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Nonlinear Pass-Through of Exchange Rate Shocks on Inflation: A Bayesian Smooth Transition VAR Approach

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ABSTRACT

Determining the exchange rate pass-through on inflation is a necessity for central banks as well as for firms and households. This is an apparently easy and intuitive task, but it faces high complexity and uncertainty. This paper examines the short and long-term impact of an exchange rate shock on inflation along the distribution chain in the presence of endogeneity, nonlinearity and asymmetry. The econometric model is a smooth transition autoregressive vector estimated by Bayesian methods. This incorporates a model of pricing and the endogenous nature of the exchange rate pass-through (PT). The paper uses monthly data from Colombia for the period 2002 to 2015. The main findings are that PT is incomplete (as predicted and found by most of the recent literature) endogenous and then changes over time, nonlinear and asymmetric in the short and long terms to the state of the economy (i.e., PT is nonlinear state-dependent) and to exchange rate shocks. Historically, findings have showed that the accumulated PT on inflation of import prices rises from 20% in the first month of the exchange rate shock to a maximum of around 66% in the first year. The equivalent figures on the inflation of producer goods go from 13% to 52%; on the inflation of imported consumer goods from 6% to 48%, and on the CPI inflation from 4% to 30%. At four years, the respective figures for accumulated PT are 98%, 84%, 94% and 80%, but uncertainty about these estimates increases rapidly over time.

***Classification JEL*:** F31, E31, E52, C51, C52
Keywords: Exchange rate pass-through, pricing along the distribution chain, endogeneity, nonlinearity, asymmetry, logistic smooth transition VAR (LST-VAR), Bayesian approach.

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1. INTRODUCTION

From the point of view of the authorities on small open economies, particularly monetary authorities, there are a least two main reasons to study the impacts of exchange rate shocks. The first one is to learn about the exchange rate ability of being a short term macroeconomic adjustment mechanism. If the prices of imported goods respond in a complete or perfect manner to variations in the exchange rate, the expenditure-switching effects will act fully, and the exchange rate will have an entirely stabilizing role (Obstfeld and Rogoff, 1995; Obstfeld, 2001). This is a fundamental assumption of the potentiality of the nominal exchange rate as a real short-term adjustment mechanism, even in DSGE models. If they do not, the adjustment probably needs to be done by a larger adjustment of the exchange rate (Adolfson, 2001, 2007) or by other instruments, such as the domestic interest rate (Smets and Wouters, 2002). This would imply that from the theoretical point of view, the outcome predicted by flexible price models (that when monetary authority stabilizes prices, simultaneously do so with the output gap) is no longer feasible (Ibid, page 973).

The second reason is to determine their inflationary impact and implications for making monetary policy decisions (Ball, 1999; Taylor, 2000; Devereux and Yetman, 2003; Flamini, 2007; Mishkin, 2008; Forbes, 2015; Forbes et al., 2015). If the degree of exchange rate pass-through is complete, its fluctuations, *ceteris paribus*, are transmitted one-to-one to the inflation of imported goods, and probably to producer and consumer goods. Consequently, authorities may need to respond in order to reach their inflation goals. Otherwise, this response may neither be necessary, nor optimal. In spite of the critical implications just mentioned, "limited understanding of how exchange rate movements affect inflation is – to be candid – quite frustrating for those of us tasked to set monetary policy" (Forbes, 2015, page 3).

Movements in exchange rate not only worry authorities; they also preoccupy domestic firms and households. The former, because they change the local price of imported inputs, so they impact their production costs and expectations about their future behavior. The latter, since exchange rate movements may disturb their consumption decisions, whenever the final prices of goods in local currency are modified.

The purpose of this paper is to examine the short and long-term impact of exchange rate shocks on Colombian inflation along the distribution chain (henceforth PT) in the presence of endogeneity, nonlinearity and asymmetry. The analytical framework is an adjusted and augmented version of McCarthy's (2007) pricing model. The empirical model is a logistic smooth transition VAR (LST-VAR) estimated by Bayesian methods. This model incorporates the pricing model mentioned and the dependence of the PT not only on the exchange rate shocks, but also on the state of the economy. Given the empirical methodology we will use, the historical decomposition of shocks will be also obtained, shown and analyzed. The paper uses Colombian monthly data along with price and trade data from its main trading partners for the period from 2002 to 2015 (since when an inflation-target regime has been in place). Notice that in Colombia imported goods correspond to 24% of the producer price index. On the other hand, the main imported consumer goods represent 9% of the consumer price index (CPI). Lastly, the total tradable goods constitute 42% of the CPI.

Two caveats are worth mentioning before continuing. Firstly, since the interest of this paper is not to explain the type of shock that the economy and the exchange rate itself are experiencing or their general equilibrium implications (as a DSGE model would do), it is limited to evaluating quantitatively the inflationary effects of exchange rate shocks. Of course, we are aware that the impact of those shocks will depend on the type of shock the economy and the exchange itself are facing, as the seminal paper of Klein (1990) showed, nowadays DSGE models would predict (Corsetti et al., 2005), and some recent empirical literature have found for the linear case (Shambaugh, 2008; Forbes et al., 2015). However, in this paper we are interested in what the data reveal, not in what a particular model assumes or predicts or how it behaves. Obviously, we do not mean to say that equilibrium conditions or assumptions about the short and long-term behavior of the macroeconomic variables analyzed in this paper such as PPP do not matter. What we do mean is that we wish for data to speak up freely.[1] Secondly, the paper does not make the reaction function of the monetary authority explicit; however, for one of the estimations shown later we will condition the degree of PT on the historical behavior of the operative instrument of the monetary authority.

This paper contributes to the literature mainly in four ways. Firstly, it models the endogenous, nonlinear and asymmetric nature of the PT in a setup that clarifies the channels through which exchange rate shocks affect inflation of imported, producer, imported consumer and consumer goods. Secondly, this paper implements a Bayesian approach for estimation, inference and prediction, which surmounts the following issues of “frequentist” approaches: multivariate estimations of linear and nonlinear smooth transition models are too rich in their parameters; optimization algorithms of the likelihood functions of their univariate and multivariate estimations are unstable; inference depends on sample size considerations and can be very sensitive to model specification such as lag order; and prediction and understanding dynamics depends on asymptotically justified methods such as the bootstrap (Koop and Potter, 1999).[2,3] Thirdly, it goes further to obtain

[1] Regarding long-term restrictions, as done for instance by Blanchard and Quah (1989), two aspects are worth noting. First, we would not know how to justify that the PT is completed in the long term (that is, PPP holds), since most of the empirical literature has generally shown that it is incomplete, even for long periods, in spite of the fact that for a DSGE model it is a standard assumption. Second, even if one assumes that PPP holds, one has to impose additional restrictions (usually Cholesky on long term) that make economic sense and allow one to recover the structural errors from the nonlinear model implemented. Accordingly, such restrictions must be proven by test to ensure that they are validated by the data and are statistically significant across the different regimes of the transition variables, which have not yet been formulated by theory in the context of nonlinear models estimated by Bayesian methods. Additionally, the complexity involved in calculating GIFT under such restrictions in the framework of nonlinear models puts them outside of the scope of this paper, rather an open research agenda.

[2] On the contrary, the Bayesian approach: Integrates out nuisance parameters; allows joint estimation of all model parameters avoiding grid-search type of procedures, which may generate unstable estimations; inference does not depend on sample-size considerations and it is based on model-averaged measures, which addresses uncertainties about model-specification; considers “the additional uncertainty present in likelihoods

a historical decomposition of shocks (HD) for the proposed LST-VAR model, as did Balke (2000) and Avdjiev and Zeng (2014) for the credit market and the economic activity. This will allow us to differentiate which of the macroeconomic shocks – implicit in our LST-VAR system- were the main determinants of the behavior of prices along the distribution chain and to reveal the relative role played by shocks to the exchange rate. As will be clear, this will bring empirical support to the predictions of the Klein's (1990) model on the endogeneity of prices and exchange rates to macroeconomic shocks and offer alternative evidence to the findings of Shambaugh (2008) and Forbes et al. (2015).

Theoretically, the assumption of complete transmission of the exchange rate on prices arises from the exchange rate monetary models, specifically from the assumed validity of the law of one price or its generalization (purchasing-power parity hypothesis) at all moments in time. This "law" states that prices of goods sold in a country should be equal to the prices of the goods sold abroad when measured in the same currency. In other words, any fluctuation in the exchange rate of a country's currency should be reflected on local inflation to the same degree.

The validity of this assumption, as well as its exogenous nature were doubted in static partial equilibrium models that go back to Krugman (1986) and Dornbusch (1987) and in macroeconomic models to Klein (1990), respectively. Thus, the incompleteness of the PT emerges when there are non-competitive market structures along the production or distribution chains, and strategic pricing by foreign producers and exporters or by local importers and producers (Krugman, 1986; Dornbusch, 1987; Ball et al., 1988; Corsetti and Dedola, 2005; Takhtamanova, 2008), nominal rigidities (Ball et al., Ibid; Corsetti et al., Ibid), menu costs (Ghosh and Wolf, 2001), shifts in the composition of country import bundles (Campa and Goldberg, 2005) or increased sensitivity of tradable and nontradable

that are not single-peaked in finite samples;" prediction and dynamics do not rely upon asymptotic methods, but on the different models and the observed sample(Ibid, pages 259-261).

[3] Fernandez-Villaverde et al. (2009) list and explain neatly additional justifications for using Bayesian methods in economic and econometric analyses.

consumer good prices to movements in exchange rates due mainly to a large expansion of imported input use across sectors (Campa and Goldberg, 2006). On the other hand, the endogeneity arises because the PT "depends upon the underlying macroeconomic structure of the economy" so that exchange rates and import prices are jointly determined (Kein, 1990).

The nonlinear and asymmetric behavior of the PT is related to the sign, size and nature (transitory versus permanent) of the exchange rate shocks, to their volatility and to the state of the economy (Borensztein and De Gregorio, 1999; Taylor, 2000; Smets and Wouters, 2002; Devereux and Yetman, 2003; Corsetti et al., 2005; Mishkin, 2008). Lastly, they materialize as a consequence of an inventory management strategy. In our paper, the state of the economy is summoned by the historical behavior of CPI inflation (variation, volatility and deviation from trend), historical performance of exchange rates (variation and volatility of the nominal rate and "misalignment" of the real exchange), output gap as a measure of a certain phase of the economy in the business cycle, degree of economic openness, movements of commodity prices and a trend variable, as a "time ordering" variable. Of course, the degree of PT will also depend on the credibility and reaction of the monetary authority, which we will roughly capture as said above.[4]

The international and Colombian empirical literature has concluded almost unanimously that the PT is incomplete, and recently that it is endogenous, nonlinear and asymmetric in both the short and the long terms, as shown by González et al. (2010) for Colombia. These results are independent from the theoretical and empirical approximation used and the country, period and data frequencies analyzed.

In the case for Colombia, Table 1 contains the main literature on this matter.[5] For instance,

[4] Measurements of the inflation expectations and credibility of the monetary authority would be two additional "state variables" one may want to use, as did Forbes et al. (2015), in a different approach to ours, though. We do not include them due to difficulties in measuring them.

[5] A review of international empirical literature on PT in the last decade is shown in Appendix A1. For an

Rincón (2000), the first elaborated study written on exchange rate pass-through in Colombia, found that the PT was incomplete. This result forever changed the monetary view of the local monetary authorities on the degree of transmission of exchange rate fluctuations on inflation. The estimated long-term elasticities on import and export prices to a change in the exchange rate were 0.84 and 0.61 respectively. The long-term elasticity on consumer prices was found to be 0.1.

Later on, Rowland (2003) also found that the PT was incomplete. Import prices responded quickly to an exchange rate shock and 0.8 of it was passed onto prices of imports within 12 months. The corresponding transmission for producer prices was 0.28 and for consumer prices less than 0.15. Thus, according to the author, an exchange rate shock had little impact on consumer price inflation.

On the other hand, Rincón et al. (2005) made a disaggregate analysis and estimated the PT for import prices of a sample of the sectors in the Colombian manufacturing industry. The authors found clear evidence of heterogeneity in the degree of PT across sectors as well as in the incomplete transmission of the exchange rate both in the short and long terms. The degree of estimated PT was located between 0.1 and 0.7 for the short term and 0.1 and 0.8 for the long term. In spite of the fact that they did not develop it, they made explicit the possible presence of nonlinearities in the relationship between the exchange rates and prices in the Colombian case.

As for a comparison between Colombia and other Latin American countries, Ramirez (2005) found evidence of a decline in the PT after different types of events had taken place: central bank independence, floating exchange rate and adoption of the inflation targeting regime. The author showed that the country for which the clearest evidence of changes in the PT induced by IT was Brazil.

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overview of the academic literature, see Burnstein and Gopinath (2013).

Table 1: Colombian literature on exchange rate pass-through

Authors	Year	**Freq.**[1]	**Sample**	**Econometric model**	**Econometric Approach**[2]	**Variables**[3]	**Inflation**[4]
Rincón	2000	M	1980-1998	VEC	LR	L and Diff	Pm; Px; CPI
Rowland	2003	M	1983-2002	VAR, VEC	LR	L and Diff	Pm; W; CPI
Rincón et al.	2005	M	1995-2002	VEC	LR	Diff	Pm
Ramirez[5]	2005	M	1980-2004	ARDL, RR	LR	Diff	Pm; W
Parra	2010	Y	1994-2005	Calibration	Elasticity	L	Pm; Pt; Pnt; CPI
González et al.	2010	Q	1985-2007	LST-VAR	NL	Diff	Pm
Rincón and Rodríguez	2015	Q	1985-2014	LST-VAR	LR	Diff	Pm; CPI

Source: Authors' review.
[1] Q: Quarterly; M: Monthly; Y: Yearly.
[2] NL: Non-Linear; LR: Linear; RR: Rolling regression.
[3] L: Levels; Diff: Differences.
[4] Pm: Imported producer goods; W: Producer goods; Px: Exported goods; CPI: Consumer goods; Pt: Tradable goods; Pnt: Nontradable goods.
[5] Brazil, Chile, Colombia and Mexico.

