Commodity price shocks and inflation within an optimal monetary policy framework: the case of Colombia

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Commodity price shocks and inflation within an optimal monetary policy framework: the case of Colombia

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Abstract

A small open macroeconomic model, in which an optimal interest rate rule emerges to drive the inflation behavior, is used to model inflation within an inflation targeting framework. This set up is used to estimate the relationship between commodity prices shocks and the inflation process in a country that both export and import commodities. We found evidence of a positive, yet small, impact from food international price shocks to inflation. However, these effects are no longer observable once the sample is split in the periods before and after the boom. The lack of effect from oil and energy price shocks we obtain supports the recent findings in the literature of a substantial decrease in the pass-through from oil prices to headline inflation. Thus, our interpretation is that monetary authority has faced rightly the shocks to commodity prices. Inflation expectations are the main determinant of inflation during the inflation targeting regime. Commodity prices movements are to a great extent included in the information set to form expectations.

Keywords: *commodity prices, inflation-targeting regime, optimal monetary policy, expectations*.
***JEL* Classification**: *E*43, *E*58.

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1. Introduction

The behavior of commodity prices is matter of permanent concern among its producers, investors, policy makers and economists. The reason is that commodity prices changes potentially may bring about new economic conditions and give signals on the future path of some relevant domestic macroeconomic variables. That is the case of inflation in countries where commodity prices shocks represent important sources of either demand or supply pressures. In consequence, the question whether monetary authorities should react to commodity prices fluctuations effects on domestic inflation is not trivial.

Output disturbances are different in nature and require different policy responses. The basic theory on monetary economics, suggest that monetary authority should offset demand shocks but accommodate supply shocks (Clarida, Galí and Gertler, 1999). Thus, identifying the nature of shocks is just one of the tasks to which monetary authorities are faced to (see Uribe, 2010). In this sense, it is necessary to gauge the magnitude of the effects and whether a significant long-lasting impact exists, in order to determine an adequate policy response. For example, fluctuations of the commodity exports prices that lead to reactions of aggregate national income may represent an important source of inflation due to demand pressures in countries where these products are the core of the economic activity (IMF, 2008). However, if the country is net importer of commodities the policy reaction could be different depending on the pass-through from import prices to inflation[1].

Regardless of the apparent importance of commodity prices shocks on inflation, there is no much research devoted to the study and estimation of this phenomenon by invoking an economic model in which the inflation process can be derived as we do below. Most research is carried out in the spirit of either general equilibrium (Medina and Soto, 2007) or empirical models (Ricaurte and Pedersen, 2014). In a recent work, Jalil and Tamayo (2011) estimated first and second round effects of food international prices on inflation of Brazil, Chile, Colombia, México and Peru. The authors found that, for Colombia, the effects of commodity price shocks disappear four months after the shock estimating an elasticity of 0.27 of domestic prices to the international prices. When inflation is decomposed into core inflation without food and food price changes, the elasticities are, on average, 0.194 and 0.477, respectively. With respect to the second round effects, they provided evidence that the effects take place within a

[1] Some standard small open economy models link the inflation impact of imports prices to the weight given to imports in the CPI (see for example, Galí et al., 2005), while others, such as McCallum and Nelson (2001), show that the transmission to inflation is limited to the extent to which relative price shocks affect aggregate supply.

period close to four months, though the numerical magnitude is lower than 10% of the first round effects.

On the effects of commodity prices shocks on inflation and inflation expectations in Colombia, recently Arango, Chavarro and González (2013) found evidence of first-round and second-round effects between 1990 and 2010. Their empirical results showed that there is a positive and significant pass-through from food and oil international prices to the domestic prices of some selected items of the CPI and PPI baskets. Nevertheless, the magnitudes of the effects are small: they found an elasticity of domestic prices to international prices between 0.1 and 0.3 on average[2]. The estimated effects on core inflation and inflation expectations are higher, especially when shocks to food prices are considered. In particular, a 1% rise in the international price of food produces a rise of 0.56% on core inflation and explains about 32% of the changes on inflation expectations in a one-month horizon, with an important decline on the latter when the time-horizon is extended. According to these authors, given the reduction of the pass-through coefficient of food prices to core inflation since the inflation-target regime was established, there have been significant gains by controlling inflation.

However, the approaches of Jalil and Tamayo (2011) and Arango, Chavarro and González (2013) are empirical in essence. None of them present a theoretical setting in which the behavior of monetary authority within a proper framework to face shocks is made explicit. This is relevant because Colombia's central bank follows an inflation-targeting strategy and is committed to control inflation to provide conditions for sustainable economic growth path. In our view, the final pass-through from commodity prices shocks to domestic inflation should be analyzed knowing the reaction function implicit on the monetary policy rule.

Accordingly, this article is aimed to determine how much of international commodity price shocks is passed through inflation under an optimal monetary policy framework. This subject is important for two reasons. On the one hand, Colombia is a commodity exporter hence changes in commodity world markets may have a direct impact on the economy through channels encompassing GDP growth, exchange rate movements, financial (un)balances, inflation behavior and a higher exposure to the dynamics of aggregate demand in emerging and developed economies. On the other hand, it is worth to evaluate how an optimal monetary policy framework leads to a higher domestic price stability given the commodity prices movements.

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[2] For items as cocoa, coffee, sugar, palm-oil, sun-flower oil and soy-oil the elasticity is higher than 0.5.

The theoretical body we use is based on Walsh (2002) and De Gregorio (2007) which consists of a text-book model used to explain the inflation targeting strategy that is explained below[3]. In that sense, this paper might be though as an empirical attempt to verify the goodness of this simple model to explain the inflation determinants in a small open economy. However, as we will see below, the success of the model is not clear-cut. Moreover, the results suggests that commodity price shocks and other demand and supply shocks are of minor importance while expectations are the main determinant of inflation during the inflation targeting regime. Thus, we claim that the monetary authority has faced rightly the commodity price shocks during this regime.

The article develops in six sections of which this Introduction is the first. The second shows some facts of the recent behavior of commodity prices and inflation. The third section presents and explains the model and provides some intuition. The fourth section is devoted to explain the way in which structural shocks, commodity prices shocks and inflation expectations are obtained. Section fifth shows and discusses the results. Finally, the sixth section draws some conclusions.

2. Some facts on recent behavior of commodity prices

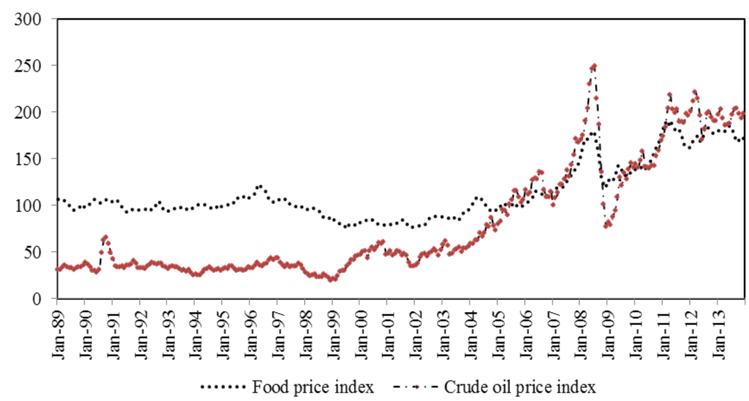
Figure 1 shows nominal food and crude oil price indexes[4]. After a period of relative stability, during the past decade the index of food world prices grew up by more than 110% between January 2000 and December 2013 and by more than 339% in the case of crude oil during the same period. In real terms, between January 2000 and December 2013, the percentage variations of food and crude oil prices were of 52% and 218%, respectively, while from January 1990 to December 1999 the registered percentage variations were of -41% and -9% respectively. All these price movements, as has been argued in previous research (see Frankel, 2006; Bernanke, 2006) are consequence of both supply and demand shocks. On the one hand, an increasing demand coming from large emerging economies as China and India has soared commodity prices. The transition to other types of energy, in particular an increasing demand for biofuels, has raised the price of land and, in turn, increased the cost of food production. Financial developments in commodities markets, climate phenomena and supply shocks in the crude oil market are also among the reasons that explain the upsurge in commodity world prices.

Potentially, commodity price booms bring about first and second round effects on inflation. The former consist of primary or direct effects while the latter are linked to a rise in underlying inflation.

[3] This framework was also used by Vargas and Cardozo (2013).
[4] Our reference prices are food and crude oil international price indexes from the IMF.

