, Vol. 95, pp. 97-116.

Krolzig, H. M. (1997), *Markov-switching Vector Autoregressive. Modelling, Statistical Inference and Application to Business Cycle Analysis,* Lecture Notes in Economics and Mathematical Systems, Springer, Berlin.

Kumar, M. S., and T. Okimoto (2007), "Dynamics of Persistence in International Inflation Rates", *Journal of Money, Credit and Banking*, Vol. 39, No. 6, pp. 1457-1479.

Kwiatkowski, D., P. C. Phillips, P. Schmidt, e Y. Shin (1992), "Testing the Null Hypothesis of Stationarity against the Alternative of a Unit Root: How Sure are We that Economic Time Series Have a Unit Root?", *Journal of Econometrics*, Vol. 54, No. 1-3, pp. 159-178.

Levin, A. T., and J. M. Piger (2004), *Is Inflation Persistence Intrinsic in Industrial Economies?,* Working Paper, No. 334, European Central Bank.

Leybourne, S. J., T.-H. Kim, V. Smith, and P. Newbold (2003), "Test for a Change in Persistence against the Null of Difference-Stationarity", *Econometric Journal*, Vol. 6, pp. 290-310.

Linde, J. (2005), *Estimating New-Keynesian Phillips curves: A Full Information Maximum Likelihood Approach,* Working Paper Series, No. 129, Sveriges Riksbank.

Mankiw, G. (2001), "The Inexorable and Mysterious Tradeoff between Inflation and Unemployment", *The Economic Journal*, Vol. 111, No. 471, pp. 45-61.

Milani, F. (2005), *Adaptive Learning and Inflation Persistence,* University of California, Department of Economics, Irvine.

Mishkin, F. S. (2007), *Inflation Dynamics,* NBER Working Paper, No. 13147.

Murray, C., A. Nikolsko-Rzhevskyy, and D. Papell (2008), *Inflation Persistence and the Taylor Principle,* Munich Personal RePEc Archive.

Newey, W. K., and K. D. West (1994), "Automatic Lag Selection in Covariance Matrix Estimation", *Review of Economic Studies*, Vol. 61, pp. 631-654.

Ng, S., and P. Perron (2001), "Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power", *Econometrica*, Vol. 69, No. 6, pp. 1519-1554.

O'Reilly, G., and K. Whelan (2004), *Has Euro-area Inflation Persistence Changed Over Time?,* Working Paper, No. 335, European Central Bank.

Orphanides, A., and J. Williams (2005), "Imperfect Knowledge, Inflation Expectations and Monetary Policy", en B. Bernanke and M. Woodford (eds.), *The Inflation Targeting Debate*, University of Chicago Press.

Paloviita, M. (2004), *Inflation Dynamics in the Euro Area and the Role of Expectations: Further Results,* Research Discussion Papers, No. 21/2004, Bank of Finland.

Paya, *I.*, A. Duarte and K. Holden (2010), *A Note on the Relationship between Inflation Persistence and Temporal Aggregation*, mimeo.

Phelps, E. S. (1967), "Phillips curves, Expectations of Inflation, and Optimal Inflation Over Time", *Economica*, Vol. 135, pp. 254-281.

Phillips, P. C., and P. Perron (1988), "Testing for a Unit Root in Time Series Regression", *Biometrika*, Vol. 75, No. 2, 335-346.

Pivetta, F., and R. Reis (2007), "The Persistence of Inflation in the United States", *Journal of Economic Dynamics & Control*, Vol. 31, No. 4, pp. 1326-1358.

Ravenna, F. (2000), *The Impact of Inflation Targeting in Canada: A Structural Analysis,* mimeo., New York University.

Robalo Marques, C. (2004), *Inflation Persistence: Facts or Artefacts?,* Working Paper, No. 371, European Central Bank.

Rogoff, K. S. (2003), "Globalization and Global Disinflation", in *Monetary Policy and Uncertainty: Adapting to a Changing Economy,* Federal Reserve Bank of Kansas City, University Press of the Pacific.

Rose, A. K. (1988), "Is the Real Interest Rate Stable?", *Journal of Finance*, Vol. 43, pp. 1095-1112.

Rudd, J., and K. Whelan (2005), *Modelling Inflation Dynamics: A Critical Review of Recent Research,* Finance and Economics Discussion Series, No. 66, Federal Reserve Board, Divisions of Research & Statistics and Monetary Affairs, Washington D. C.

Rudd, J., and K. Whelan (2006), "Can Rational Expectations Sticky-Price Models Explain Inflation Dynamics?", *American Economic Review*, Vol. 96, No. 1, pp. 303-320.

Rudebusch, G. D. (2002), *Assessing the Lucas Critique in Monetary Policy Models,* Working Paper, No. 02, Federal Reserve Bank of San Francisco.

Sbordone, A. M. (2007), *Inflation Persistence: Alternative Interpretations and Policy Implications,* Staff Reports, No. 28, Federal Reserve Bank of New York.

Smets, F. (2004), "Maintaining Price Stability: How Long is the Medium Term?", *Journal of Monetary Economics*, Vol. 50, 1293-1309.

Stock, J. H., and M. W. Watson (2006), *Why Has US Inflation Become Harder to Forecast?,* NBER Working Paper, No. 12324.

Svensson, L. E. O. (1999), "Inflation Targeting: Some Extensions", *Scandinavian Journal of Economics*, Vol. 101, No. 3, pp. 337-361.

Svensson, L. E. O. (2005), *Optimal Inflation Targeting: Further Developments of Inflation Targeting,* texto mimeografiado.

Taylor, J. B. (1979), "Staggered Wage Setting in a Macro Model", *American Economic Review*, Vol. 69, 108-113.

Taylor, J. B. (2000), "Low Inflation, Pass-through, and the Pricing Power of Firms", *European Economic Review*, Vol. 44, pp. 1389-1408.

Vargas, H. (2007), *The Transmission Mechanism of Monetary Policy in Colombia. Major Changes and Current Features,* Borradores de Economía, No. 431, Banco de la República, Colombia.

Walsh, C. E. (2004), *Monetary Theory and Policy*, 2nd edition, MIT Press.

Williams, J. (2006), *The Phillips curve in an Era of Well-Anchored Inflation Expectations,* Federal Reserve Bank of San Francisco.

Wolman, A. (1999), "Sticky Prices, Marginal Cost, and the Behavior of Inflation", *Federal Reserve Bank of Richmond Economic Quarterly*, Vol. 85, pp. 29-48.

Woodford, M. (2005), *Central Bank Communications and Policy Effectiveness,* NBER Working Paper, No. 11898.

Woodford, M. (2007), "Interpreting Inflation Persistence: Comments on the Conference on 'Quantitative Evidence on Price Determination'", *Journal of Money, Credit and Banking*, Vol. 39, No. 1, pp. 203-210.

Zárate, H. (2010), *Reglas de fijación de precios de los productores colombianos: evidencia a partir de los modelos de duración con micro datos del IPP*, Borradores de Economía, No. 600, Banco de la República, Colombia.