Parra (2010) considered some of the hypotheses developed by the international literature on open macroeconomics to explain the disconnection between the nominal exchange rate and domestic inflation, which is based on the presence of margins of distribution and marketing on the imported goods. Parra concluded by calibration that, on average, a 1% nominal devaluation of the local currency would imply a 0.28 increase in the CPI.

Last but not least, González et al. (2010) showed that the PT on whole import prices was incomplete not only in the short but also in the long run. Their estimations showed that the PT coefficient was between 0.06 and 0.58. They also found that the degree and dynamics of the PT were endogenous and asymmetrical to the behavior of the exchange rate and to the state of the economy. Thus, the PT was greater when the economy was booming and more open, the devaluation/appreciation of the exchange rate accelerates and was less volatile, the real exchange rate was overvalued, and the inflation rate was high and less volatile, and it decelerated. By the same token, but this time on the CPI, Rincon and

Rodriguez (2015) found that the PT was 0.04.

Therefore, it is clear that if PT is incomplete, endogenous and nonlinear, the models used by central banks for analysis and inflation forecasts should include this fact. At the same time, the monetary authority should take them into account when evaluating the scope of their policy decisions as well as to appraise their achievements.[6] Surely, for example, if the degree and dynamics of the PT depend positively on the level of inflation, the authorities will be inclined, *ceteris paribus*, to maintain low levels of inflation.

The main finding of this paper is that the pass-through is incomplete (as predicted and found by most of the recent literature reviewed in the paper) endogenous and then varies over time, nonlinear and asymmetric in the short and long terms to the state of the economy (i.e., PT is state-dependant) and to exchange rate shocks, which contrast strongly, for example, with those well-known findings by Campa and Goldberg (2005, 2006) for a sample of OECD countries. Historically, *ceteris paribus*, the accumulated PT on the inflation of import prices rises from 20% in the first month of the exchange rate shock to a maximum of around 66% in the first year. The equivalent figures on the inflation of producer goods go from 13% to 52%; on the inflation of imported consumer goods from 6% to 48%, and on the CPI inflation from 4% to 30%. At four years, the accumulated PT on inflation of imported consumer goods is 98%, 84% on producer goods, 94% on imported consumer goods, and 80% on total consumer goods. Of course, uncertainty on the PT estimates is higher the further from the initial shock the figure is. Last but not least, according to the HD of shocks, price variations are endogenous to the different macroeconomics shocks faced by the economy and the exchange rate itself and to the state of the economy.

[6] For example, as has been recalled by literature, if PT is incomplete, models such as Gali and Monacelli (2000), which predict that under an optimal monetary policy "there is no tradeoff between output gap stabilization and price stability and there is no need for an explicit consideration of the exchange rate," should be reviewed (Smets and Wouters, 2002, page 948). Notice that this criticism was rapidly recognized by Monacelli (2003, page 8), who concludes that in response to certain shocks (e.g, efficient productivity shocks) "incomplete pass-through has the effect of generating endogenously a short-run tradeoff between the stabilization of inflation and of the output gap."

The policy implications of our findings are evident. Firstly, models used in central banks for policy making need to be adjusted to the incomplete, endogenous, nonlinear and asymmetric nature of PT. Secondly, there should not exist a specific rule on PT on inflation for policy making, even in the short term. Thirdly, transmission of movements in the exchange rate on inflation vanishes along the distribution chain, as expected, and this behavior seems independent from any market behavior by firms, the state of the economy or shocks. Fourthly, uncertainty about PT estimates increases rapidly across time after the shock.

This document consists of five sections in addition to the introduction. The second section describes the transmission channels of exchange rate shocks to imported, producer, imported consumer and total consumer good prices. The third presents an adjusted and augmented version of McCarthy's (2007) pricing model along the distribution chain, which is the analytical framework of the paper. The fourth section explains the data and introduces the regression model and Bayesian smooth transition estimation approach. Results are shown and analyzed in the fifth section. The last part summarizes the conclusions. It is worth noting that all aspects related to the implementation of the empirical methodology are left to the appendixes.

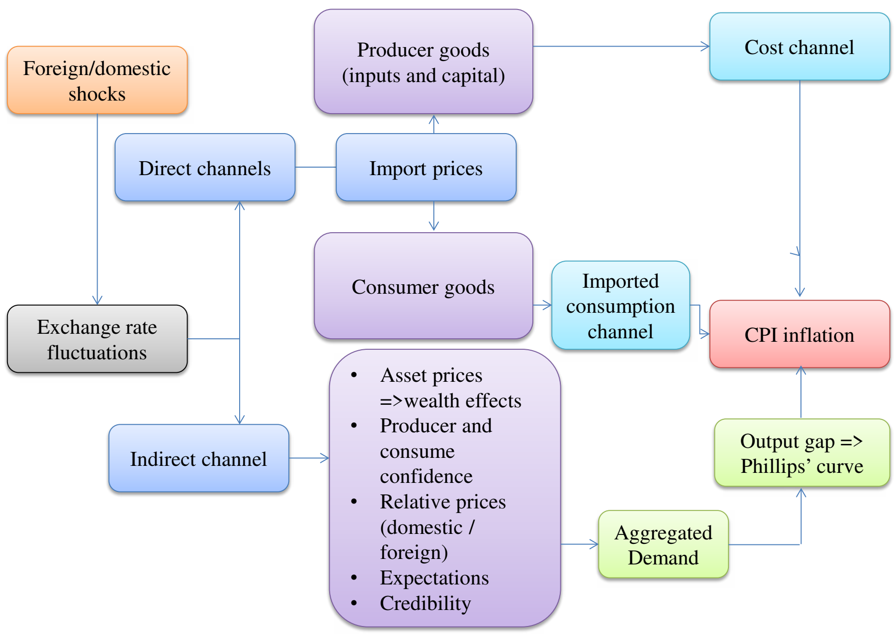
2. TRANSMISSION CHANNELS OF EXCHANGE RATE SHOCKS ON INFLATION

Exchange rate fluctuations manifest themselves on inflation through at least three channels, two of them direct and one indirect (Figure 1). The first channel acts through the direct effect of exchange rate fluctuations on import prices and then on producer goods. For producers, the cost of production changes because many products use imported inputs, and, through the cost channel, so does the CPI inflation.[7] The degree of transmission through

[7] Notice that CPI inflation may be affected through the cost channel not only because prices of tradable goods are changing, for instance because of prices of imported inputs used by producers, but also due to the fact that prices of non-tradable goods or services may adjust, too. For instance, changes in the exchange rate may

this channel will depend, among others, on the importing firms' market power over the internal market, on their ability to compensate *menu costs* in price changes or their strategic management of inventories, on the nominal rigidities embedded in the economy, on the sign, size, volatility and nature of exchange rate shocks, and on the state of the economy, as was said before.

Figure 1: Transmission channels of exchange rate shocks on inflation



Source: Authors' construction, based on Miller (2003) and own deductions.

The second channel is the direct effect on imported consumer goods (which are also intermediated by importers) and which directly impacts the CPI. This channel can be called the imported consumption channel. It also manifests itself in changes in the demand of domestic goods derived from price variations of the imported goods competing with them, putting upward/downward pressure on the CPI. The degree of substitutability between imported and local goods will be determinant of the degree of transmission through this channel.

alter transportation or telecommunication prices due to adjustments in the prices of imported equipment.

The indirect channel works through multiple means and disturbances that impact the aggregated demand and the CPI through the Phillips' curve. Among these mechanisms are asset prices, confidence of households and firms, relative domestic/foreign prices, inflation expectations and credibility on the monetary authority.

Of course, the timing, degree and dynamics of the impact of exchange rate shocks on prices at each stage are different, as will be shown later.

3. ANALITICAL FRAMEWORK

In order to study the impact of exchange rate shocks on prices, this section follows McCarthy's (2007) pricing model along the distribution chain. However, we adjust and augment his model in three directions. Firstly, we introduce marginal costs of foreign producers of domestic imports (mgc^*), which captures not only the impact of their noncompeting behavior on the domestic inflation when the exchange rate of the domestic currency changes (as was originally pointed out and modeled by Dornbusch (1987)) but also the effects of global supply shocks.[8,9] Secondly, we changed the order of the system of equations to allow for demand shocks to affect supply, and not the other way around, in order to somehow incorporate the predictions from Neo-Keynesian DSGE models for small open economies.[10] Thirdly, we differentiate import prices that affect producers from those that alter consumers directly. Thus as we will show next, there will be four price stages: import, producer, imported consumer and total consumer goods.

Hence, price variations at a specific distribution stage in period t have different

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[8] Dornbusch models a foreign firm which optimally fixes its export price with a markup above its marginal cost, and the markup is a growing function of its product market share in the domestic country.

[9] Introducing international prices in the model also tackles criticisms to the empirical literature on exchange rate pass-through on inflation that did not differentiate between changes in the exchange rate *vis-à-vis* changes in international prices, as was recalled by Shambaugh (2008).

[10] Due to the presence of sticky prices or noncompetitive behavior by producers, supply is demand determined in the short term.

components (see Figure 1): (1) The expected inflation at the respective stage based on all information available at period *t*-1; (2) the effects of period *t* foreign marginal cost shock on inflation at that stage; (3) the impact of period *t* exchange rate shock at a particular stage; (4) the influence of period *t* domestic demand and supply shocks at a particular stage; (5) inflation shocks of other goods at previous stages; (6) the respective inflation shock at period *t*, which is nothing but the fraction or residual of inflation at each stage not explained by the other components (for instance, shocks to mark-ups of firms, as predicted by the Dornbusch's model).

Therefore, the inflation rates in period *t* at each of the stages – import (*m*), producer (*w*), imported consumer (*mc*) and total consumer (*cpi*) goods – can be written as:

(1) Foreign marginal cost: $\Delta mc_t^* = E_{t-1}(\Delta mgc_t^*) + \varepsilon_t^{\Delta mgc^*}$

(2) Exchange rate: $\Delta e_t = E_{t-1}(\Delta e_t) + \alpha_1 \varepsilon_t^{\Delta mgc^*} + \varepsilon_t^{\Delta e}$

(3) Inflation of import prices: $\pi_t^m = E_{t-1}(\pi_t^m) + \beta_1 \varepsilon_t^{\Delta mgc^*} + \beta_2 \varepsilon_t^{\Delta e} + \varepsilon_t^{\pi^m}$

(4) Domestic demand: $D_t = E_{t-1}(D_t) + \gamma_1 \varepsilon_t^{\Delta mgc^*} + \gamma_2 \varepsilon_t^{\Delta e} + \gamma_3 \varepsilon_t^m + \varepsilon_t^D$

(5) Domestic supply: $S_t = E_{t-1}(S_t) + \delta_1 \varepsilon_t^{\Delta mgc^*} + \delta_2 \varepsilon_t^{\Delta e} + \delta_3 \varepsilon_t^m + \delta_4 \varepsilon_t^D + \varepsilon_t^S$

(6) Inflation of producer goods: $\pi_t^w = E_{t-1}(\pi_t^w) + \theta_1 \varepsilon_t^{\Delta mgc^*} + \theta_2 \varepsilon_t^{\Delta e} + \theta_3 \varepsilon_t^m + \theta_4 \varepsilon_{t\ 2}^D + \theta_5 \varepsilon_t^S + \varepsilon_t^{\pi^w}$

(7) Inflation of imported consumer goods: $\pi_t^{mc} = E_{t-1}(\pi_t^w) + \vartheta_1 \varepsilon_t^{\Delta mgc^*} + \vartheta_2 \varepsilon_t^{\Delta e} + \vartheta_3 \varepsilon_t^m + \vartheta_4 \varepsilon_t^D + \vartheta_5 \varepsilon_t^S + \vartheta_6 \varepsilon_t^w + \varepsilon_t^{\pi^{mc}}$

(8) Inflation of total consumer goods: $\pi_t^{cpi} = E_{t-1}\left(\pi_t^{cpi}\right) + \varphi_1 \varepsilon_t^{\Delta mgc^*} + \varphi_2 \varepsilon_t^{\Delta e} + \varphi_3 \varepsilon_t^m + \varphi_4 \varepsilon_t^D + \varphi_5 \varepsilon_t^w + \varphi_6 \varepsilon_t^{mc} + \varepsilon_t^{\pi^{cpi}}$

The exchange rate shock is pulled out from its own perturbation. The demand shock is extracted from a measure of the output gap and the supply shock from non-core inflation, as any 'modern' central banker would do. $\varepsilon_t^{\Delta mgc^*}$, $\varepsilon_t^{\Delta e}, \varepsilon_t^D$ and ε_t^S are the structural innovations to foreign marginal cost, exchange rate, domestic demand and domestic supply, respectively. These shocks are assumed as contemporaneous, independent, and uncorrelated with every variable in the information set and with any other shock; in other words, they are assumed to be rational expectation errors. ε_t^m, ε_t^w, ε_t^{mc} and ε_t^{cpi} are the structural innovations to import, producer, imported consumer and total consumer inflation. It is also understood that they are contemporaneously independent and uncorrelated. $E_{t-1}(.)$ is the mathematical expectation of the respective conditional variable on all the information available and observable variables at time *t*-1, including past data.

The conditional expectations given in equations (1) to (8) are replaced by projections of the lags of the variables in the system. Hence, they can be expressed as a VAR system, where the vector of variables summarizing this is:

$$Y_t = \begin{bmatrix} \Delta mgc_t^* \\ \Delta e_t \\ \pi_t^m \\ D_t \\ S_t \\ \pi_t^w \\ \pi_t^{mc} \\ \pi_t^{cpi} \end{bmatrix} \tag{9}$$

with a vector of structural shocks given by,

$$\boldsymbol{\varepsilon}_t = \begin{bmatrix} \varepsilon_t^{\Delta mgc^*} \\ \varepsilon_t^{\Delta e} \\ \varepsilon_t^{\pi^m} \\ \varepsilon_t^{D} \\ \varepsilon_t^{S} \\ \varepsilon_t^{\pi^w} \\ \varepsilon_t^{\pi^{mc}} \\ \varepsilon_t^{\pi^{cpi}} \end{bmatrix} \tag{10}$$

4. DATA, REGRESSION MODEL AND ESTIMATION APPROACH

4.1 The Data

We use monthly data from Colombia and its main trading partners for the period between 2002:06 and 2015:05 (the time series data and their sources is described in Appendix A.2). An index weighted by foreign trade was constructed to obtain a nominal effective exchange rate measure (trade weights were obtained from the Colombia's main trading partners). Here a rise in the index is a depreciation of the domestic currency (peso).