This is the case when the increases in food and fuel prices drive up expectations and underlying inflation producing further price increases and demand for higher wages. This is especially important for those economies where commodities account for a large share of final expenditure and where monetary policy has only limited credibility. To the extent that commodity prices shocks are large and persistent, inflation risks increase and second round effects arise, requiring an accurate and timely policy response. That is, if shocks to commodity prices are transitory, they are expected to damp in the short run with persistent effects on neither expectations nor underlying inflation. In contrast, with large and persistent shocks, as were recent episodes, monetary authorities face a challenge since the shocks are transmitted to inflation expectations and prices of other goods and services in the economy (Bernanke, 2006).

Figure 1. Food and crude oil price indexes
Base (2005=100)



Source: IMF; National Administrative Department of Statistics (DANE); authors' calculations.

Figure 2 presents some of the variables we use to analyze the effect of commodity price shocks on inflation in Colombia; later we introduce the expectations processes. The upper panel presents the headline inflation and the annual variation of crude oil (LHS) and food international prices (RHS), both expressed in Colombian pesos. Two things are worth highlighting. First, there is some coincidence between international commodity price movements and domestic headline inflation during the same period.[5] Second, the more recent developments of inflation in Colombia would suggest an effective

[5] For example, in 2007, inflation in Colombia reached a level of 5.69%, surpassing the upper limit of the inflation target by 119 basis points. This, as pointed out by the monetary authority of Colombia (see, inflation report December 2007), was mainly due to a food inflation higher than expected with world commodity prices explaining a large part of this increase. At

reaction of monetary authority, as new increases in crude oil and food world prices did not have an impact on inflation which has been maintained within the rank-target (see the LHS lower panel). The lower panel (RHS) of Figure 2 shows the behavior of policy rate (measured by interbank rate) and inflation.

Figure 2. Commodity prices annual variation, headline inflation, and policy rate.

Note: in the upper panels, the right axis measures the annual percentage change of international prices; in the right-lower panel, the right vertical axis measures the Interbank rate. Source: IMF; National Administrative Department of Statistics (DANE); authors' calculations.

3. The model

As we mentioned before, the aim of this paper is to analyze the effects of commodity prices shocks on domestic inflation in Colombia based on a model in which monetary authority reacts to deviations of output from its flexible price equilibrium level, deviations of the inflation rate from its target and

the end of 2008, inflation in Colombia jumped to 7.67%, missing this time the upper limit of the target by 317 basis points. Once again, the monetary authority of Colombia argued that high international oil prices and other commodity prices, not only created inflation pressures on domestic food and fuel prices, but also had a considerable impact on inflation expectations. The length of increasing international commodity prices and its impact on expectations for further prices increases and total inflation was underestimated by some central banks, a situation that also apparently occurred in Colombia. As we will see below, there is no evidence to reject such statement if we include the permanent component of commodity prices into the picture.

deviations of real exchange rate from its long run equilibrium value. In the context of a small open economy with an inflation-targeting strategy, we formulate a data generating process for inflation, π_t, and estimate the effect on this of commodity prices shocks, inflation expectations, and demand and cost-push shocks.

The framework (see Walsh, 2002) is based on two relationships: an expectations augmented Phillips curve and a description of monetary policy behavior, reflecting the policy maker's preferences in trading off output gap, inflation and exchange rate. The latter implies a central bank that sets its policy instrument to stabilize inflation, output gap and exchange rate. A monetary policy rule (MPR thereafter) emerges when monetary authority balances the marginal costs and benefits of its policy actions. In other words, the MPR shows a relationship between the output gap, misalignments of exchange rate, and deviations of inflation from the target consistent with a monetary authority designed to minimize the costs of output and inflation variability when the monetary authority behaves optimally.[6]

The MPR shows the reaction of the monetary authority. Once she observes the current inflation, decides optimally on the size of the output gap and the exchange rate deviation. In this set up, the long-run equilibrium occurs when the output gap equals zero, current inflation equals the central bank's target and the exchange rate is on the long-run level. As pointed out by Clarida, Galí and Gertler (1999), the policy design problem consists of characterizing how the interest rate should adjust to the current state of the economy. We follow De Gregorio (2007) and Walsh (2002) to lay out a model consisting of three basic equations: an expectations-augmented Phillips curve, which schedules the aggregate supply of the economy, an IS-type aggregate demand and a MPR derived below from the objective function of a monetary authority assumed to follow an optimum rule.

The Phillips curve and the IS curve are given by:

$$\pi = \pi^e + \theta(y - \bar{y}) + \delta(q - \bar{q}) + \omega\varepsilon^{food} + \varepsilon \tag{1}$$

$$y - \bar{y} = A - \varphi(i - \pi^e) + \alpha q + \rho\mu^{crude\ oil} + \mu \tag{2}$$

[6] Nevertheless, factors other than systematic monetary policy influence aggregate demand and output in ways that monetary authority cannot perfectly foresight. In addition, policy makers may have goals beyond inflation and output gap stabilization that would shift the relation between the output gap and inflation described by the monetary policy rule. A random disturbance variable denoting the net impact on output of those additional factors can then be added to the model.

where, π stands for the annual rate of inflation, π^e are the inflation expectations, y is the output, $\bar{y}$ is flexible price equilibrium output level, q stands for the real exchange rate, $\bar{q}$ is the long run value of the real exchange rate, A is a composite factor accounting for autonomous spending, i is the nominal interest rate, $\bar{\pi}$ is the annual inflation target, ε^{food} and $\mu^{crude\ oil}$ are the components of commodity prices orthogonal to expectations mechanisms, ε and μ stand for cost-push and demand shocks, respectively and θ, δ, φ, ω, α, $\rho$are unknown parameters.

According to equations (1) and (2), a fraction of cost-push and demand shocks is strictly related to pressures coming from shocks to international food and Crude oil prices respectively. Thus, both ε and μ are residuals of a regression of each on both ε^{food} and $\mu^{crude\ oil}$. The way in which ε, μ, ε^{food} and $\mu^{crude\ oil}$ are identified and obtained is explained below.

Following De Gregorio (2007), the optimization problem faced by monetary authority can be written as: $min\, \lambda(y-\bar{y})^2 + (\pi-\bar{\pi})^2 + \beta(q-\bar{q})^2$ subject to (1) and (2). The loss function accounts for deviations of output from its flexible price equilibrium level, inflation rate from its target and deviations of real exchange rate from its long run equilibrium value. The model also includes an uncovered interest parity condition, $r = r^* + \bar{q} - q$, and the Fisher equation, $i = r + \pi^e$.

From the first order conditions of the optimization problem, the MPR is given by

$$\pi - \bar{\pi} = -\left(\frac{\alpha\lambda}{\alpha\theta+\delta}\right)(y-\bar{y}) - \left(\frac{\beta}{\alpha\theta+\delta}\right)(q-\bar{q}) \qquad (3)$$

This curve reflects the trade-off faced by monetary authority in terms of keeping inflation, output and real exchange rate as close as possible to their target or equilibrium levels. After replacing MPR in the Phillips curve and the IS curve, we find the optimal interest rate rule (IRR),

$$i = \bar{\imath} + \left(1 + \frac{\theta\alpha+\delta}{\upsilon}\right)[\pi^e - \bar{\pi}] + \frac{\theta(\alpha\theta+\delta)+\alpha\lambda}{\upsilon}(\rho\mu^{crude\ oil} + \mu) + \frac{(\alpha\theta+\delta)}{\upsilon}(\omega\varepsilon^{food} + \varepsilon) \qquad (4)$$

Where $\bar{\imath} = r^* + \bar{\pi}$ and $\upsilon = \alpha^2\lambda + \varphi\alpha\lambda + \beta + (\theta\alpha+\delta)(\delta+\alpha\theta+\varphi\theta)$.

The IRR, shows the reaction of the monetary authority when inflation expectations are different from the target, or commodity price, demand or other cost-push shocks reveal. It is evident, that the higher the value of β the less the reaction of monetary authority to shocks or expectations[7]. Recall that parameter υ contains β, and the former appears in the denominator of each coefficient.

[7] Parameter β represents the weight of the deviations of real exchange rate from the long run value.