4.2 The Regression Model: A Nonlinear Logistic Smooth Transition VAR Model

The estimations of the PT on imported, producer, imported consumer and total consumer goods start from the pricing model along the distribution chain given by equations (1) to (10) in section 3. This model will be specified as a logistic smooth transition VAR (LST-VAR) model (Luukkonen, Saikkonen and Terasvirta, 1988; Granger and Teräsvirta, 1993; Teräsvirta, 1994; Van Dijk, Terasvierta and Franses, 2002), which allows us to model and diagnose the types of endogeneities, nonlinearities and asymmetries of the PT discussed above.[11] The model will be estimated by Bayesian methods, following closely the approach implemented by Gefang and Strachan (2010) and Gefang (2012). We explain the methodology step by step in Appendix A.3.

Inflation of imported producer, imported consumer and total consumer goods will depend on their own lags, lags of foreign marginal cost and their lags, lags of exchange rate movements and their lags, lags of demand and supply and their lags and on the different shocks. Moreover, their regime changes are determined by the transition variables, whose dynamic is captured by a logistic smooth transition function. The *p*-lags order LST-VAR

[11] Thus, we selected the transition model on the basis of the economic theory, as well as the Bayes Factors results, which suggests the use of a logistic smooth transition model in order to capture possible asymmetrical behaviors for extreme values of the variable that describes the transition or state of the economy.

model is written as (see He et al., 2009), which we represent here as of order one for illustration purposes:

$$(11) \qquad Y_t = \begin{bmatrix} \Delta mgc_t^* \\ \Delta e_t \\ \pi_t^m \\ D_t \\ S_t \\ \pi_t^w \\ \pi_t^{mc} \\ \pi_t^{cpi} \end{bmatrix} = A(L)Y_{t-1} + F(V_{t-d}\,; \gamma, c)B(L)Y_{t-1} + \boldsymbol{\mu}_t \ ,$$

with $A(L)$ and $B(L)$ being p-order polynomial matrixes; L being the lag operator; $F(V_{t-d}\,; \gamma, c)$ being a diagonal matrix whose elements f_j are transition functions, with $f_j(\cdot) = \{1 + \exp[-\gamma(V_t - c)]\}^{-1}$ representing the cumulative function of logistical probability for the *j*-th transition variable, V_t the vector of transition variables and γ the smoothing parameter for the change in the value of the logistic function ($\gamma > 0$). Thus, the smoothness of the transition from one regime to the other has the following behavior: If γ is very large, the logistic function $f_j(V_t; \gamma, c)$ approaches the indicator function $I(V_t > c)$. As a consequence, changes from 0 to 1 become instantaneous at $V_t = c.$ When γ approaches zero, the logistic function becomes a constant (equal to 0.5) and the LST-VAR model reduces to a linear VAR model with parameters $\Phi_j = A_j + \frac{B_j}{2}$, for *j*= *0, 1, ..., p*.

On the other hand, *c* is the localization parameter and can be interpreted as the threshold between the two regimes, in the sense that the logistic function $f_j(\cdot)$ changes monotonically from 0 to 1 as V_t increases.[12] Finally, $\boldsymbol{\mu}_t$ is a vector of white noise processes. The parameters γ and c together with V_t govern the transition between regimes. Thus when $\gamma \to \infty$ and $V_t < c$ we are under the regime of $A(L)Y_{t-1}$, while when $\gamma \to \infty$ and $V_t > c$ we

[12] As will be shown later, parameters γ and c will change with each transition variable V.

are then under $[A(L) + B(L)]Y_{t-1}$. For finite values of γ, one has a continuum between the two extreme regimes.

The structural shocks in equation (11) are identified by using the Cholesky decomposition. In other words, we define $\boldsymbol{\mu}_t = \boldsymbol{A}^{-1}\boldsymbol{\varepsilon}_t$, with $\boldsymbol{A}$ being an inferior triangular matrix and $\boldsymbol{\varepsilon}$ the vector of the structural shocks, which are assumed to have the following properties: $E\left[\varepsilon_t^i / \Omega_{t-1}\right] = 0$, $E\left[\varepsilon_t^{i^2} / \Omega_{t-1}\right] = \sigma^{i^2}$, not cross-correlated and $\Omega_{t-1} = \left[y_{t-1}^i,\ y_{t-2}^i, \dots, y_{t-p}^i\right]$, with i=$\Delta mgc^*, \Delta e, \pi^m, D,\ S, \pi^w, \pi^{mc}, \pi^{cpi}$.

But why do we choose a Cholesky decomposition method, which has been critiqued heavily in different contexts? There are several reasons. First, it does not affect the robustness of our PT estimates since they are constructed using generalized impulse response functions (GIRF), which are invariant to the ordering of the variables in VAR systems (Pesaran and Shin, 1998; Ewing, 2001).[13] Second, we will introduce an additional identification assumption, which consists on imposing a positive PT and conditioning the accumulated GIFT of the numerator and denominator of equation (12) to it. This makes sense by definition and goes along with the idea of identification by sign restrictions of Canova and De Nicolo (2002). Third, innovative work in the field of Bayesian nonlinear VARs such as (Gefang and Strachan, 2010; Gefang, 2012) considers that Cholesky decomposition is a good approximation of identification, which is complemented with GIFT to overcome the issue of ordering the variables in a VAR system. Therefore, those critiques from Faust and Rogers (2003) because we are using a recursive identification method do not seem to hold for our estimations.

Notice that one possibility to know the p-order of the system, to choose the transition variables V, and to know the lag delay d of the transition variables and the values of the parameters γ and c is to have a range of models and then choose the best one using a criterion, for example, the maximization of the likelihood function, as did Gonzalez et al.

[13] The methodological appendixes will explain how the GIRF functions are calculated.

(2010). An alternative, as presented in this paper, is to use Bayesian methods to formally compare among different model specifications (remember that under the Bayesian approach models become random variables). Specifically, we calculate the Bayes factor from the Savage–Dickey density ratios (SDDR) for many combinations of the arguments and compute posterior model probabilities to select the dominant model for inference.[14,15] This permits us to account for model specification and coefficient uncertainties, as well as for the driving forces of the nonlinearities. From there we construct GIRF and then trace out the dynamics of the PT coefficients.[16]

The selection of the transition variables will be made among the following ones, according to what the theory presented above suggests and what the Bayesian method determines: Variation of the CPI inflation ($\Delta\pi^{cpi}$), volatility of inflation ($V(\pi^{cpi})$) and CPI inflation without trend ($\bar{\pi}^{cpi}$), as an effort to differentiate a "high" inflation regime from a "low" one. Also, variation of the exchange rate change ($\Delta(\Delta e)$), volatility of the exchange rate ($V(\Delta e)$) and a measurement of misalignment of the real exchange rate (Dq) (which is estimated as the cyclical component of the Hodrick-Prescott decomposition on the real exchange rate index) are analyzed. It is worth noting that we use the volatility of the exchange rate of the Colombian peso as a measure of the nature of its changes: if the volatility is high we suppose that exporters perceive such changes as transitory, while if it is low, we assume that exporters perceive such changes as permanent. The other transition variables are output gap (Gy), degree of economic openness ($Opennes$), variation of

[14] Keep in mind that the Bayes factor is the posterior odds of the null hypothesis; i.e., the degree to which we favor a null hypothesis over an alternative one after observing the data, given the prior probabilities on the null and alternative. Details on how to calculate the Bayes factors are explained, for instance, in Koop (2003) and Gefang (2012, Appendix A).

[15] The Savage–Dickey density ratio is a computational strategy to calculate the Bayes factor, and then, if needed, the posterior odds ratio for nested models comparison. The SDDR numerator is calculated with the draws from the Gibbs Sampler and the denominator is evaluated just with the priors at the restricted parameters, with some coefficients equal to zero in our application (see Koop (2003)).

[16] As is stated by some authors (Koop, Pesaran and Potter, 1996; Koop and Potter, 1999), impulse response functions of nonlinear models are history and shock dependent. "This contrasts with the traditional impulse response analysis in a linear VAR in which positive and negative shocks are treated symmetrically and independent… [of state of the economy]" (Gefang and Strachan, 2010, page 19).

commodity prices ($Pcomm$), the interbank interest rate, as the operational instrument of the monetary policy (IBR), as well as a trend variable as a "time ordering" variable ($Trend$). The operational interest rate aims to condition the PT on the behavior of the main monetary policy instrument of the Colombian monetary authority.

Thus, according to predictions from theory, in general PT should be larger when inflation is high, it accelerates and is less volatile, because firms may gain price-fixing power (in the first two cases) and cause expectations that those changes may be long lasting so they cannot stand to keep prices unchanged; the exchange rate depreciation/appreciation accelerates and its volatility is low, as firms perceive those movements as long-lasting or permanent and, by the same token, they rapidly transmit movements in the exchange rate to prices; the real exchange rate is undervalued, since the further from above the exchange rate is from its equilibrium, the larger the transmission of depreciation on prices should be in order to restore such equilibrium. Conversely, the further from below the exchange rate is from its equilibrium, the lower or more neutral the transmission of depreciation on prices should be; the output gap is positive, as demand pressures on inflation are higher, as predicted nowadays by any New Keynesian DSGE model; economic openness is larger because the more tradable the goods of the economy are, the more responsive should prices be to exchange rate changes (this assumption has been recently challenged by Forbes (2015)). As for commodity prices, interbank interest rate and trend, it is difficult to make any prediction. As for the operative target of monetary policy (interbank interest rate), Mishkin (2008) points out that a stable monetary policy supported by an institutional framework that allows the central bank to have a policy that is independent of fiscal considerations and political pressures is one that effectively removes a potentially important source of large PT. Since we do not a have a measure of the "stability" or credibility of monetary policy, we will let data reveal predictions for the latter three transition variables.

The PT coefficient for a period τ is calculated as the accumulated response of inflation to a shock to the exchange rate relative to the accumulated response of the exchange rate to the same shock (Goldfajn and Werlang, 2000; Winkelried, 2003; Mendoza, 2004; González et al., 2010; Mendoza, 2012; Rincón and Rodríguez, 2015):

$$PT_\tau = \frac{\sum_{j=0}^{\tau} \frac{\partial \pi_{t+j}^{n}}{\partial \varepsilon_t^{\Delta e}}}{\sum_{j=0}^{\tau} \frac{\partial \Delta e_{t+j}}{\partial \varepsilon_t^{\Delta e}}}, \quad n = m, w, mc, cpi, \qquad (12)$$

where $0 \leq PT_\tau \leq 100$. That is to say, the degree of PT measures the relative change in accumulated inflation up to moment τ in the presence of a shock in the exchange rate in period 0, with respect to accumulated changes up to period τ of the exchange rate with respect to the change itself in period 0. Upon correcting for this last effect, the possibility of overestimating the degree of PT is avoided. We describe how we estimate the PT coefficients under the Bayesian approach step by step in Appendix A.4.

5. RESULTS

5.1 Model comparison and selection

Table 2 shows the natural logarithms of the Bayesian factors (BF) for each of the models to a restricted zero-lag model (a model with only a constant term).[17] It is assumed as independent; that is, we assign the same prior weight to each of the candidate models. Hence, the table reports the best alternative combinations of VAR-lag or LST-VAR-lag and delay for each candidate transition variable (denominators) when compared to the restricted model (numerator). Hence, the closest the estimated BF is to zero, the more preferable the unrestricted model will be, or under which the observed data are most likely. In other words, the more negative "Ln(BF)" is, the better specification is obtained. The results (last column) show strong support for the nonlinear specification for all transition variables. Therefore, data seem to validate an endogenous and nonlinear dynamics of the

[17] We present natural logs of BF because of computational approximation problems with the BF.

exchange rate shocks on the inflation of imported, producer, imported consumer and total consumer goods. Accordingly, the generalized impulse response functions and estimates of the PT coefficients reported below will be based upon the results reported in Table 3.

Table 2. Bayes factor for selected models

Model	Transition variable	*p*-lag	*d*-lag	Ln(BF)
VAR	$\Delta(\pi^{cpi})$	3	NA	-889.8
LST-VAR	$\Delta(\pi^{cpi})$	3	1	-14798.0
VAR	$V(\pi^{cpi})$	4	NA	-2838.1
LST-VAR	$V(\pi^{cpi})$	4	1	-15222.0
VAR	$\bar{\pi}^{cpi}$	4	NA	-3698.3
LST-VAR	$\bar{\pi}^{cpi}$	4	1	-16750.0
VAR	$\Delta(\Delta e)$	4	NA	-583.2
LST-VAR	$\Delta(\Delta e)$	4	1	-15023.0
VAR	$V(\Delta e)$	4	NA	-3998.5
LST-VAR	$V(\Delta e)$	4	1	-17534.0
VAR	*Dq*	4	NA	-1724.5
LST-VAR	*Dq*	4	1	-16212.0
VAR	*Gy*	2	NA	-1146.1
LST-VAR	*Gy*	2	1	-14440.0
VAR	*Openness*	4	NA	-3184.9
LST-VAR	*Openness*	4	3	-15539.0
VAR	*Pcomm*	4	NA	-5348.2
LST-VAR	*Pcomm*	4	3	-15128.0
VAR	*IBR*	4	NA	-1578.5
LST-VAR	*IBR*	4	2	-16125.0
VAR	*Trend*	3	NA	-9328.9
LST-VAR	*Trend*	3	1	-16530.0

Source: Authors' calculations. "BF" means 'Bayes factor', Ln: natural logarithm, and "NA" means 'Not Apply'.