After some algebra manipulation, the inflation process can be written as,

$$\pi = \left(\frac{\alpha^2\lambda+\varphi\alpha\lambda+\beta}{\upsilon}\right)\pi^e + \left[1-\left(\frac{\alpha^2\lambda+\varphi\alpha\lambda+\beta}{\upsilon}\right)\right]\bar{\pi} + \left(\frac{\beta\theta-\delta\alpha\lambda}{\upsilon}\right)\left(\rho\mu^{crude\ oil}+\mu\right) + \left(\frac{\alpha^2\lambda+\varphi\alpha\lambda+\beta}{\upsilon}\right)(\omega\varepsilon^{food}+\varepsilon) \qquad (5)$$

where the sources of inflation process in this model become clear. In first place, we observe that the higher the expectations the higher the annual inflation. At the same time, positive realizations of, almost, all shocks will render a higher inflation rate. However, in the case of shocks to oil prices or structural demand, the inflation reaction will be different depending on which force is greater either $\beta\theta$ or $\delta\alpha\lambda$. The former parameters represent, on the one hand, the weight of deviations of exchange rate from the long run value of the real exchange rate in the loss function and the parameters linked to the marginal cost in the Phillips curve. On the other hand, the parameters, $\delta\alpha\lambda$, represent the contribution to inflation of deviations of exchange rate from its long run value in the Phillips curve, the coefficient of real exchange rate in the IS equation, and the weights of the gap in the loss function, respectively. Thus, if the value of the product $\beta\theta$ is greater (less) than the product $\delta\alpha\lambda$, any positive shock to oil prices or a demand shock will increase (reduce) inflation. In particular, if the monetary authority expresses a concern on the deviations of the real exchange rate from its long run value, the increase of the nominal interest rate will be less than otherwise. In the extreme case that the monetary authority does not express any concern at all about the real exchange level in the loss function (β=0), any shock to oil prices or demand shock, will reduce the inflation given the reaction condensed in the IRR.

The inflation process can also be written as:

$$\pi-\bar{\pi} = \left(\frac{\alpha^2\lambda+\varphi\alpha\lambda+\beta}{\upsilon}\right)(\pi^e-\bar{\pi}) + \left(\frac{\beta\theta-\delta\alpha\lambda}{\upsilon}\right)(\rho\mu^{crude\ oil}+\mu) + \left(\frac{\alpha^2\lambda+\varphi\alpha\lambda+\beta}{\upsilon}\right)(\omega\varepsilon^{food}+\varepsilon) \qquad (6)$$

which is the equation we actually estimate. In essence, it shows that, within this economic framework, deviations of inflation from the target are caused by deviations of inflation expectations from the target, and shocks to commodity prices, demand and other cost-push shocks. When expectations are rational the inflation process can be written as:

$$\pi-\bar{\pi} = \left(\frac{\beta\theta-\delta\alpha\lambda}{\upsilon}\right)(\rho\mu^{crude\ oil}+\mu) + \left(\frac{\alpha^2\lambda+\varphi\alpha\lambda+\beta}{\upsilon}\right)(\omega\varepsilon^{food}+\varepsilon) \qquad (7)$$

In this case, the inflation in excess of the target is only generated by shocks. In the next section we show how some variables included in the model are built.

4. Data: commodity price shocks, inflation expectations, monthly inflation target and supply and demand shocks.

The estimation of equation (6) requires some data that are not readily available. That is the case of the inflation expectations mechanisms, trajectories of commodity price shocks orthogonal to inflation expectations, a monthly series of inflation target and identified structural shocks. We now consider each in turn.

Expectations mechanisms

The first mechanism we implement to figure out the inflation expectations is the break-even inflation (BEI from now on) which uses information of secondary market of debt in Colombia. In this case, by invoking Fisher equation, inflation expectations are computed at different horizons as the difference between the nominal yield of fixed income bonds and the real yield on an inflation linked bonds, both issued by the government. Accordingly, BEI rates from 1-year and 2-years yield curves stand for our market-based measure of inflation expectations.

The second indicator of inflation expectations comes from a survey-based measure conducted in Colombia since 2003 by the central bank. This survey gathers information, on a monthly basis, from a panel of economists integrated by approximately 40 experts who are asked about their inflation expectations by the end of the month, the end of the current year and one year ahead.

Finally, inflation expectations are obtained by assuming that agents form their expectations about future inflation, for one and two-years ahead (s = 12, 24 months) according to a specific process. To this aim, we use an imperfect rational expectations mechanism, which is a moving average process given by:

$$\pi^{e}_{t\text{-}s,\,t} = \kappa\,\pi^{headline}_{t\text{-}s} + (1-\kappa)\pi^{headline}_{t} \qquad (8)$$

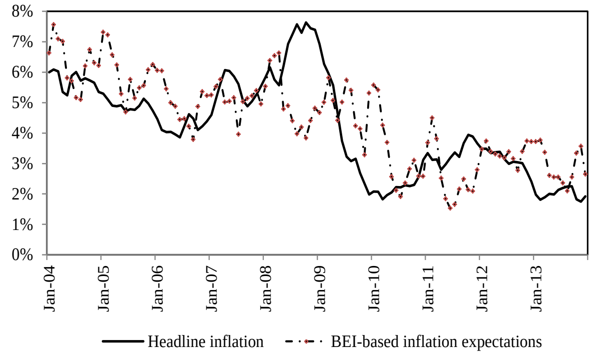
where both headline inflation and inflation expectations correspond to annual inflation rates. This mechanism is based on the hypothesis that agents assign a weight κ[8] to inflation observed s periods ago and a (1-κ) weight to current inflation when predicting how inflation is expected to behave in the future. This mechanism supports the inertia property of the inflation expectations process. Figure 3 presents the relationship between headline inflation and inflation expectations. Figures are depicted

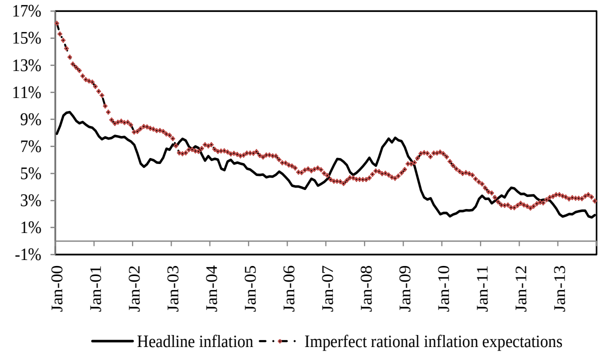
[8] The value of κ we use is 0.44.

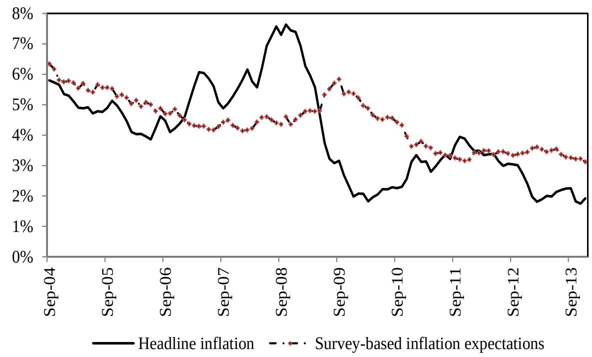
accounting for the fact that agents form their inflation expectations in advance, so that current inflation outcomes are related to their corresponding inflation expectations formed 12 and 24 months ago.

Figure 3. Expectations mechanisms and headline inflation

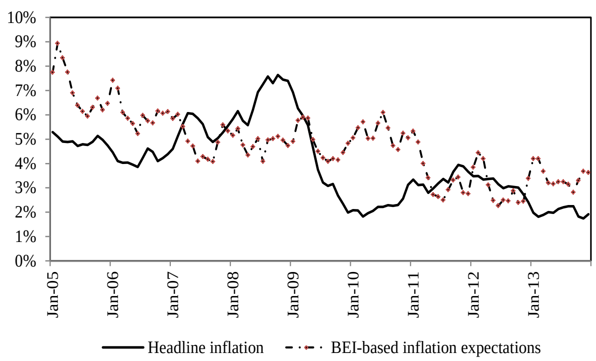
Panel A. Inflation expectations one year ahead

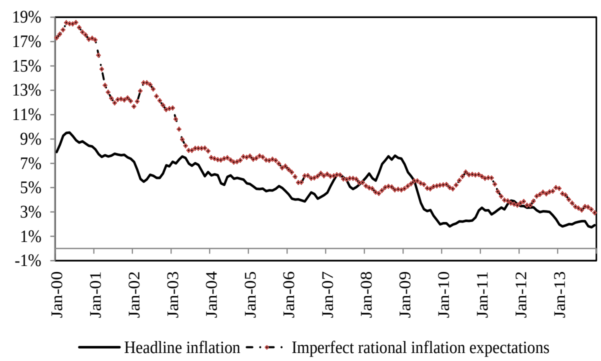






Panel B. Inflation expectations two years ahead





Source: DANE; Banco de la República; authors' calculations.