5.2 Estimations of transition functions and their parameters

The estimation of the regression model given by equation (11) is done by the Gibbs sampler scheme described in Appendix A.3, which requires initial values. For the localization parameter c_j, the search is limited to the range of the percentile 16%=c_{min} to 84%=c_{max} of the transition variable under consideration. As said before, the importance of the parameter c is that it allows the regimes to be cataloged based on the values of the transition variables, for instance, highs and lows, or as rises and falls, etc.

The results reported in Table 3 first indicate that the estimated c is located fairly at the center of the distribution of the jth transition variable, except for the variation of the exchange rate change ($\Delta(\Delta e)$) and the misalignment of the real exchange rate (Dq).[18] For example, when the transition variable is the detrended CPI inflation, the c estimate is -2.54 and the Threshold is -0,37, and the number of observations classified in the "Low" regime is 77 and in the "High," 74. That is to say, the observed inflation has been in the "inflationary" regime in almost 50% of the cases along the sample.

Table 3: Estimated parameters for the selected models

Transition variable	**Estimated parameters**		**# obs. per regime**		**Threshold**	p-lag	d-lag
	γ	c	Low	High			
$\Delta(\pi^{cpi})$	1.28	-12.57	78	74	0.10	3	1
$V(\pi^{cpi})$	2.26	0.43	99	52	0.53	4	1
$\bar{\pi}^{cpi}$	3.39	-2.54	77	74	-0.37	4	1
$\Delta(\Delta e)$	7.18	-1703.77	79	72	0.0	4	1
$V(\Delta e)$	4.85	1.60	93	58	2.52	4	1
Dq	2.57	-552.45	77	74	0.00	4	1
Gy	1.02	-1.10	78	75	-0.01	2	1
Openness	3.69	26.36	78	73	36.22	4	3
Pcomm	6.03	289.16	70	81	394.82	4	3
IBR	1.59	430.20	78	73	579.96	4	2
Trend	31.25	269.06	76	76	276.50	3	1

Source: Authors' calculations.

[18] Possible reasons for the results with these two variables are that the former is highly volatile and the latter is calculated from a filter, and we are using the average of the deviation of the filtered series as the threshold, instead of using the average deviation from the average of the filtered series.

In order to have a better comprehension of the form of the asymmetric effects and the dynamics of the transition variables and the estimated logistic transition functions, we plot in each figure (Figures A.5.1 to A.5.8 in Appendix A.5) the time series of the transition variables (top), their smooth transition functions (center) and the time profile of the smooth transition functions (below). For the purpose of illustrating the results, the figures for the volatility of the CPI inflation (Figure A.5.2) and for the variation of the exchange rate change (Figure A.5.4) are explained.

In the first case, the transition between one regime and another is very smooth (central chart). Not only the trajectory of the variable (top), but also its historical transition function (lower) show three critical moments throughout the sample. The first one may be related to the cycle on the international price of commodities, which impacted severely at world level, and volatility of the inflation around 2007. The second one could be due to the inflationary impact of the high and rapid depreciation of the Colombian peso around 2009 as a consequence of the collapse of Lehman-Brothers in September 2008 and the deepening of the international financial crisis. The third one, at the end of the sample, has been caused mainly by the domestic positive shock in the price of the agricultural products and the high, rapid and volatile changes of the domestic currency, according to the monetary authorities (as for the level, the peso depreciated around 56% between September 2014 and 2015).

In the case of the variation of the exchange rate change, an abrupt transition between the “low” and “high” regime is evidenced (central chart of Figure A.5.4), which is explained by the relative larger calculated value of the smoothing parameter γ. As said before, in this case the logistic function $f_j(V_t;\gamma,c)$ approaches the indicator function $I(V_t > c)$ and the changes from 0 to 1 become quite instantaneous at $V_t = c = 0$.

In summary, the transition functions seem to corroborate that the logistic smooth transition model and the transition variables we selected are most likely to capture the nonlinear behavior of the PT embedded in the data.

5.3 Estimations of the degree and dynamics of the PT

Tables 4-7 display the degree and dynamics of the PT coefficients on inflations of import, producer, imported consumer and total consumer goods. Thus, tables show the median PT estimates for prices at each stage conditional on each of the identified regimes of transition variables, in the presence of positive and negative structural shocks of 1% and 5% to the variation of the nominal exchange rate (Peso/USD). Notice that we took the median of the PT rather than the mean because is a more robust measure to extreme values and preferred in cases where parameter distribution is asymmetric, as is the current case. In addition, figures from A.6.1 to A.6.4 in Appendix A.6 show the median of the time path of the PT coefficients, as well as its 68% most credible intervals (percentiles 16 and 84), for inflations along the distribution chain before a positive shock of 1% to the exchange rate change and for both regimes and only three of the transition variables (the other figures are available upon request). The reader can notice not only the statistical significance of the PT estimates and their asymmetric nature, but also their increasing uncertainty along their time path, as measured by the credible intervals.

The first conclusion we can extract form tables 4 to 7 is that the degree of PT is incomplete for the data analyzed both in the short and long terms, even for import prices, which should be the most connected prices to the exchange rate. This shows evidence against a complete exchange rate transmission even in the long term, as predicted by the purchasing power parity hypothesis embedded in most of DSGE models. Thus, when a positive or negative structural shock to the exchange rate takes place, this is not fully passed through to prices, and this finding is independent of the sign and size of the shock and the state of the economy. Notice that, by definition, the estimated PT is always positive, no matter the sign of the shock to the exchange rate. This does not mean that when there is a negative shock (appreciation of the peso), the import prices rise. Instead, *ceteris paribus*, these prices fall by the values of the PT estimates reported on the right-hand side of Tables 4-7.

Table 4.1 Median estimates of the PT coefficients on inflation of imported goods (π^{m})

Transition Variable	Size shock %Points	Positive shock to the exchange rate change: 1 month	6 months	1 year	4 years	Negative shock to the exchange rate change: 1 month	6 months	1 year	4 years
						CPI inflation accelerates			
$\Delta(\pi^{cpi})$	1	38.4	48.1	46.4	72.9	58.9	72.6	78.8	87.4
	5	30.0	42.3	54.1	82.6	NaN	NaN	NaN	NaN
						CPI inflation decelerates			
	1	41.1	44.0	45.9	71.7	75.5	83.2	83.8	86.3
	5	29.4	39.9	47.2	77.3	NaN	NaN	NaN	NaN
						High Volatility of CPI Inflation			
$V(\pi^{cpi})$	1	35.0	51.9	55.9	62.2	74.4	68.3	70.2	74.1
	5	32.0	45.7	59.0	78.6	NaN	NaN	NaN	NaN
						Low Volatility of CPI Inflation			
	1	41.6	46.7	50.5	66.2	64.5	64.8	68.9	81.8
	5	40.0	45.3	54.4	69.6	NaN	NaN	NaN	NaN
						"High" CPI inflation			
$\bar{\pi}^{cpi}$	1	35.1	48.4	59.4	80.3	63.7	68.2	72.5	83.3
	5	34.6	48.8	59.1	81.8	82.5	90.1	95.8	94.4
						"Low" CPI inflation			
	1	34.8	46.3	56.5	75.7	53.5	71.0	86.1	95.8
	5	25.8	41.6	59.0	79.7	NaN	NaN	NaN	NaN
						Depreciation / appreciation of the peso accelerates			
$\Delta(\Delta e)$	1	35.1	47.5	54.9	75.6	58.3	65.7	79.6	87.2
	5	31.7	43.3	55.0	79.3	NaN	NaN	NaN	NaN
						Depreciation / appreciation of the peso decelerates			
	1	37.5	44.6	51.8	68.3	63.5	74.2	83.3	91.9
	5	30.9	43.7	56.7	81.4	NaN	NaN	NaN	NaN
						High volatility of the exchange rate			
$V(\Delta e)$	1	46.2	48.8	57.9	78.6	62.4	65.1	71.5	78.0
	5	34.7	44.8	55.0	74.5	NaN	NaN	NaN	NaN
						Low volatility of the exchange rate			
	1	33.1	53.2	60.6	84.9	56.5	72.9	76.6	76.2
	5	33.8	44.4	55.4	80.9	NaN	NaN	NaN	NaN
						Undervalued real exchange rate			
Dq	1	34.2	48.7	59.2	72.0	62.9	69.7	74.1	83.2
	5	37.3	49.2	60.4	73.1	NaN	NaN	NaN	NaN
						Overvalued real exchange rate			
	1	41.3	52.3	62.0	72.5	71.3	75.5	74.8	83.0
	5	44.5	52.6	60.9	72.1	NaN	NaN	NaN	NaN

Source: Authors' calculations. "NaN" means that the PT estimate did not meet the $0 \leq PT \leq 100$ condition.

Table 4.2 Median estimates of the PT coefficients on inflation of imported goods (π^m)

		Positive shock to the exchange rate change				Negative shock to the exchange rate change			
Transition Variable	**Size shock %Points**	**1 month**	**6 months**	**1 year**	**4 years**	**1 month**	**6 months**	**1 year**	**4 years**
					Positive				
Gy	1	36.8	53.3	53.5	70.3	61.4	76.9	66.4	71.8
	5	42.3	63.7	63.5	64.0	NaN	NaN	NaN	NaN
					Negative				
	1	33.5	53.3	59.9	64.4	62.6	76.2	70.8	65.8
	5	42.8	65.4	65.6	65.1	NaN	NaN	NaN	NaN
					High economic openness				
Openness	1	36.3	44.2	53.8	74.7	70.1	75.3	73.8	86.9
	5	36.8	48.3	56.7	76.5	NaN	NaN	NaN	NaN
					Low economic openness				
	1	34.3	46.3	57.3	75.9	54.9	71.3	80.0	87.3
	5	33.4	48.3	62.6	76.5	NaN	NaN	NaN	NaN
					High				
Pcomm	1	24.6	40.0	56.3	80.9	NaN	NaN	NaN	NaN
	5	21.8	38.8	56.5	84.3	NaN	NaN	NaN	NaN
					Low				
	1	23.2	38.9	56.5	80.7	24.0	49.5	71.3	94.7
	5	22.4	39.2	57.0	85.6	NaN	NaN	NaN	NaN
					"High"				
IBR	1	40.5	43.4	46.7	76.9	59.2	72.6	76.8	71.9
	5	40.8	50.2	61.5	78.3	95.0	97.0	95.7	61.7
					"Low"				
	1	25.0	33.1	41.5	77.7	64.7	67.7	69.4	96.2
	5	29.0	37.2	46.4	80.2	NaN	NaN	NaN	NaN
					Above average				
Trend	1	44.2	51.7	60.4	69.0	82.6	83.0	73.9	69.4
	5	53.5	67.1	64.5	70.2	84.6	82.4	70.8	78.2
					Below average				
	1	29.7	37.7	56.8	88.3	45.0	59.0	71.4	97.6
	5	20.4	42.4	64.6	87.2	NaN	NaN	NaN	NaN

Source: Authors' calculations. "NaN" means that the PT estimate did not meet the $0 \leq PT \leq 100$ condition.

Table 5.1 Median estimates of the PT coefficients on inflation of producer goods (π^{w})

Transition Variable	Size shock %Points	Positive shock to the exchange rate change: 1 month	6 months	1 year	4 years	Negative shock to the exchange rate change: 1 month	6 months	1 year	4 years
					CPI inflation accelerates				
$\Delta(\pi^{cpi})$	1	34.2	36.9	36.7	70.5	35.1	42.6	47.3	71.4
	5	18.8	25.1	28.3	67.3	37.6	44.6	41.4	53.5
					CPI inflation decelerates				
	1	36.7	37.3	36.6	75.7	34.3	37.9	36.4	71.2
	5	18.0	23.9	26.9	71.5	38.3	44.9	40.2	52.7
					High Volatility of CPI Inflation				
$V(\pi^{cpi})$	1	31.5	34.5	38.3	77.4	34.3	32.6	34.9	62.4
	5	23.4	25.7	28.7	76.6	42.0	39.6	35.1	43.6
					Low Volatility of CPI Inflation				
	1	25.0	33.6	37.1	70.5	34.6	39.2	44.2	78.9
	5	20.2	26.3	32.9	75.8	38.3	40.5	43.2	59.1
					"High" CPI inflation				
$\bar{\pi}^{cpi}$	1	44.4	42.4	51.2	69.5	48.4	52.7	46.3	53.5
	5	29.6	30.2	33.5	60.0	52.9	56.0	42.3	28.8
					"Low" CPI inflation				
	1	18.6	23.9	35.8	77.3	23.0	27.5	39.7	84.1
	5	14.6	21.3	34.0	77.6	48.9	43.5	52.2	84.0
					Depreciation / appreciation of the peso accelerates				
$\Delta(\Delta e)$	1	30.8	33.9	35.9	74.3	36.7	37.8	39.3	69.2
	5	22.4	25.9	29.9	73.6	39.7	44.0	40.8	61.6
					Depreciation / appreciation of the peso decelerates				
	1	31.2	32.0	36.4	75.4	32.7	36.8	38.5	72.5
	5	21.2	24.2	27.9	71.4	39.7	44.3	42.7	60.9
					High volatility of the exchange rate				
$V(\Delta e)$	1	33.2	33.6	34.8	77.2	40.6	39.6	36.9	74.2
	5	25.1	26.6	28.7	72.7	43.9	43.6	37.3	59.2
					Low volatility of the exchange rate				
	1	26.3	30.8	34.8	81.7	33.0	33.6	35.0	85.1
	5	20.6	26.5	31.9	79.1	42.5	44.1	35.9	54.6
					Undervalued real exchange rate				
Dq	1	32.1	36.2	44.2	75.1	39.1	43.9	46.5	68.7
	5	25.7	30.2	35.6	68.3	41.6	48.5	47.3	52.7
					Overvalued real exchange rate				
	1	34.0	36.4	45.3	72.1	40.7	48.4	53.8	65.8
	5	25.6	31.3	38.5	65.1	42.9	49.8	47.6	40.0

Source: Authors' calculations.