Thus, when expectations are imperfect rational the inflation process can be written as:

$$\pi - \bar{\pi} = \frac{\kappa(\alpha^2\lambda+\varphi\alpha\lambda+\beta)}{\upsilon-(1-\kappa)(\alpha^2\lambda+\varphi\alpha\lambda+\beta)}(\pi_{-s} - \bar{\pi}) + \frac{\beta\theta-\delta\alpha\lambda}{\upsilon-(1-\kappa)(\alpha^2\lambda+\varphi\alpha\lambda+\beta)}\left(\rho\mu^{crued\ oil} + \mu\right) + \frac{(\alpha^2\lambda+\varphi\alpha\lambda+\beta)}{\upsilon-(1-\kappa)(\alpha^2\lambda+\varphi\alpha\lambda+\beta)}(\omega\varepsilon^{food} + \varepsilon) \quad (9)$$

Commodity prices shocks

In assessing the pass-through of commodity prices shocks to inflation is crucial to define what a commodity price shock is. To this end, we use the Hodrick-Prescott filter to decompose the annual variation of commodity prices between permanent and transitory components, being the latter the unexpected component.

Accordingly, we have chosen three commodity price indexes from the IMF Primary Commodity Prices: crude oil, energy and food. On the demand side, we consider shocks to oil and energy price fluctuations and denote them by $\mu^{crude\ oil}$ and μ^{energy}, respectively, while shocks to food price fluctuations are denoted by ε^{food}. All these shocks should satisfy the key restriction of being orthogonal to the inflation expectations mechanisms defined above that we test. We also test the assumption that inflation expectations should be correlated to the permanent (long-run) component of crude oil, energy and food prices.

To verify the latter assumption, we first calculate the Pearson correlation coefficients between each of the expectations mechanisms and the permanent and transitory components of commodity prices fluctuations. Table 1 shows the estimated correlation coefficients between each expectations mechanism and both the permanent and transitory components of annual variation of commodity prices in dollars. For all the mechanisms, inflation expectations are correlated with the long run component of commodity prices annual variation. The imperfect rational expectations mechanism shows the lower correlation coefficient while expectations as predicted by BEI mechanism show the highest correlation. The cyclical components of annual variation in commodity prices show no correlation with inflation expectations.

Secondly, we estimate regressions of inflation expectations on every alternative for both $\mu^{crude\ oil}$, μ^{energy} , and ε^{food}, of the form:

$$\pi^e = \alpha + \phi^o\mu_c^{crude\ oil} + \xi_B \quad (9)$$

$$\pi^e = \alpha + \phi^e \mu_c^{energy} + \xi_e \tag{10}$$

$$\pi^e = \alpha + \phi^f \varepsilon_c^{food} + \xi_f \tag{11}$$

Where the subscript c accounts for the nature of the price fluctuation component considered: permanent (P) or transitory (T). Equations (9) to (11) are used to test the null hypotheses: $H_0: \phi^o = 0$; $H_0: \phi^e = 0$; $H_0: \phi^f = 0$. We expect these hypotheses are all rejected when the transitory component is used, c=T. We expect these hypotheses are not rejected when the permanent component is considered, c=*P*.

Table 1. Correlation of inflation expectations with permanent and transitory components of annual variation of commodity prices denominated in dollars

Price	One year ahead			Two years ahead	
	Survey	BEI	Imperfect rational	BEI	Imperfect rational
Crude oil					
Permanent	**0,39***	**0,54***	**0,20***	**0,47***	**0,29***
p-value	0,00	0,00	0,01	0,00	0,00
Transitory	-0,09	0,07	0,03	0,11	0,10
p-value	0,30	0,46	0,67	0,22	0,19
Energy					
Permanent	**0,46***	**0,60***	**0,27***	**0,52***	**0,34***
p-value	0,00	0,00	0,00	0,00	0,00
Transitory	-0,06	0,09	0,04	0,15	0,11
p-value	0,48	0,29	0,59	0,09	0,14
Food					
Permanent	**0,40***	**0,52***	**-0,47***	**0,44***	**-0,54***
p-value	0,00	0,00	0,00	0,00	0,00
Transitory	-0,08	0,10	0,00	0,14	0,09
p-value	0,36	0,23	0,96	0,11	0,26

Note: numbers correspond to the Pearson correlation coefficient, with the associated *p*-value below. * Represents significance at 1%.**

Table 2 shows the estimates of equations (9) to (11). Results are in line with those presented in Table 1. Indeed, we always find a statistically significant relationship between the permanent component of commodity prices annual variation and inflation expectations. In particular, 29% of the variation of BEI-based inflation expectations is explained by the variation of the permanent component of crude oil, 36% by the permanent component of energy and 27% by the permanent component of food[9]. With survey-based inflation expectations these percentages are 15%, 21% and 16%, respectively. With imperfect rational expectations the corresponding percentages are 4%, 7% and 22%.

Monthly target for the annual rate of inflation

Our estimations of the inflation process require having a monthly-basis adjusted value of the target for the annual rate of inflation, a variable that is not available. To do so, we first establish a criterion to determine whether the target was reached or not in a sample of 22 years from 1991 to 2013. Thus, we calculate the ratio of the observed inflation rate to its target value and evaluate whether this ratio exceeds or falls behind a maximum level; we denote this value by g[10]. Essentially, we are estimating a monthly target based on the path of years for which target has been reached (see Arango *et al*. 2013a).

Table 2. Regression of inflation expectations on permanent and transitory components of commodity prices annual variation denominated in dollars.

Price	One year ahead			Two years ahead	
	Survey	BEI	Imperfect rational	BEI	Imperfect rational
Crude oil					
Permanent	**0,04*****	**0,09*****	**0,05*****	**0,08*****	**0,09*****
R^2	0,15	0,29	0,04	0,22	0,09
Transitory	0,00	0,00	0,00	0,01	0,01
R^2	0,01	0,00	0,00	0,01	0,01
Energy					
Permanent	**0,05*****	**0,11*****	**0,07*****	**0,09*****	**0,11*****
R^2	0,21	0,36	0,07	0,28	0,12
Transitory	0,00	0,01	0,00	0,01	0,01
R^2	0,00	0,01	0,00	0,02	0,01
Food					
Permanent	**0,12*****	**0,28*****	**-0,23*****	**0,23*****	**-0,33*****
R^2	0,16	0,27	0,22	0,20	0,29
Transitory	-0,01	0,01	0,00	0,02	0,02
R^2	0,01	0,01	0,00	0,02	0,01

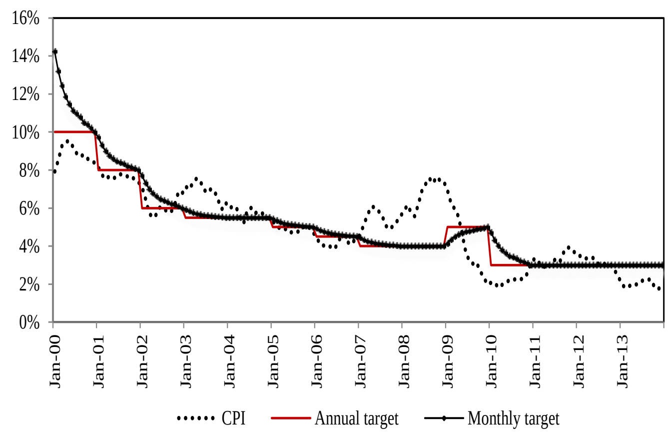
Note: numbers below each coefficient refer to the proportion of variation of expectations explained by each component of commodity prices variation. *** Represents significance at 1%.

Once we established the number of years for which target was attained, we calculate the average contribution of each month of the year to the annual rate of inflation. This is, in a year in which the target was hit, on average how much of the annual inflation rate was reached on January, how much on February, and so on, until the last month of the year. We obtain an average monthly contribution to hit

[9] Each regression is run separately in order to establish the partial percentage variation of inflation expectations explained by the variation of the permanent component of each commodity price annual variation.
[10] We fixed g equal to 0.05 and found a total of 7 (seven) years in which this criterion is met.

the target from the sample of years matching the criterion. Then, we use these contributions and the corresponding target for every year of the sample to calculate, in a monthly basis, the annual inflation target. Figure 4 shows our monthly-basis adjusted target along with inflation rates observed from 2000:01 to 2013:12.

Figure 4. Monthly target of the annual rate of inflation



Source: DANE; authors' calculations based on Arango et al. (2013a)

Structural shocks

Apart from the commodity price shocks, the model also includes two additional shocks which are plugged into the Phillips curve and IS curve. The first is a cost-push (supply) shock and the second a demand shock. The approach we followed to obtain the set of structural supply and demand shocks is based on the estimation of a structural VAR model for the price level and output, which is derived from a basic aggregate demand - aggregate supply model, AD-AS. A first set of structural shocks is obtained by using the Blanchard and Quah (1989) approach (BQ thereafter), in which the usual long run restrictions are imposed to identify the shocks. In particular, the authors suggest that the aggregate demand shock has no long-run effect on real output. The BQ identification method assumes that the variance-covariance matrix of structural shocks is diagonal (or even the identity matrix) i.e. no correlation between the two shocks is allowed.