Table 5.2 Median estimates of the PT coefficients on inflation of producer goods (π^w)

		Positive shock to the exchange rate change				**Negative shock to the exchange rate change**			
Transition Variable	**Size shock %Points**	**1 month**	**6 months**	**1 year**	**4 years**	**1 month**	**6 months**	**1 year**	**4 years**
					Positive				
Gy	1	27.3	40.4	40.9	46.8	36.0	52.9	47.5	46.4
	5	19.6	37.2	41.0	47.4	44.6	58.3	55.3	47.9
					Negative				
	1	30.2	44.7	44.4	46.2	36.6	55.0	51.5	41.0
	5	20.0	38.0	40.8	44.8	43.1	57.8	55.1	35.6
					High economic openness				
Openness	1	44.6	40.1	44.5	68.0	51.7	49.5	45.3	56.1
	5	31.4	31.5	35.3	65.6	51.5	53.3	41.3	34.1
					Low economic openness				
	1	29.1	34.5	46.2	76.5	36.8	45.3	49.8	74.1
	5	20.8	29.0	41.0	74.9	44.4	45.7	42.1	52.4
					High				
Pcomm	1	18.3	29.1	43.7	80.2	22.1	32.4	48.1	88.2
	5	12.9	25.7	41.9	84.0	26.3	41.3	51.9	88.3
					Low				
	1	18.7	29.7	43.0	79.9	20.6	32.4	47.9	88.0
	5	13.2	25.7	41.9	83.5	29.9	34.6	50.7	87.9
					"High"				
IBR	1	43.9	42.2	41.1	69.8	52.9	44.8	38.0	57.7
	5	24.9	27.3	29.1	56.8	46.7	46.0	35.4	37.5
					"Low"				
	1	30.5	31.9	40.9	77.2	30.4	33.7	42.5	77.8
	5	19.5	23.4	33.0	77.9	44.9	44.6	37.7	45.5
					Above average				
Trend	1	36.3	53.2	51.6	60.2	49.1	57.2	51.1	59.8
	5	29.6	42.2	44.2	58.6	47.4	53.0	39.7	43.5
					Below average				
	1	33.9	41.2	46.4	64.1	40.1	50.6	55.5	72.3
	5	23.8	35.0	45.6	65.3	42.8	55.0	64.6	67.9

Source: Authors' calculations.

From tables 4 to 7, one can summarize, *ceteris paribus,* the minimum and maximum degree of the accumulated transmission at each of the distribution stages at any time period τ (see equation (12)). Thus, the accumulated PT on inflation of import price rises from 20% in the first month of the shock to a maximum of around 66% in the first year. In other words, 66% of the peso depreciation/appreciation is transmitted to the inflation of import goods in the first year. The equivalent figures on the inflation of producer goods go from 13% to 52%; on the inflation of imported consumer goods from 6% to 48% and on the CPI inflation from 4% to 30%. At four years, *ceteris paribus*, the accumulated PT on inflation of imported consumer goods is 98%, on producer goods is 84%, on imported consumer goods 94% and on total consumer goods 80%. Two remarks are needed here. The first is that estimations show neatly how the degree of transmission vanishes along the distribution chain. The second is that uncertainty about the PT estimates increases rapidly across time, as is captured by the magnitude of the Bayesian credible intervals (see figures A.6.1 to A.6.4).

Second, the results show overwhelming evidence and statistical support of the endogeneity of the PT coefficient to state of the economy (Table 8), which causes it to change over time. In the short term (until one year), the PT is greater before a positive shock to the exchange rate when CPI inflation accelerates, its volatility is high and it is high; exchange rate depreciation/appreciation accelerates and its volatility is low; real exchange rate is overvalued; output gap is positive (for imported consumer and total consumer goods); economic openness is low; the price of commodities is high (for producer and total consumer goods); the interbank interest rate is low (for imported consumer and total consumer goods); and the trend is above the average (for producer and total consumer goods). Notice that results obtained for the import prices are similar to those found by Gonzalez et al. (2010).

In the long term (up to four years), the PT is greater before a positive shock to the exchange rate when CPI inflation decelerates, its volatility is low (for imported consumer and total consumer goods) and it is low; the exchange rate depreciation/appreciation accelerates and its volatility is low; the real exchange rate is overvalued; the output gap is positive; economic openness is low; the price of commodities is high (except for imported consumer goods); the interbank interest rate is low (except for total consumer goods); and the trend is below the average.

Third, the evidence indicates the nonlinear nature of the degree of PT, as was shown in tables 4 to 8. For example, if the inflationary regime is "High," 20% of the 1% shock to the peso at time *t* is transmitted to CPI inflation in one month and 29% up to one year. Meanwhile, if the inflationary regime is "Low" the transmission decreases from 10% to 23% in the same period. It is worthy to mention that the size of the PT for the CPI inflation found is much higher than those findings by the literature on Colombia reported in the introduction (among them, our research). Another example is that if the depreciation/appreciation of the peso accelerates, the PT reaches 13% in the first month, 21% after one year and 64% four years later. On the contrary, if the depreciation/appreciation of the peso decelerates, the PT reaches 12%, 19% and 62%, respectively.

Fourth, the PT responds differently to the size and sign of shocks; that is, the PT is asymmetric. For instance, as shown in tables 7.1 and 7.2, the degree of PT on inflation of total consumer goods is not the same if the size of the shock to exchange rate is 1% than if is 5%. This behavior is independent of state of the economy and regime the transition variable is at. Moreover, its size and dynamic change when the sign of the shock changes. To illustrate, let us select a 5% shock when the CPI inflation accelerates (Table 7.1). In the case of a positive shock, the accumulated PT on inflation of total consumer goods is 11% in the first year, while it is 13% if the shock is negative.

Table 6.1 Median estimates of the PT coefficients on inflation of imported consumer goods (π^{mc})

Transition Variable	Size shock %Points	Positive shock to the exchange rate change: 1 month	6 months	1 year	4 years	Negative shock to the exchange rate change: 1 month	6 months	1 year	4 years
		CPI inflation accelerates							
$\Delta(\pi^{cpi})$	1	14.2	16.8	26.8	79.0	14.3	19.7	32.0	80.6
	5	7.9	14.1	27.0	78.1	9.8	17.2	31.0	73.3
		CPI inflation decelerates							
	1	11.9	14.8	24.0	79.3	8.7	14.5	22.1	77.1
	5	7.9	12.2	21.9	78.4	9.5	16.1	26.6	67.0
		High Volatility of CPI Inflation							
$V(\pi^{cpi})$	1	11.4	19.9	30.3	81.2	12.1	19.1	36.7	68.6
	5	7.5	13.3	26.9	82.4	17.8	23.0	36.8	46.4
		Low Volatility of CPI Inflation							
	1	10.7	25.0	36.4	79.0	15.1	23.6	42.0	82.5
	5	8.1	17.9	30.8	73.6	14.1	28.6	41.9	74.7
		"High" CPI inflation							
$\bar{\bar{\pi}}^{cpi}$	1	17.0	24.5	30.0	69.6	20.7	27.3	31.2	49.7
	5	11.2	17.7	22.6	58.6	16.5	23.0	26.3	35.7
		"Low" CPI inflation							
	1	16.1	23.8	41.0	75.9	5.4	19.7	41.7	93.2
	5	9.7	19.6	37.2	80.3	NaN	NaN	NaN	NaN
		Depreciation / appreciation of the peso accelerates							
$\Delta(\Delta e)$	1	9.3	17.7	31.7	81.1	9.8	18.0	31.7	78.8
	5	7.3	14.6	28.9	79.2	9.9	21.5	38.3	72.6
		Depreciation / appreciation of the peso decelerates							
	1	9.7	16.2	29.7	75.1	11.9	21.1	36.5	84.7
	5	6.3	14.0	29.0	81.5	9.3	22.0	38.0	66.7
		High volatility of the exchange rate							
$V(\Delta e)$	1	8.9	21.0	38.8	78.5	11.3	23.6	43.5	76.0
	5	6.6	17.6	36.6	80.7	9.2	28.7	52.9	70.4
		Low volatility of the exchange rate							
	1	11.5	25.3	41.9	82.0	10.8	30.0	49.1	83.3
	5	6.7	20.6	39.3	81.0	9.8	29.7	56.4	75.5
		Undervalued real exchange rate							
Dq	1	14.9	24.4	38.9	72.1	16.5	29.4	45.3	62.0
	5	8.8	19.7	36.1	71.6	13.4	29.4	45.0	53.5
		Overvalued real exchange rate							
	1	18.3	28.9	41.3	70.8	21.8	30.7	40.8	56.8
	5	11.5	20.8	33.3	65.4	16.0	25.1	33.3	36.9

Source: Authors' calculations. "NaN" means that the PT estimate did not meet the $0 \leq PT \leq 100$ condition.

Table 6.2 Median estimates of the PT coefficients on inflation of imported consumer goods (π^{mc})

Transition Variable	Size shock %Points	Positive shock to the exchange rate change: 1 month	6 months	1 year	4 years	Negative shock to the exchange rate change: 1 month	6 months	1 year	4 years
					Positive				
Gy	1	22.1	25.6	27.3	41.7	19.5	24.7	28.2	34.1
	5	9.8	16.0	21.0	40.9	14.2	28.2	32.8	29.4
					Negative				
	1	21.0	25.4	26.9	39.9	19.9	30.9	28.4	45.4
	5	9.9	16.8	20.4	42.0	14.6	23.3	27.9	33.0
					High economic openness				
Openness	1	19.3	25.1	29.2	66.2	21.1	26.5	30.0	51.3
	5	12.6	16.7	22.2	60.0	16.1	20.3	24.0	38.2
					Low economic openness				
	1	17.6	27.2	38.7	72.7	15.7	29.5	39.6	70.9
	5	10.1	21.2	34.2	70.9	14.5	24.7	32.3	49.2
					High				
Pcomm	1	16.4	25.6	40.9	74.6	12.7	26.2	46.7	91.7
	5	9.1	19.8	39.3	86.5	NaN	NaN	NaN	NaN
					Low				
	1	12.4	25.7	42.9	80.1	12.7	24.2	44.2	93.7
	5	9.2	19.4	39.5	85.7	NaN	NaN	NaN	NaN
					"High"				
IBR	1	19.3	22.3	25.2	64.6	22.6	27.9	30.9	49.9
	5	12.2	14.4	20.6	67.1	20.2	20.5	24.8	36.4
					"Low"				
	1	17.6	22.8	33.0	72.3	20.5	27.1	31.4	60.6
	5	10.5	18.3	31.7	74.6	19.2	24.1	29.6	36.6
					Above average				
Trend	1	21.0	33.2	44.4	69.5	22.6	35.3	48.6	71.5
	5	9.6	20.2	35.3	66.7	12.1	23.3	36.9	61.7
					Below average				
	1	18.6	34.3	47.8	72.2	14.5	31.1	50.5	82.8
	5	9.3	25.4	45.1	76.1	7.0	31.3	54.8	77.4

Source: Authors' calculations. "NaN" means that the PT estimate did not meet the $0 \leq PT \leq 100$ condition.

Table 7.1 Median estimates of the PT coefficients on inflation of total consumer goods (π^{cpi})

Transition Variable	Size shock %Points	Positive shock to the exchange rate change: 1 month	6 months	1 year	4 years	Negative shock to the exchange rate change: 1 month	6 months	1 year	4 years
		CPI inflation accelerates							
$\Delta(\pi^{cpi})$	1	14.2	14.8	16.8	49.6	14.4	15.9	18.1	53.6
	5	6.6	8.7	10.7	44.8	8.9	10.9	12.9	40.0
		CPI inflation decelerates							
	1	13.5	13.4	15.1	58.4	14.6	15.0	16.2	55.3
	5	6.0	8.1	9.7	51.5	9.2	10.6	11.9	44.7
		High Volatility of CPI Inflation							
$V(\pi^{cpi})$	1	14.2	17.5	21.4	62.5	13.5	16.0	19.1	57.4
	5	5.8	10.6	13.6	61.1	8.1	12.0	13.9	50.3
		Low Volatility of CPI Inflation							
	1	9.1	16.0	22.4	64.1	10.1	17.9	24.0	65.1
	5	4.7	11.1	17.4	60.5	7.9	15.4	21.6	57.7
		"High" CPI inflation							
$\bar{\pi}^{cpi}$	1	20.1	26.3	29.3	61.3	20.0	24.9	22.3	40.6
	5	13.6	17.7	19.8	51.0	13.4	17.7	15.5	28.9
		"Low" CPI inflation							
	1	9.7	14.7	23.1	72.1	8.5	15.0	25.1	79.0
	5	4.4	10.7	19.2	71.8	6.6	15.4	26.1	81.5
		Depreciation / appreciation of the peso accelerates							
$\Delta(\Delta e)$	1	13.3	17.1	20.5	64.1	12.6	17.7	20.3	58.2
	5	6.3	11.4	14.1	54.5	7.9	14.3	16.4	49.7
		Depreciation / appreciation of the peso decelerates							
	1	11.9	16.0	19.3	62.3	12.5	17.7	19.9	57.5
	5	6.4	11.5	14.2	55.2	8.0	14.0	16.3	49.4
		High volatility of the exchange rate							
$V(\Delta e)$	1	10.7	14.6	17.6	59.4	11.0	16.0	18.7	58.2
	5	5.3	10.6	13.5	56.8	6.9	14.3	17.6	53.7
		Low volatility of the exchange rate							
	1	8.0	15.5	21.7	71.1	8.7	17.6	23.0	70.4
	5	3.9	11.1	17.0	67.7	6.4	15.7	21.3	63.6
		Undervalued real exchange rate							
Dq	1	12.5	19.3	23.6	60.4	13.3	20.3	24.2	53.2
	5	6.7	13.3	17.2	49.1	8.4	15.5	18.9	40.4
		Overvalued real exchange rate							
	1	13.6	21.2	29.1	60.8	14.8	23.2	29.1	49.4
	5	7.4	14.5	20.5	48.7	9.7	18.1	22.6	34.5

Source: Authors' calculations.

Table 7.2 Median estimates of the PT coefficients on inflation of total consumer goods (π^{cpi})

Transition Variable	Size shock %Points	Positive shock to the exchange rate change: 1 month	6 months	1 year	4 years	Negative shock to the exchange rate change: 1 month	6 months	1 year	4 years
					Positive				
Gy	1	12.9	22.9	27.9	44.8	12.0	26.3	32.5	43.1
	5	5.0	15.0	22.3	43.3	6.9	19.6	26.0	36.5
					Negative				
	1	12.7	22.8	27.9	42.4	14.1	28.6	31.7	37.1
	5	4.9	15.5	21.6	40.2	7.2	18.9	22.8	34.4
					High economic openness				
Openness	1	20.7	25.3	26.9	61.8	18.9	23.5	22.3	44.6
	5	11.9	16.8	18.3	52.1	12.7	17.0	15.5	31.7
					Low economic openness				
	1	12.4	19.9	28.1	64.9	13.2	20.3	26.3	59.8
	5	6.1	14.5	22.0	62.7	9.4	15.8	18.2	45.0
					High				
Pcomm	1	9.1	18.4	30.6	75.8	8.5	17.9	32.8	83.6
	5	4.5	14.4	27.9	80.2	5.9	16.9	32.0	87.2
					Low				
	1	9.4	18.6	30.0	75.3	7.2	17.1	32.2	86.6
	5	4.7	14.5	28.3	80.9	4.8	16.7	30.9	85.9
					"High"				
IBR	1	15.1	19.1	20.4	62.4	17.6	22.0	19.9	48.9
	5	9.2	13.2	13.8	58.1	12.4	18.2	14.4	36.3
					"Low"				
	1	12.7	18.0	26.0	60.5	12.6	22.6	32.6	71.1
	5	5.5	13.5	23.2	63.3	11.2	20.3	28.0	59.5
					Above average				
Trend	1	17.9	29.2	32.2	42.3	18.6	28.5	30.8	39.6
	5	6.4	14.1	17.3	30.8	8.7	15.6	15.9	21.4
					Below average				
	1	10.5	18.3	23.7	51.9	11.7	19.8	25.2	52.5
	5	5.3	12.1	18.2	43.4	7.9	15.9	22.1	41.8

Source: Authors' calculations.

Three interesting results can be emphasized, and they have to do with the PT when the transitions variables are the volatility of the exchange rate, the degree of misalignment of the real exchange rate and the degree of economic openness. With regard to the first variable, the degree of PT is unanimously higher on all inflation and for the short and medium term when the exchange rate volatility is low. That means that firms transmit exchange rate changes to prices more rapidly and to a higher degree when they expect changes to be of long duration. This result is completely opposite to those by Campa and Golberg (2005), for instance, who found that "countries with higher rates of exchange rate volatility have higher pass-through elasticities." As for the second variable, our findings seem to oppose the expectations, i.e., that the degree of PT should be higher when the real exchange rate is undervalued than otherwise. Indeed, a positive structural shock to exchange rate should pass through to inflation of tradable goods to a higher degree and so rapidly that the nominal exchange can act as a correction mechanism allowing for the real exchange rate to appreciate, *ceteris paribus*. With respect to the third transition variable (*Openness*), one would expect, according to theory, that if the economy is more open the transmission should be higher; however, we consistently found that it happens the other way around. What explains this result? Is it a problem of measurement of the degree of economic openness? Is this finding a result of a very complex strategic behavior of fixing prices by firms when the economy is more open? We do not have an answer for this riddle.

Table 8. When has PT been higher?

Transition variable	Regimen	Inflation							
		Import		Producer		Imported consumer		Total consumer	
		1 year	4 years	1 year	4 years	1 year	4 years	1 year	4 years
$\Delta(\pi^{cpi})$	*Accelerate*	√	√	√		√		√	
	Decelerate				√		√		√
$V(\pi^{cpi})$	*High*	√		√	√		√		
	Low		√			√		√	√
$\overline{\pi}^{cpi}$	*High inflation*	√	√	√				√	
	Low inflation				√	√	√		√
$\Delta(\Delta e)$	*Accelerate*	√	√			√	√	√	√
	Decelerate			√	√				
$V(\Delta e)$	*High*								
	Low	√	√	√	√	√	√	√	√
Dq	*Undervalued*				√		√		
	Overvalued	√	√	√		√		√	√
Gy	*Positive*		√		√	√	√	?	√
	Negative	√		√					
Openness	*High*								
	Low	√	√	√	√	√	√	√	√
Pcomm	*High*		√	√	√			√	√
	Low	√				√	√		
IBR	*High*	√		√					√
	Low		√		√	√	√	√	
Trend	*Above average*	√		√				√	
	Below average		√		√	√	√		√

Source: Tables 4-7.

5.4 Historical decomposition of shocks

In this subsection we show and analyze the historical decomposition of shocks (HD) for the LST-VAR model given by equation (11) (see Balke (2000) and Avdjiev and Zeng (2014) for TVAR applications). Remember that HD allows one to approximate the magnitude of the contribution of each shock to the unpredicted value of every endogenous variable at each period of time. This allows us to differentiate which of the shocks were the main determinants of the behavior of the endogenous variables at each time period (in our case, the determinants of the different inflations along the distribution chain) and to reveal the relative role played by shocks to the exchange rate.

For multivariate models such as the one considered in this paper and under some structure for the identification of shocks (Cholesky decomposition, in our case), the results of impulse response functions are valid only under static -or not regime change- scenarios during the sample period; despite the fact that one averages all the answers at each regime of the transition variable by apart. Therefore, it is important to analyze the responses of the endogenous variables to exogenous shocks of different magnitudes at different times. The methodology employed for this purpose in linear VAR and (linearized) DSGE models is the HD of shocks. Notice that in these cases, the HD is completed (exact),[19] but in the case of nonlinear models like LST-VARs, the HD may not be so and the missing part is called "remainder," which could be significant.

Before showing the results, it is worth mentioning the main differences between variance decomposition, which is the standard procedure used by literature, and historical decomposition. The first one can think of is that the former is a hypothetical exercise, while the latter is an approximated description of the history of a time series.

Under the understanding that both are based on the same model, for the same data set and the same specification, variance decomposition calculates the variance of the prediction

[19] That is, the components add up to the forecast error at each time period.

error of each of the endogenous variables for several periods forward (e.g. from 1 to K periods). This indicates the percentage share of the prediction error for each of the endogenous variables in the whole prediction error (from 1 to K). In this case, the identification structure of the errors does not matter. Moreover, as one is working with variances and they are always non-negative, participation is calculated as the variance of the particular variable relative to the sum of the variances of all endogenous variables in the system.

On the other hand, HD is an accounting exercise which explains the prediction within the sample as a function of the errors for each period. It can be done well with a reduced or not identified form, or with structural or identified shocks. Furthermore, because in a dynamic model errors have lagged effects, there is a need to accumulate the discounted effects from previous mistakes. Finally, the prediction error is broken down under HD , not the variance; hence, it can be less than zero.

Therefore, we calculate the HDs for inflations of imported, producer, imported consumer and total consumer goods, conditional on each of the state variables, so that we have 44 HDs. Here we will show results for each of the inflations, but for only six transition variables: variation of the CPI inflation ($\Delta\pi^{cpi}$), variation of the exchange rate change ($\Delta(\Delta e)$), volatility of the exchange rate ($V(\Delta e)$), output gap (Gy), variation of commodity prices ($Pcomm$) and the interbank interest rate (IBR) (the other figures are available upon request). The interpretation of the HD figures is the following: A positive bar value of a particular variable indicates that the shock pushed the n-th inflation upward in that period; otherwise, an inverse interpretation applies.[20]

Figures 2 to 5 show the HDs for the inflation of the different prices along the distribution chain conditional on the transition variables mentioned. To illustrate our findings, we

[20] Since the methodology requires to define a forecast horizon, we use K=36 months. As a result, we cannot predict or at least not break down the forecast error for the first K-months.

explain the results for the inflation of total consumer goods during the last part of the sample (year 2015). Of course, the same reconstruction of their history can be done for each of the prices at each period of time.

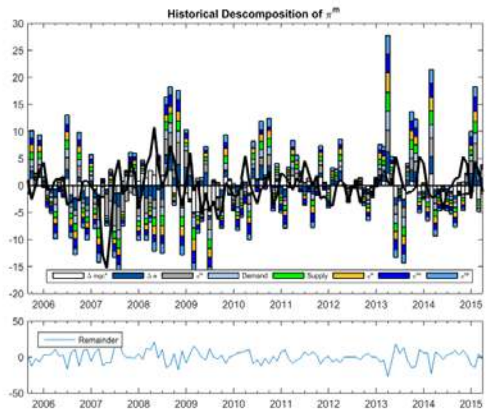
Thus, Figure 5 shows that when the transition variable is the variation of the CPI inflation (figure (a)), one of the most important upward drivers of the CPI inflation is the exchange rate shock (Δe), which acts directly and through the different channels explained in the introduction (costs and imported consumption channels). A second main driver is the inflation's own persistence shock (π^{cpi}), which is related to positive shocks to the indexation of prices of goods and services to past inflation. However, supply and demand shocks appear as second-order upward drivers. On the other hand, the shock to the external marginal costs (Δmgc^{*}) pressured CPI inflation downwards. Notice that this shock may also explain the negative pressure coming from the import price shock.

When the transition variables are the variation (figure (b)) or volatility (figure (c)) of the exchange rate change, or the variation of commodity prices (figure (e)), the results seem to confirm the upward role played by most of the shocks and the downward role enacted by the external marginal cost shock. Nevertheless, observe that the size of the impact of each of the shocks on CPI inflation depends on the transition variable being in place. On the other hand, all variables except the external marginal costs push inflation up when the transition variable is the output gap (figure (d)).[21] Finally, when the transition variable is the interbank interest rate or operative instrument of the central bank (figure (f)), supply and demand shocks put negative pressure on CPI inflation.

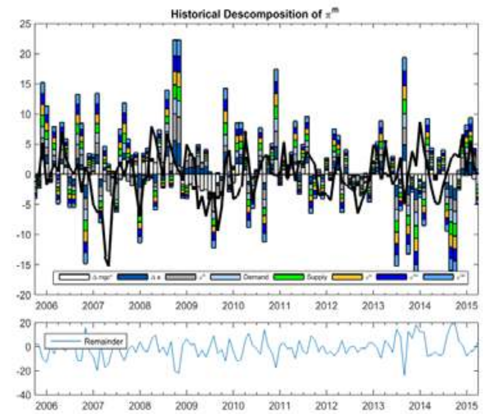
[21] Observe that for all cases the remainder is quite large when the transition variable is the output gap. One explanation may be the presence of structural breaks in its time path, which would affect the cumulative function of logistical probability embedded in equation (11), and then its forecast and the respective remainder. We carried out the Bai and Perron's (1998, 2003) sequential test for multiple structural breaks, which effectively showed the presence of three breaks in the series (2008M10, 2006M07 and 2011M02).

Figure 2. HD for π^m

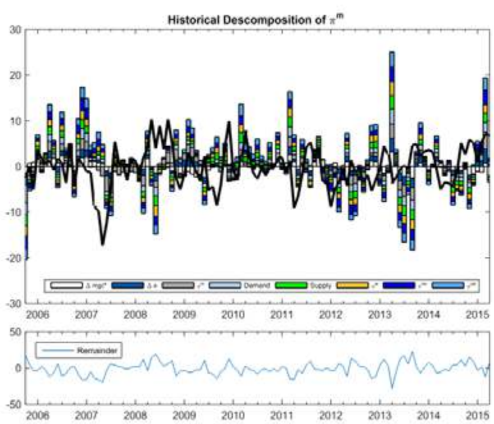
(a) Transition variable: $\Delta(\pi^{cpi})$



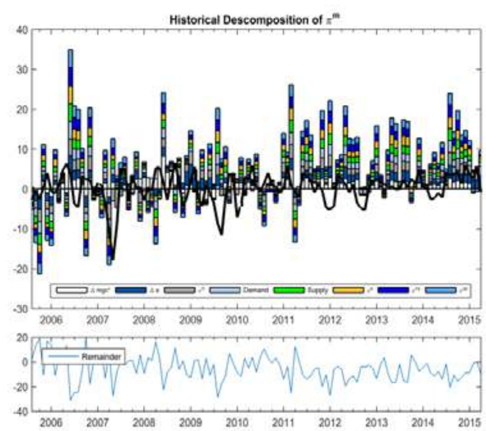
(b) Transition variable: $\Delta(\Delta e)$



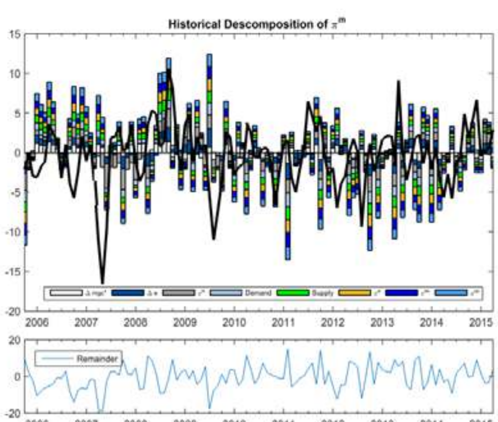
(c) Transition variable: $V(\Delta e)$



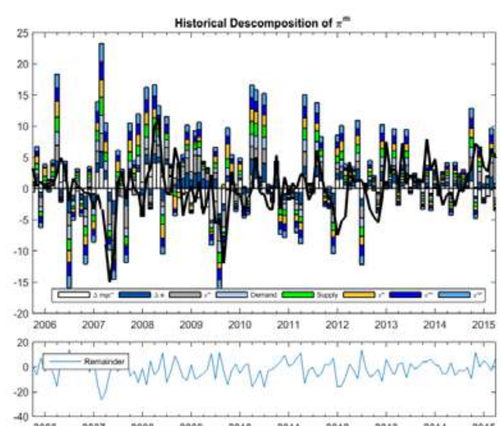
(d) Transition variable: Gy



(e) Transition variable: *Pcomm*



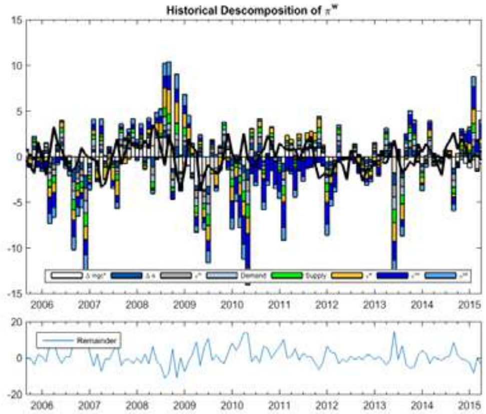
(f) Transition variable: *IBR*



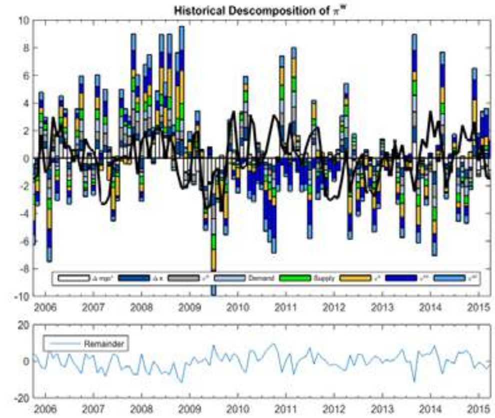
Source: Authors' calculations.