A second set of structural shocks is obtained by using Cover, Enders and Hueng (2006) approach, (CEH thereafter), in which using the same AD-AS model, besides the long-run neutrality condition of BQ, they allow some correlation between the demand and supply shocks. More generally, they do not impose any constraints to the variance-covariance matrix of structural shocks. They impose the normalization restrictions usually suggested in an AD-AS model: one-unit supply shock shift AS by one unit and the effect of one-unit demand shock is also one-unit over AD (see Appendix 1 for details).

According to the authors, there are several arguments to justify the contemporaneous correlation between supply and demand shocks. On one hand, monetary or fiscal policy may react according to current and past state of economic activity. On the other hand, from the new Keynesian point of view, some firms increase output, rather than prices in response to a positive demand shock. Finally, to obtain orthogonal supply and demand shocks from commodity shocks, a regression of structural shocks on the commodity shocks are estimated and the residuals from that regression are the shocks that enter into the inflation model.

5. Estimation and results

Estimations were performed using the time series of commodity prices denominated in dollars and in local currency (Colombian pesos). The latter is aimed to capture some masked effect that could be in place via the exchange rate. Tables 3 and 4 present the estimation results using commodity prices denominated in dollars, while Tables 5 and 6 show the results for commodity prices denominated in local currency. Estimations are presented for the different expectations mechanisms and combination of commodity shocks. For the imperfect rational expectations mechanism the sample period goes from January 2000 up to December 2013; for the case of BEI expectations, the samples go from January 2004 to December 2013 with expectations one year ahead, and from January 2005 to December 2013 with inflation expectations two years ahead[11]; finally, for the survey-based expectations, the sample period goes from September 2004 to December 2013. Estimations were performed for the whole period of the inflation targeting regime: January 2000 to December 2013 and two subsamples: from January 2000 up to December 2006 which corresponds to the period before the commodity boom and from January 2007 to December 2013.

According to the results in Table 3, with commodity prices denominated in dollars and BQ structural shocks, there is no evidence of effects in the deviation of the rate of inflation from its target coming from neither shocks to commodity prices nor structural shocks. Even though this result holds

[11] The series of BEI expectations are available from January 2003. The reason to conduct estimations in this way responds to the fact that, in our model, agents form their inflation expectations in advance, so that current inflation outcomes must relate to inflation expectations formed *s* periods ago. Indeed, the series of BEI one year ahead, relate to inflation outcomes since January 2004, and the two years ahead series relate to inflation outcomes since January 2005.

for the whole period, it does not for the two subsamples since demand shocks seem to play a role for the inflation process not only between 2000 and 2006, with negative sign, but also between 2007 and 2013, with a positive one[12]. Only expectations seem to be relevant for the whole period and the subsamples.

Table 3. Estimation results using Blanchard-Quah shocks, with expectations one year ahead, and commodity prices denominated in dollars.

Expectation mechanism	*Inflation-Targeting-Regime (January 2000 to December 2013)*									
	Constant	*Expectations deviation*	*Demand-shock*	*Cost-push shock*	*Crude oil*	*Energy*	*Food*	*Number of observations*	*F*	*Adj_R*^{2}
BEI (from 2003:01)	0.000	**0.418****	0.004	-0.001	-0.013		0.025	120	2.04	0.13
	0.000	**0.432*****	0.004	-0.001		-0.006	0.013	120	2.00	0.09
Imperfect rational	-0.002	0.170	0.000	0.000	-0.019		0.036	168	0.60	0.05
	-0.002	0.156	0.000	0.000		-0.015	0.026	168	0.35	0.04
Survey	**0.009****	**-1.712*****	0.006	-0.003	-0.015		0.035	112	3.77	0.16
	0.009**	**-1.726*****	0.005	-0.002		-0.007	0.020	112	3.53	0.12
Rational expectations	-0.001		0.000	0.000	-0.019		0.033	168	0.67	0.00
	-0.001		0.000	0.000		-0.014	0.023	168	0.36	0.01
	January 2000 to December 2006									
Imperfect Rational	**-0.006****	**0.384*****	**-0.005****	0.001	-0.020		0.003	84	16.64	0.24
	-0.006**	**0.373*****	**-0.005****	0.001		-0.021	0.003	84	18.39	0.27
Rational expectations	-0.004		**-0.005****	0.002	-0.021		0.002	84	1.80	0.16
	-0.004		**-0.005****	0.002		-0.023	0.003	84	1.80	0.14
	January 2007 to December 2013									
BEI	0.001	**0.569*****	0.005	-0.002	-0.014		0.027	84	3.93	0.15
	0.001	**0.626*****	0.004	-0.001		-0.001	0.003	84	3.93	0.12
Imperfect rational	0.003	-0.076	**0.007***	-0.003	-0.019		0.038	84	1.33	0.05
	0.003	-0.124	**0.007***	-0.002		-0.007	0.014	84	1.50	0.06
Survey	**0.012****	**-2.183*****	0.006	-0.002	-0.019		0.041	84	6.86	0.20
	0.012**	**-2.200*****	0.005	-0.001		-0.006	0.017	84	5.65	0.15
Rational expectations	0.002		**0.007****	-0.003	-0.020		0.041	84	1.70	0.06
	0.002		**0.006****	-0.002		-0.008	0.018	84	1.94	0.01

Source: authors' calculations

In this connection, is important to highlight the coefficients of the expectations processes. Apparently, the BEI is the only one which has a coefficient with a significant and positive sign for the whole period as for the subsample from 2007 up to 2013. Imperfect rational expectations also have a positive sign such as the one predicted by the specification (6) above but only for period 2000-2006. If we observe Figure 3, the BEI expectations fluctuate around the observed inflation; that is, BEI expectations has a behavior closer to a proper expectation mechanism in the sense that sometimes is above the observed inflation and sometimes is below. By contrast, the survey and imperfect rational mechanisms spend long periods either above or below the observed inflation.

Noticeable, according to specification (6), the model implies that the difference between coefficients of expectations deviations and the cost-push shocks should not be statistically different

[12] Noticeable, it occurred just with imperfect rational and rational expectations mechanisms.

form zero. However, based on the results of Table 3, this hypothesis does not seem easy to verify with these data, which either weakens the validity of the model or casts some doubt on the construction of some variables we have used, in particular, the structural shocks, which are obtained outside the system of equations that conform the model.

Results in Table 4 with CEH shocks are qualitatively close to the estimates of Table 3. Apart from the coefficients of demand and cost-push shocks, the rest of the results hold. That is, only expectations matter for excess inflation process. Recall they are correlated to the permanent components of commodity price movements but not with the transitory ones; thus, that information is part of the set of information used to form inflation expectations.

Table 4. Estimation results using CEH shocks, with expectations one year ahead, and commodity prices denominated in dollars.

Expectation mechanism	*Inflation-Targeting-Regime (January 2000 to December 2013)*									
	Constant	*Expectation deviation*	*Demand-shock*	*Cost-push shock*	*Crude oil*	*Energy*	*Food*	*Number of observations*	*F*	*Adj_R^2*
BEI	0.000	**0.418****	1.091	-0.729	-0.013		0.025	120	2.04	0.12
	0.000	**0.432****	0.941	-0.583		-0.006	0.013	120	1.99	0.09
Imperfect rational	-0.002	0.170	0.087	-0.100	-0.019		0.036	168	0.61	0.06
	-0.002	0.156	0.007	-0.024		-0.015	0.026	168	0.35	0.02
Survey	**0.009****	**-1.713*****	2.027	-1.656	-0.015		0.035	112	3.77	0.16
	0.009**	**-1.728*****	1.736	-1.365		-0.007	0.020	112	3.53	0.12
Rational expectations	-0.001		0.125	-0.130	-0.019		0.033	168	0.00	0.00
	-0.001		0.045	-0.055		-0.014	0.023	168	0.36	0.01
	January 2000 to December 2006									
Imperfect Rational	**-0.006****	**0.384*****	**-1.327****	0.915	-0.020		0.003	84	16.75	0.24
	-0.006**	**0.373*****	**-1.380***	0.964		-0.021	0.003	84	18.54	0.22
Rational expectations	-0.004		**-1.483***	1.110	-0.021		0.002	84	1.81	0.16
	-0.004		**-1.539***	1.163		-0.023	0.003	84	1.81	0.14
	January 2007 to December 2013									
BEI	0.001	**0.570*****	1.443	-1.016	-0.014		0.027	84	3.93	0.15
	0.001	**0.627*****	0.843	-0.408		-0.001	0.003	84	3.93	0.12
Imperfect rational	0.003	-0.076	**0.007***	-0.003	-0.019		0.038	84	1.33	0.05
	0.003	-0.124	**0.007***	-0.002		-0.007	0.014	84	1.50	0.00
Survey	0.01	**-2.186*****	1.714	-1.272	-0.019		0.041	84	6.89	0.20
	0.013**	**-2.203*****	1.173	-0.713		-0.006	0.017	84	5.65	0.15
Rational expectations	0.002		2.371	-1.906	-0.020		0.040	84	1.70	0.06
	0.002		1.876	-1.391		-0.008	0.018	84	1.94	0.00

Source: authors' calculations. *** represents significance at 1%, ** at 5% and * at 10%.

On the other hand, it is important to verify the role played by the exchange rate in the effects of commodity price shocks in the inflation rate. In this sense, Uribe (2010) asserted that in Colombia, during 2007 and 2008, shocks to prices of food and oil were weakened because of the appreciation of local currency.

When commodity price shocks are denominated in local currency, a positive and significant impact from food prices to the deviation of inflation is estimated under both the imperfect rational and rational expectations mechanisms, during the period of the inflation targeting regime (Tables 5 and 6). These effects are no longer observable once the sample is divided in the two corresponding periods, before and after the boom in commodity world prices. Effects from commodity prices shocks are found with neither BEI nor the survey-based measures. In all cases, inflation expectations are a significant determinant of the annual rate of inflation. These results may suggest that, under this optimal monetary policy framework –everything else equal-, inflation deviations are explained solely by deviations of inflation expectations from target.[13] Therefore, as long as monetary authority reacts timely and accurately, such deviations should tend to decline, driving both inflation and inflation expectations to the target. Moreover, an optimal monetary policy regime effectively conducts to a lesser exposure of inflation to commodity prices cyclical fluctuations.

Table 5. Estimation results using Blanchard-Quah shocks, with expectations one year ahead, and commodity prices denominated in local currency

Expectation mechanism	*Constant*	*Expectation deviation*	*Demand-shock*	*Cost-push shock*	*Crude oil*	*Energy*	*Food*	*Number of observations*	*F*	*Adj_R²*
	Inflation-Targeting-Regime (January 2000 to December 2013)									
BEI	0.000	**0.443*****	0.004	-0.001	-0.009		0.031	120	2.55	0.12
	0.000	**0.452*****	0.004	-0.001		-0.003	0.026	120	2.80	0.09
Imperfect rational	-0.002	0.206	0.000	0.000	-0.017		**0.044****	168	1.02	0.09
	-0.002	0.200	0.000	0.000		-0.014	**0.040****	168	0.87	0.08
Survey	**0.009****	**-1.627*****	0.006	-0.002	-0.009		0.031	112	4.93	0.16
	0.009**	**-1.660*****	0.005	-0.002		-0.002	0.025	112	4.75	0.12
Rational expectations	-0.001		0.000	0.000	-0.018		**0.041****	168	0.00	0.00
	-0.001		0.000	0.000		-0.014	**0.036****	168	1.05	0.01
	January 2000 to December 2006									
Imperfect Rational	**-0.006****	**0.413*****	**-0.005****	0.001	-0.021		0.036	84	14.79	0.25
	-0.006**	**0.400*****	**-0.005****	0.001		-0.022	0.037	84	17.06	0.23
Rational expectations	-0.004		**-0.005****	0.002	-0.022		0.033	84	2.19	0.16
	-0.004		**-0.005****	0.002		-0.024	0.035	84	2.16	0.15
	January 2007 to December 2013									
BEI	0.001	**0.564*****	0.005	-0.002	-0.011		0.041	84	5.18	0.15
	0.001	**0.589*****	0.004	-0.001		-0.003	0.031	84	6.24	0.11
Imperfect Rational	0.002	-0.029	**0.007***	-0.003	-0.013		0.047	84	1.56	0.08
	0.003	-0.038	**0.006***	-0.002		-0.006	0.038	84	1.79	0.04
Survey	**0.012****	**-2.118*****	0.005	-0.002	-0.012		0.045	84	7.47	0.20
	0.012**	**-2.155****	0.004	-0.001		-0.004	0.035	84	7.68	0.15
Rational expectations	0.002		0.006	-0.003	-0.013		0.048	84	1.96	0.06
	0.002		0.006	-0.002		-0.006	0.039	84	2.13	0.00

Source: authors' calculations. * represents significance at 1%, ** at 5% and * at 10%.**

[13] Recall we were expecting that cost-push shocks were also significant and the coefficient equal to the coefficient of deviations expectations. However, this restriction is validated only with CEH identification strategy

Table 6. Estimation results using CEH shocks, with expectations one year ahead, and commodity prices denominated in local currency

Expectation mechanism	*Inflation-Targeting-Regime (January 2000 to December 2013)*									
	Constant	*Expectation deviation*	*Demand-shock*	*Cost-push shock*	*Crude oil*	*Energy*	*Food*	*Number of observations*	*F*	*Adj_R*^{2}
BEI	0.000	**0.444*****	1.083	-0.759	-0.009		0.031	120	2.54	0.14
	0.000	**0.452*****	0.978	-0.682		-0.003	0.026	120	2.80	0.12
Imperfect rational	-0.002	0.206	0.119	-0.158	-0.017		**0.044****	168	1.02	0.09
	-0.002	0.201	0.060	-0.111		-0.014	**0.040****	168	0.87	0.05
Survey	**0.009****	**-1.628*****	1.954	-1.595	-0.009		0.031	112	4.94	0.16
	0.009**	**-1.662*****	1.773	-1.443		-0.002	0.025	112	4.76	0.14
Rational expectations	-0.001		0.164	-0.192	-0.018		**0.041****	168	0.00	0.08
	-0.001		0.107	-0.146		-0.014	**0.036****	168	1.05	0.04
	January 2000 to December 2006									
Imperfect Rational	**-0.006****	**0.413*****	**-1.288****	**0.865***	-0.021		0.036	84	14.85	0.25
	-0.006**	**0.400*****	**-1.345*****	0.918		-0.022	0.037	84	17.11	0.23
Rational expectations	-0.004		**-1.469*****	1.087	-0.022		0.033	84	2.20	0.16
	-0.004		**-1.527*****	1.143		-0.024	0.035	84	2.17	0.15
	January 2007 to December 2013									
BEI	0.001	**0.565*****	1.415	-1.060	-0.011		0.041	84	5.17	0.19
	0.001	**0.589*****	1.106	-0.776		-0.003	0.031	84	6.22	0.16
Imperfect Rational	0.002	-0.029	**0.007***	-0.003	-0.013		0.047	84	14.85	0.14
	0.003	-0.038	**0.006***	-0.002		-0.006	0.038	84	17.11	0.10
Survey	**0.012****	**-2.120*****	1.502	-1.108	-0.012		0.045	84	7.48	0.23
	0.012**	**-2.157*****	1.206	-0.835		-0.004	0.035	84	7.69	0.19
Rational expectations	0.002		2.182	-1.777	-0.013		0.048	84	1.96	0.09
	0.002		1.928	-1.542		-0.006	0.039	84	2.14	0.05

Source: authors' calculations. *** **represents significance at 1%,** ** **at 5% and** * **at 10%.**

The positive effect observed of international food prices shocks, denominated in local currency, for the whole sample period when expectations are imperfect rational or rational, are in line with the statements of the monetary authority of Colombia in 2007 and 2008 (see footnote 5). It seems that pressures to international food prices were effectively transmitted to inflation. However, when the sample period is split these effects are no longer observable casting some doubt on the interpretation of the monetary authority about the inflation outcomes in those years.[14]

The evidence corresponding to the cases of crude oil and energy prices is not only consistent with the recent findings in the literature of a decrease in the contribution of oil prices to headline inflation (see for example De Gregorio et al., 2007), but is also related to the fact that long-term fluctuations in energy and crude oil prices are to a great extent already incorporated on inflation expectations[15].

[14] A possible interpretation is that movements in commodity prices were transmitted to inflation via expectations.
[15] As shown in Tables 1 and 2, second round effects coming from annual variation in international food prices might be at play via inflation expectations.

Moreover, to the extent that inflation expectations may contain a broad range of information about inflation coming from different sources,[16] it makes sense to find out that this is the main and more robust variable accounting for the deviations of the rate of inflation from target, as supported by estimation results. Accordingly, a central message is that central bank's accomplishment of its price stability mandate by means of anchoring inflation expectations to the target is not only crucial, but is probably the essential feature and task under an optimal monetary policy regime.

Under specifications (6) and (9), all coefficients have sensible signs; moreover, the negative sign of the coefficient associated crude oil and demand shocks, because $\delta\alpha\lambda>\beta\theta$, would support the interpretation that the real exchange rate deviations from its long run value is not a very important consideration for the monetary authority. In this sense, the rule allowed the board to face the shocks rightly regardless of the natural trade-offs.