Figure 3. HD for π^w

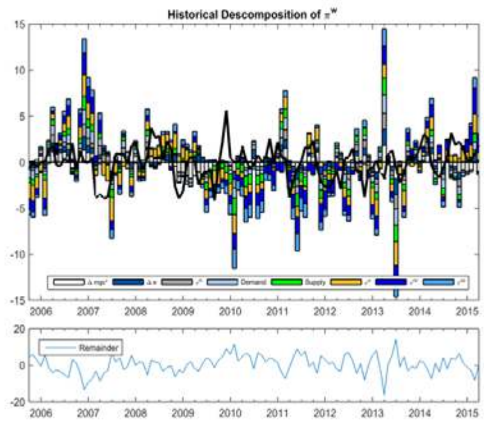
(a) Transition variable: $\Delta(\pi^{cpi})$



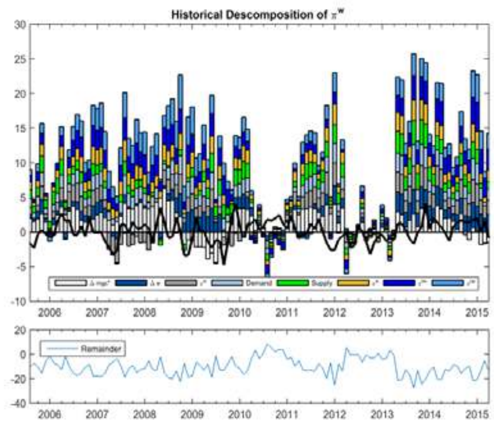
(b) Transition variable: $\Delta(\Delta e)$



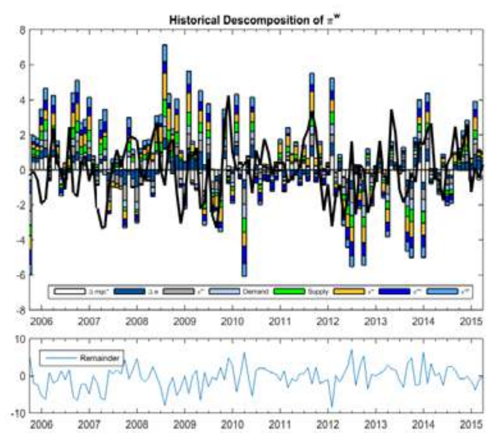
(c) Transition variable: $V(\Delta e)$



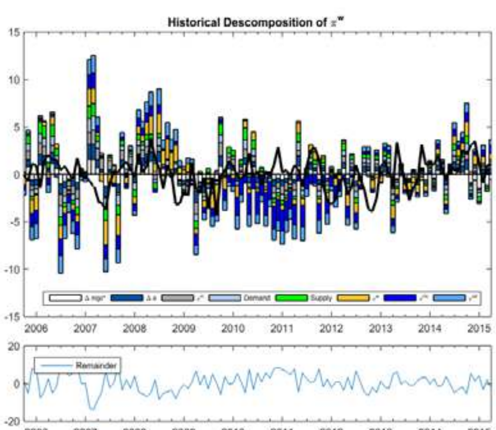
(d) Transition variable: Gy



(e) Transition variable: *Pcomm*



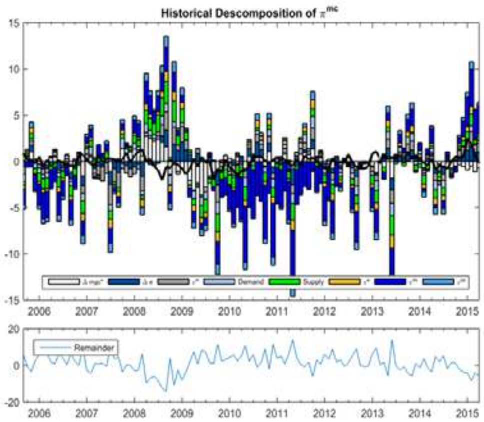
(f) Transition variable: *IBR*



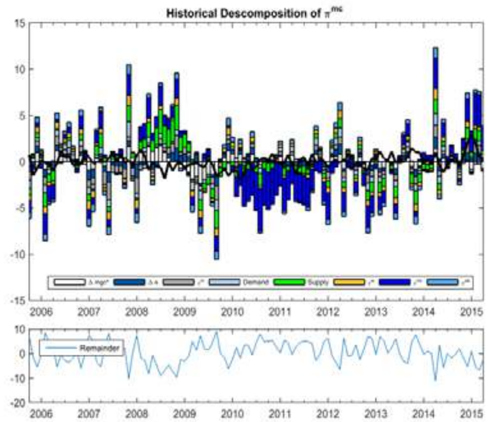
Source: Authors' calculations.

Figure 4. HD for π^{mc}

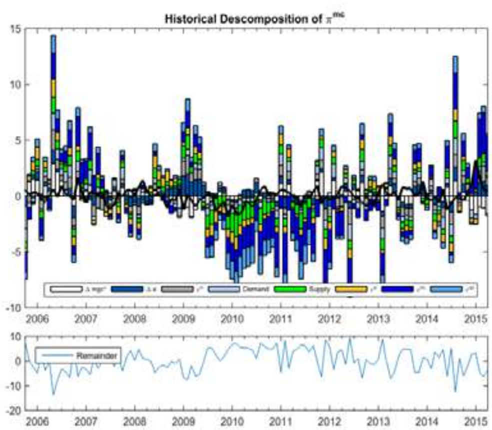
(a) Transition variable: $\Delta(\pi^{cpi})$



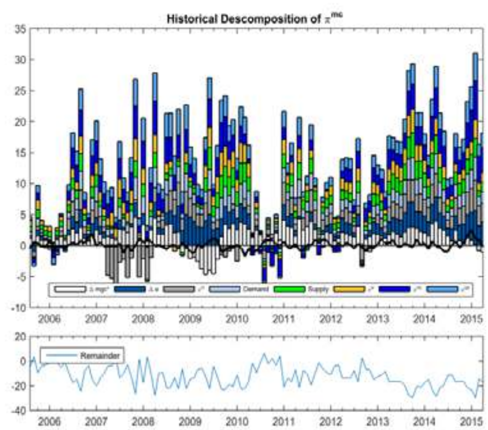
(b) Transition variable: $\Delta(\Delta e)$



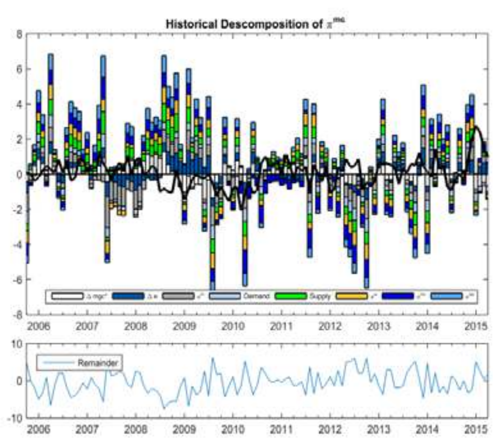
(c) Transition variable: $V(\Delta e)$



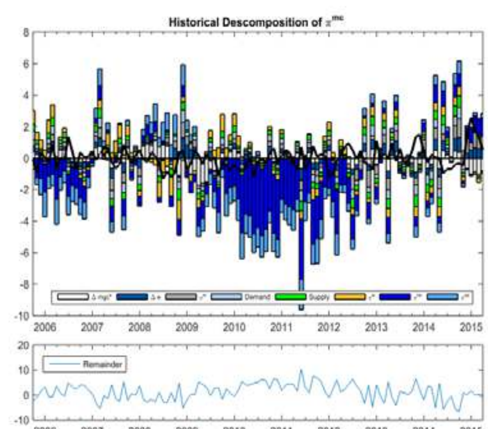
(d) Transition variable: Gy



(e) Transition variable: *Pcomm*



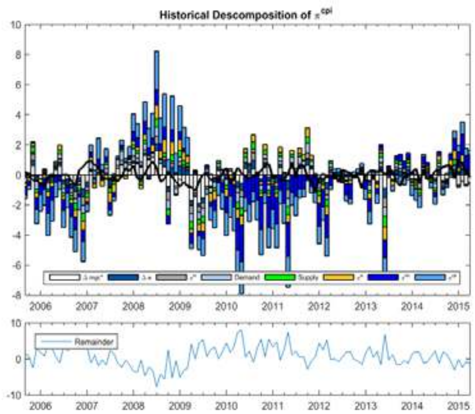
(f) Transition variable: *IBR*



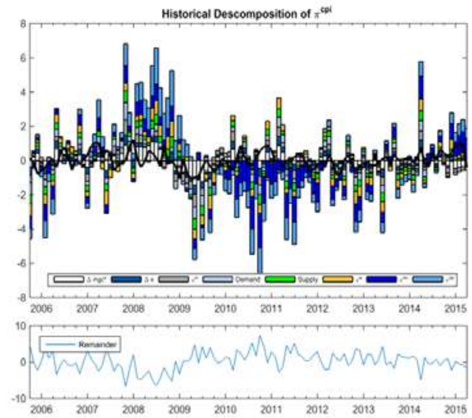
Source: Authors' calculations.

Figure 5. HDs for π^{cpi}

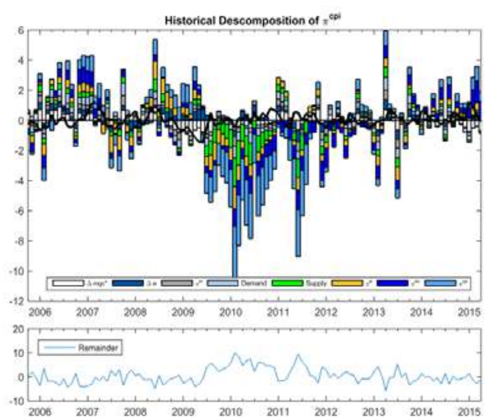
(a) Transition variable: $\Delta(\pi^{cpi})$



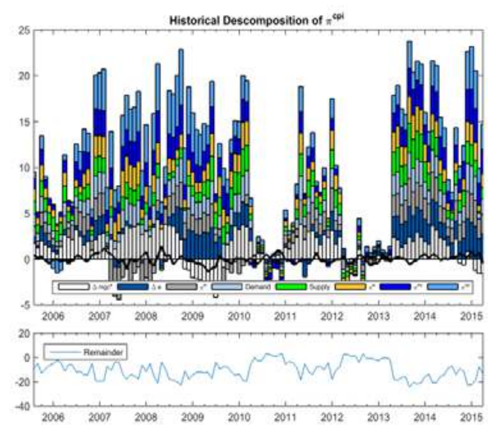
(b) Transition variable: $\Delta(\Delta e)$



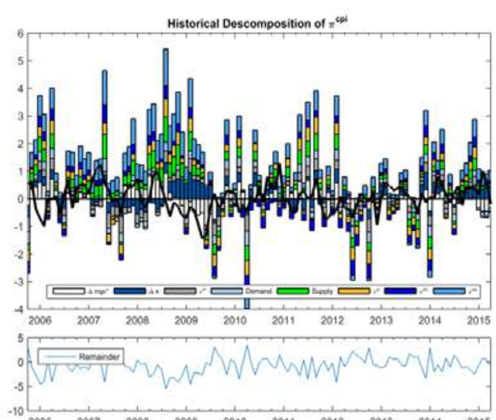
(c) Transition variable: $V(\Delta e)$



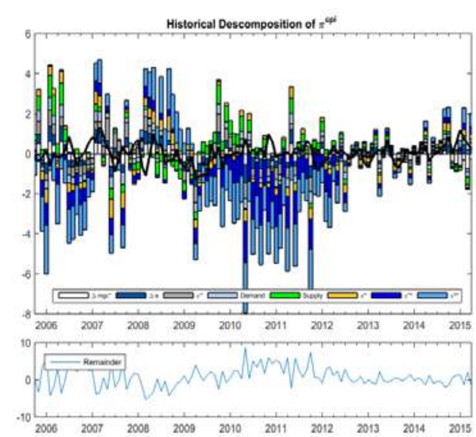
(d) Transition variable: Gy



(e) Transition variable: *Pcomm*



(f) Transition variable: *IBR*



Source: Authors' calculations.

Accordingly, the HD exercises show that the role played by each of the shocks on the determination of price variations along the distribution chain depends very much on the state of the economy, a finding that is not uncovered by linear variance decomposition procedures. Also, they reveal that the final impact of exchange rate shocks on price variations is determined by or is endogenous to other shocks the economy and the exchange rate itself are facing, which agrees with Klein (1990) and the findings of Shambaugh (2008) and Forbes et al. (2015) in the linear case.

6. CONCLUSIONS

Exchange rate movements are a matter of study and many times raise concern not only from authorities, but also from firms and households. For authorities, both because they can learn about the exchange rate ability of being a short term macroeconomic adjustment mechanism, and also because they can place their inflation target at risk when they pass-through to prices. For firms, because they impact their production costs, since they change the domestic price of imported inputs. For consumers, since exchange rate changes can disturb their consumption decisions whenever the final prices of goods in local currency are modified.