Estimation results for commodity prices denominated in local currency and with inflation expectations two years ahead are presented in Appendix 2. Results show an important decrease on the coefficients associated with the deviation of expectations from target for the imperfect rational mechanism and no effect at all when BEI expectations are considered indicating that, as time-horizon increases, inflation expectations converge to target.

Signs of the coefficients of inflation expectations

Figure 5 depicts the deviations of observed inflation and inflation expectations from target. Two points are in order here. First, according to the behavior of the expectations generated by the survey, it seems that the "model" used by experts to form them is either seriously flawed since expectations are systematically biased or credibility of monetary authority is less than suitable. Second, survey and imperfect rational expectation mechanisms show a backward adaptive behavior which leads to a negative relationship with actual inflation outcomes, while the BEI expectations mechanism looks like a forward-looking one and renders a positive relationship with inflation outcomes.

6. Main findings and conclusions

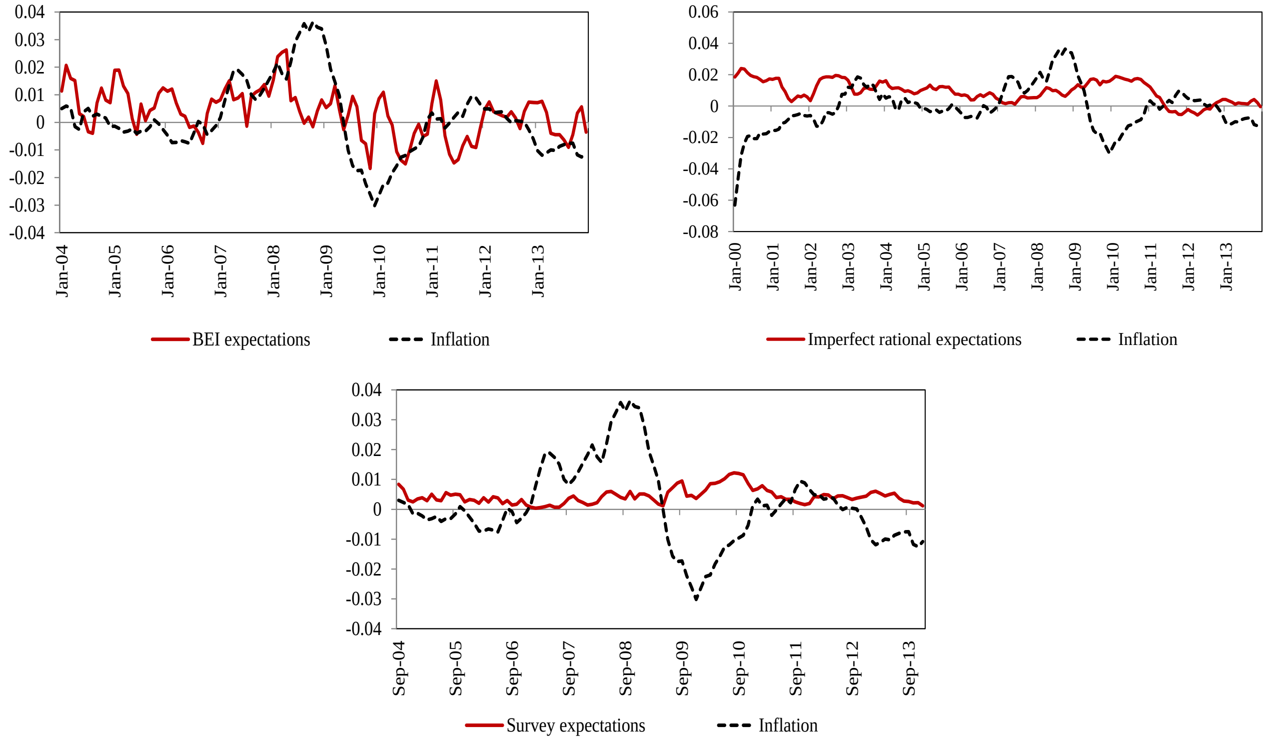
This paper analyzes the effects of the recent movements of commodity prices, in the domestic inflation of Colombia. The estimations were performed for the whole period of the inflation targeting regime: January 2000 to December 2013 and two subsamples: from January 2000 up to December 2006 which

[16] According to results in Table 2, the permanent component of commodity prices variations is statistically significant explaining inflation expectations.

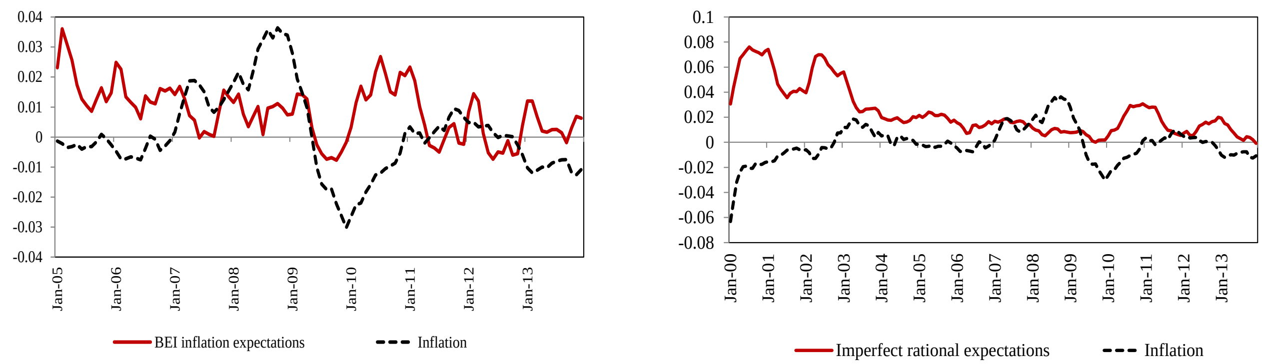
corresponds to the period before the commodity boom and from January 2007 to December 2013, subsample period after the boom. The empirical specification is derived from a simple, yet intuitive, text-book model of a small open economy that follows an optimal monetary policy rule, close to those used by inflation targeting countries.

Figure 5. Deviation of inflation expectations and headline inflation from the inflation target

Panel A. Inflation expectations one year ahead



Panel B. Inflation expectations two years ahead



Source: Central bank of Colombia; National Administrative Department of Statistics (DANE); authors' calculations.

We obtain that when commodity prices are denominated in dollars, there is no evidence of effects in the rate of inflation caused by commodity price shocks. This result holds for the whole period and the two subsamples: before and after the recent commodity price boom. Only BEI expectations seem to be relevant and imperfect rational for the first sub-period. The sign of the survey expectations is always negative, contrary to the one predicted by the model which casts some doubts about the way these expectations are formed. Demand shocks are also statistically significant but only when the sample period is split under the imperfect rational and fully rational expectation mechanisms. Importantly, the sign of the demand shocks switches from one subsample to the other which has to do with the own behavior of these shocks. The validity of the model is not clear cut from the point of view of the equality of expectation and cost-push shocks coefficients on statistical sense. However, for the case of imperfect rational expectations and CHE shocks, for the subsample 2000-2006 the estimation of the model is in agreement to the theoretical model.[17]

The whole picture shows an inflation process governed by expectations being BEI and imperfect rational the more sensible mechanisms. Food price shocks seem to have a small influence on inflation, different from crude oil and energy price shocks which have almost no contribution. This would support the recent findings in the literature of a substantial decrease in the pass-through of oil prices to headline inflation. Our interpretation is that much of permanent movements in oil and energy prices, are passed through inflation via expectations. Finally, the contribution of demand and cost-push shocks in inflation is also hard to determine.

The model and estimations suggest that under an optimal monetary policy framework –everything else equal- deviations of inflation from target will respond to deviations of inflation expectations from target. Therefore, as long as monetary authority reacts timely and accurately, such deviations will tend to decline, leading both inflation and inflation expectations to target. In our view, monetary authority has faced rightly the shocks to commodity world prices. When the target was missed, in 2007 and 2008, the reasons should be others.

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[17] This result suggests the need for future research on the estimation of the structural shocks using the system of equation as a whole.

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Appendix 1. Identification and estimation of supply and demand shocks

Given the Aggregate demand- aggregate supply model, AD-AS

$$y_t^s = y_{t/t-1} + \alpha\left(p_t - p_{t/t-1}\right) + \varepsilon_t \quad (1)$$

$$(y_t + p_t)^d = \left(y_{t/t-1} + p_{t/t-1}\right)^d + \eta_t \quad (2)$$

$$y_t^s = y_t^d \quad (3)$$

Which can be expressed in matrix form

$$\begin{bmatrix} 1 & -\alpha \\ 1 & 1 \end{bmatrix} \begin{bmatrix} y_t \\ p_t \end{bmatrix} = \begin{bmatrix} 1 & -\alpha \\ 1 & 1 \end{bmatrix} \begin{bmatrix} y_{t/t-1} \\ p_{t/t-1} \end{bmatrix} + \begin{bmatrix} \varepsilon_t \\ \eta_t \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} y_t \\ p_t \end{bmatrix} = \begin{bmatrix} y_{t/t-1} \\ p_{t/t-1} \end{bmatrix} + \begin{bmatrix} 1 & -\alpha \\ 1 & 1 \end{bmatrix}^{-1} \begin{bmatrix} \varepsilon_t \\ \eta_t \end{bmatrix}, \quad (5)$$

With variance-covariance of the vector of structural shocks $\begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon,\eta} \\ \sigma_{\varepsilon,\eta} & \sigma_\eta^2 \end{bmatrix}$

Assuming that the expectation of each variable is a linear combination of its own lags, then equation (5) reduces to a VAR model:

$$\begin{bmatrix} y_t \\ p_t \end{bmatrix} = \begin{bmatrix} A_{11}(L) & A_{12}(L) \\ A_{21}(L) & A_{22}(L) \end{bmatrix} \begin{bmatrix} y_t \\ p_t \end{bmatrix} + \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} \varepsilon_t \\ \eta_t \end{bmatrix} \quad (6)$$

The long run- response of the shocks is given by:

$$\Psi_\infty = [I - A(1)]^{-1}\Theta, \quad (7)$$

Where $\Theta = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix}$, $A(1) = \begin{bmatrix} A_{11}(1) & A_{12}(1) \\ A_{21}(1) & A_{22}(1) \end{bmatrix}$

According to BQ, imposing the assumption that the AD shock, η_t, has no long-run effect on output, and assuming that $\sigma_\varepsilon^2 = 1, \sigma_\eta^2 = 1, \sigma_{\varepsilon,\eta} = 0$ imply that

$$\mathrm{c}_{12}[1 - A_{22}(1)] + \mathrm{c}_{22}A_{12}(1) = 0$$

With this restriction, the signs of c_{ij} are not identified, and there are four possible solutions for those values, choosing the one that implies a positive long-run effect of demand shock on price and a positive long-run effect of supply shock on output.

On the other hand, CHE using the values of c_{ij} derived from equation (5), and without imposing any restriction over the var-cov matrix of structural shocks, only one solution is gotten by assuming the neutrality condition in (7)

$$\begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} = \begin{bmatrix} \frac{1}{1+\alpha} & \frac{\alpha}{1+\alpha} \\ \frac{-1}{1+\alpha} & \frac{1}{1+\alpha} \end{bmatrix}$$

$$\alpha = A_{12}(1)/[1 - A_{22}(1)]$$

and the var-cov matrix of structural shocks can be estimated from the var-cov matrix of the VAR innovations, after knowing the value of α.

$$\begin{bmatrix} var(e_{1t}) & covar(e_{1t}, e_{2t}) \\ covar(e_{1t}, e_{2t}) & var(e_{2t}) \end{bmatrix} = \begin{bmatrix} \frac{1}{1+\alpha} & \frac{\alpha}{1+\alpha} \\ \frac{-1}{1+\alpha} & \frac{1}{1+\alpha} \end{bmatrix} \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon,\eta} \\ \sigma_{\varepsilon,\eta} & \sigma_\eta^2 \end{bmatrix} \begin{bmatrix} \frac{1}{1+\alpha} & \frac{-1}{1+\alpha} \\ \frac{\alpha}{1+\alpha} & \frac{1}{1+\alpha} \end{bmatrix}$$

In order to identify orthogonal structural shocks, the two ordering in the Cholesky decomposition are used. The first order assumes there is causality from supply shock, ε_t, to the demand shock, η_t, which may be imposed by assuming that $\eta_t = \rho\varepsilon_t + \nu_t$, where ν_t is a pure AD shock and ρ is the unexpected AD change due to an AS shock. On the other hand, the second order assumes there is causality from the demand shock to the supply shock. In this case, define $\varepsilon_t = \gamma\eta_t + \upsilon_t$, where υ_t is a pure AS shock and γ is the unexpected AS change induced by an AD shock.

Model in equation (6) remains the same with any of the orderings, by assuming

$$\begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} = \begin{bmatrix} \frac{1+\alpha\rho}{1+\alpha}\sigma_\varepsilon & \frac{\alpha}{1+\alpha}\sigma_\nu \\ \frac{-(1-\rho)}{1+\alpha}\sigma_\varepsilon & \frac{1}{1+\alpha}\sigma_\nu \end{bmatrix}$$

or

$$\begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} = \begin{bmatrix} \frac{1}{1+\alpha}\sigma_\delta & \frac{\alpha+\gamma}{1+\alpha}\sigma_\upsilon \\ \frac{-1}{1+\alpha}\sigma_\delta & \frac{1-\gamma}{1+\alpha}\sigma_\upsilon \end{bmatrix}$$

then,

$$\begin{bmatrix} var(e_{1t}) & covar(e_{1t}, e_{2t}) \\ covar(e_{1t}, e_{2t}) & var(e_{2t}) \end{bmatrix} = \begin{bmatrix} c_{11} & c_{12} \\ c_{21} & c_{22} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} c_{11} & c_{21} \\ c_{212} & c_{22} \end{bmatrix}$$

Appendix 2. Results with expectations two years ahead

Table A1. Estimation results using Blanchard-Quah shocks, with expectations two years ahead, and commodity prices denominated in local currency

Expectation mechanism	*Inflation-Targeting-Regime (January 2000 to December 2013)*									
	Constant	***Expectation deviation***	***Demand-shock***	***Cost-push shock***	***Crude oil***	***Energy***	***Food***	*Number of observations*	*F*	*Adj_R*^{2}
BEI	0.001	0.065	**0.007****	-0.003	-0.012		0.037	108	2.24	0.07
	0.001	0.053	**0.006****	-0.003		-0.006	0.031	108	2.04	0.01
Imperfect rational	0.004	**-0.355*****	0.001	0.000	-0.014		**0.047****	168	4.91	0.25
	0.004	**-0.363*****	0.000	0.000		-0.010	**0.042****	168	4.80	0.22
	January 2000 to December 2006									
Imperfect Rational	0.002	**-0.285*****	-0.003	0.001	-0.015		0.033	84	8.26	0.31
	0.002	**-0.288*****	-0.004	0.001		-0.015	0.033	84	8.78	0.29
	January 2007 to December 2013									
BEI	0.001	0.160	0.006	-0.003	-0.014		0.046	84	1.73	0.06
	0.001	0.173	0.006	-0.002		-0.007	0.038	84	1.89	0.00
Imperfect Rational	0.005	**-0.365*****	0.005	-0.001	-0.015		**0.059***	84	7.26	0.18
	0.005	**-0.356*****	0.004	-0.001		-0.008	0.050	84	9.06	0.13

Source: authors' calculations.

Table A2. Estimation results using CEH shocks, with expectations two years ahead, and commodity prices denominated in local currency

Expectation mechanism	*Inflation-Targeting-Regime (January 2000 to December 2013)*									
	Constant	***Expectation deviation***	***Demand-shock***	***Cost-push shock***	***Crude oil***	***Energy***	***Food***	*Number of observations*	*F*	*Adj_R*^{2}
BEI	0.001	0.065	2.369	-1.985	-0.012		0.037	108	2.23	0.07
	0.001	0.052	2.196	-1.839		-0.006	0.031	108	2.04	0.01
Imperfect rational	0.004	**-0.355*****	0.200	-0.180	-0.014		**0.047****	168	4.90	0.25
	0.004	**-0.363*****	0.140	-0.133		-0.010	**0.042****	168	4.79	0.22
	January 2000 to December 2006									
Imperfect Rational	0.002	**-0.285*****	-0.783	0.416	-0.015		0.033	84	8.26	0.31
	0.002	**-0.288*****	-0.810	0.438		-0.015	0.033	84	8.78	0.29
	January 2007 to December 2013									
BEI	0.001	0.160	2.177	-1.809	-0.014		0.046	84	1.74	0.06
	0.001	0.172	1.940	-1.593		-0.007	0.038	84	1.91	0.00
Imperfect Rational	0.005	**-0.366*****	1.283	-0.875	-0.015		**0.059***	84	7.25	0.18
	0.005	**-0.357*****	1.062	-0.671		-0.008	0.050	84	9.03	0.14

Source: authors' calculations.