Hence, the purpose of this paper was to examine the short-and long-term impacts of exchange rate shocks on inflation along the distribution chain. To tackle this task we used a model of pricing as analytical framework and a nonlinear logistic smooth transition VAR (LST-VAR) model estimated by Bayesian methods. The paper uses Colombian monthly data along with price and trade data from its main trading partners for the period from 2002 to 2015.

Firstly, the findings showed that, the most connected prices are to the exchange rate, the degree of PT is incomplete, even for import prices. This is evidence against a complete exchange rate transmission such as that predicted by the hypothesis of purchasing power parity, which limits the ability of the nominal exchange rate to produce a fully automatic adjustment in the price of tradable goods in the short and long terms. This also implies that nominal exchange rate shocks may have long lasting effects on the real exchange rate.

Historically, the findings showed that the accumulated PT on inflation of import prices rises from 20% in the first month of the exchange rate shock to a maximum of around 66% in the first year. The equivalent figures on the inflation of producer goods go from 13% to 52%; on the inflation of imported consumer goods from 6% to 48%; and on CPI inflation from 4% to 30%. This neatly shows how the degree of transmission vanishes along the distribution chain. At four years, the respective accumulated PT are 98%, 84%, 94% and 80%, but uncertainty about these estimates increases rapidly over time.

Secondly, they also revealed that PT is endogenous to the state of the economy and to exchange rate shocks, which causes it to change over time. In other words, PT is state-dependant, which complements the findings by Shambaugh (2008) and Forbes et al. (2015) for the linear case. In the short term (until one year), the PT is greater before a positive shock to the exchange rate when CPI inflation accelerates and its volatility is high; exchange rate depreciation/appreciation accelerates and its volatility is low; the real exchange rate is overvalued; the output gap is positive (for imported consumer and total consumer goods); economic openness is low; the price of commodities is high (for producer and total consumer goods); the interbank interest rate is low (for imported consumer and total consumer goods); and the trend is above the average (for producer and total consumer goods)

Thirdly, we found that PT is nonlinear and responds differently to the size and sign of exchange rate shocks. In other words, the PT is also asymmetric. In the former case, for example, if the inflationary regime is "High," 20% of the 1% shock to the peso at time *t* is transmitted to CPI inflation in one month and 29% up to one year. Meanwhile, if the inflationary regime is "Low" the transmission decreases from 10% to 23% in the same period. In the latter case, for instance, the accumulated PT on inflation of total consumer goods before a positive shock to the exchange rate is 11% in the first year; while if the shock is negative, it is 13%. These findings further those by Shambaugh (2008) and Forbes et al. (2015), who do not take the nonlinear and asymmetric nature of PT into account.

According to the HD of shocks, price variations depend very much on the state of the economy. HDs also reveal that the final impact of exchange rate shocks on prices is determined by or is endogenous to other macroeconomics shocks that the economy and the exchange rate itself are facing, which supports the predictions of the Klein's (1990) model.

The main policy implications of the paper are the following. Firstly, models used in central banks for policy making need to be adjusted to the incomplete, endogenous, nonlinear and asymmetric nature of PT. Secondly, there should not exist a specific rule on PT on inflation for policy making, even in the short term. Yet the historical quantification of PT is a need for monetary policy making, since decisions cannot wait up to the time when experts identify shocks that the economy and exchange rates are facing barely in order to forecast the expected degree of PT. Thirdly, the transmission of movements in exchange rate on inflation vanishes along the distribution chain, as expected, and this behavior seems independent from any market behavior by firms, the state of the economy or shocks. Fourthly, uncertainty about PT increases rapidly over time after the shock.

Given the importance of evaluating the inflationary effects of movements in exchange rates for monetary policy decisions, the methodology implemented in this paper can be extended and applied to almost any country that benefits from having good data. An additional extension is to evaluate and quantify exchange rate pass-through, but allowing for movements of the exchange rate to respond nonlinearly to different types of external and domestic shocks, as was done very recently in the linear case by Forbes et al. (2015). With this new research one would show that PT is not only nonlinear state-dependent, as was shown in this paper, but also nonlinear shock-dependent.

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Appendix A1. International literature on PT

Authors	Year	Freq.[1]	Sample	Countries	Econ. model	Approach[2]	Variables[3]	Inflation[4]
Frankel et. al.	2005	Y	1990-01	76	ECM, Panel	L	L & Diff	↓
Marazzi et. al.	2005	Q	1972-04	USA	Single equation	L	Diff	↓
Campa & Goldberg	2006	Q	1975-04	18	5 categories	L	Diff	CPI: ↑ Pm: ↓
Gaytan & G.	2006	M	1992-05	Mexico	MS-VAR	NL	Diff	↓
Otani et. al.	2006	M	1980-03	Japan	Eight categories	L	Diff	↓
Rodríguez et. al.	2006	M	1994-05	Paraguay	Single equation	L	Diff	NA
Sekine	2006	Q	1974-04	G7	Single equation	DC	Diff	↓
De Bandt et. al.	2007	M	1995-05	Euro Zone	4 categories	NL	L	Pm: ↑
Ito & Sato	2008	M	1993-05	East Asian	VAR	L	Diff	CPI: ↑ Pm: ↑
Nogueira Júnior & Ledesma	2008	M	1983-05	Emerg. & Developed.	STR	NL	Diff	CPI: ↑
Al-Abri & Goodwin	2009	Q	1975-02	16 OECD	VAR-TVEC	L and NL	L & Diff	Pm: ↑
Mihailov.	2009	M	1979-02	USA-Ger-Jap	OLS-TSLS-VAR	LR	L & Diff	CPI: _ Pm: ↓
Kilic	2010	Q	1975-09	OECD	LSTM	NL	Diff	Pm: ↑ CPI: ↑
Berner	2010	M	1988-08	Germany	OLS, Weight, OLS	LR	Diff	Pm: ↑
Capistrán et al.	2011	M	1997-10	Mexico	VAR	L	Diff	Pm: ↑ CPI: ↑
An & Wang	2012	M	1980-07	OECD	VAR	L	L	Pm: ↑
Ben Cheikh.	2012	Q	1975-10	Euro Zone & USA	STM	NL.	Diff	CPI: ↑
Frankel et al.	2012	M-Y	1990-01	76	ECM	L	L & Diff	Pm: ↑
Shintani et al.	2013	M	1975-07	USA	STAR	NL.	Diff	CPI: ↑
Aleem & L.	2014	M	1994-09	Mexico	TVAR	NL.	L	CPI: ↑
Beckmann et al.	2014	M	1995-12	Germany	VEC-DOLS-SSM	L	Diff	Pm:_
					Panel-Kalman Filter			
Ozkan & Erden	2015	M	1980-13	88	DCCGARCH-Panel threshold	L	L & Diff	CPI: ↑
Donayre & Panovska	2015	M	2001-13	Canada & Mexico	TVAR	NL	Diff	CPI, Pm, Pm, WPI, IPI, CPI:↑

Source: Authors' compilation.
[1] Q: Quarterly; M: Monthly; Y: Yearly. [2] NL: Non-Linear; L: Linear; DC: Dynamic coefficient. [3] L: Levels; Diff: Differences. [4] ↑: pass-through increases; ↓: pass-through decreases; __: pass-through is stable; ---: ambiguous result; Pm: Import price index; WPI: Producer Price Index; IPI: Intermediate good prices; CPI: Consumer Price Index; NA: not applicable.

Appendix A.2. Data and sources

Sample: 2002:06 – 2015:5
Frequency: Monthly

- Pm: Price index of imported goods. Not seasonally adjusted (2014=100). Source: *Banco de la República* (http://www.banrep.gov.co/es/ipp).
- Pnm: Price index of Non-imported producer goods (2014=100). Source: *Banco de la República* (http://www.banrep.gov.co/es/ipp).
- Pw: Producer or whole prince index (2014=100). Not seasonally adjusted. Source: *Banco de la República* (http://www.banrep.gov.co/es/ipp).
- Pmc: Main imported goods of the Consumer Price Index. Not seasonally adjusted. Source: *Banco de la República* (unpublished statistics).
- Pc: Consumer Price Index (2008=100). Not seasonally adjusted. Source: *Banco de la República* (http://www.banrep.gov.co/es/ipc).
- E: Nominal effective exchange rate index (pesos/USD). It is weighted using the trade weights from the Colombian's main trading partners (these are the twenty trading partners used to calculate the real exchange rate index): USA, Canada, Japan, UK, Germany, Netherlands, Spain, France, Italy, Belgium, Switzerland, Sweden, Mexico, Panama, Venezuela, Ecuador, Peru, Brazil, Chile, Argentina. Source: *Banco de la República* (unpublished statistics).
- Open: Indicator of the country's trade openness. It is calculated as the ratio between total imports plus exports and the GDP. Sources: National Department of Statistics (DANE) (unpublished statistics) and *Banco de la República*.
- ITCR_IPP_NT: Real exchange rate index, using non-traditional weights and IPP deflactor. Source: *Banco de la República*.
http://www.banrep.gov.co/es/series-estadisticas/see_ts_cam_itcr.htm%23itcr
- GDP: Real Gross Domestic Product (COP millions). Source: *Banco de la República* (unpublished statistics).
- IPI: Industrial Production Index. Source: National Department of Statistics (DANE).
- ISE: Monthly indicator of economic activity (ISE). Source: National Department of Statistics (DANE).
(http://www.dane.gov.co/index.php/cuentas-economicas/indicador-de-seguimiento-a-la-economia-ise)
-IMACO: Index constructed by the technical team of the Central Bank from sectorial variables, which anticipates a five-month annual growth movements cumulative four-quarter of GDP. Source: http://www.banrep.gov.co/es/imaco
- MgC*: Trade weighted measure of the foreign countries' marginal costs. Foreign countries are the Colombian main trading partners. The monthly whole price index of each of these countries was used as their marginal cost proxy. Then, the price indexes were weighted by the respective monthly trade weight into the Colombian imports. Source: International Financial Statistics (IMF) and home pages from central banks.
- TIB (i): Colombian interbank interest rate. Source: *Banco de la República* http://www.banrep.gov.co/es/tib

- Pcomm: Commodity research bureau BLS/US spot all commodities. Source: Bloomberg.
- GITCRIPP_NT_HP: Real exchange rate gap. It is calculated as the difference between the observed ITCR_IPP(NT) and the Hodrick-Prescott filtered series.
- GITCRIPP_NT_CF: Real exchange rate gap. It is calculated as the difference between the observed ITCR_IPP(NT) and the Band-Pass(Christiano-Fitzgerald) filtered series.
- GIPI_HP: Output gap proxy1. It is calculated as the difference between the observed IPI and the Hodrick-Prescott filtered series.
- GIPI_CF: Output gap proxy2. It is calculated as the difference between the observed IPI and the Band-Pass (Christiano-Fitzgerald) filtered series.
- GISE_HP: Output gap proxy3. It is calculated as the difference between the observed ISE and the Hodrick-Prescott filtered series.
- GISE_CF: Output gap proxy4. It is calculated as the difference between the observed ISE and the Band-Pass (Christiano-Fitzgerald) filtered series.
- GIMACO_HP: Output gap proxy5. It is calculated as the difference between the observed IMACO and the Hodrick-Prescott filtered series.
- GIMACO_CF: Output gap proxy6. It is calculated as the difference between the observed IMACO and the Band-Pass (Christiano-Fitzgerald) filtered series.
- GGDP_HP: Output gap proxy7. It is calculated as the difference between the observed GDP and the Hodrick-Prescott filtered series.
- GGDP_CF: Output gap proxy8. It is calculated as the difference between the observed GDP and the Band-Pass (Christiano-Fitzgerald) filtered series.
- Δe_t: Exchange rate annual variation = ln (E_t) – ln (E_{t-12}).
- $\Delta(\Delta e_t)$: Percentage change of the exchange rate annual variation = $(\Delta e_t/\Delta e_{t-1}) - 1$.
- $V(\Delta e_t)$: Exchange rate volatility. It is calculated as the standard deviation of Δe using a moving window of twelve months.
- Annual inflation (π_t^l) = ln (I_t) – ln (I_{t-12}), I= Pm, Pnm, Pw, Pmc, Pc, Pcnc, Pcc.
- $\Delta\pi^{CPI}{}_t$: Percentage change of the CPI annual inflation = $(\pi^{CPI}{}_t/\pi^{CPI}{}_{t-1}) - 1$.
- $V(\pi^{CPI}{}_t)$: Volatility of the CPI annual inflation. It is calculated as the standard deviation of π_t using a moving window of twelve months.
- $\bar{\pi}$: De-trended Pc annual inflation. It is obtained as the residual of a lineal regression of the annual Pc inflation rate against a constant and a trend.

Appendix A.3. Bayesian econometric method

The Bayesian analysis requires the likelihood function of the model, the prior distribution and at least an approximation to the posterior distribution. We follow closely Koop (2003), Gefang and Strachan (2010) and Gefan (2012) and reproduce parts of their derivations here.

A3.1 ***Likelihood function***

Write model (11) in a compact form as

(A3.1.1) $$Y = X^{\theta}B + E.$$

where $B = (A_0, A_1, \dots, A_p, B_0, B_1, \dots, B_p)'$. But model (A3.1.1) can be vectored and transformed into, (A3.1.2) $$y = x^{\theta} b + e,$$

where $y = vec(Y)$, $b = vec(B)$, $x^{\theta} = I_n \otimes X^{\theta}, X^{\theta} = \left[x_1^{\theta\prime}, \dots, x_T^{\theta\prime}\right]'$, with $x_t^{\theta} = [x_t \; F(z_{t-d})x_t]$, $\theta = (\gamma, c)'$, and $e = vec(E)$. Given that errors terms are assumed to be white noise processes, the likelihood function of the model can be expressed as

(A3.1.3) $$L(b, \Sigma, \gamma, c) \propto |\Sigma|^{-T/2} exp\left\{-\frac{1}{2} e'(\Sigma^{-1} \otimes I_T)e\right\}.$$

Now notice that the term in the exponent of (A3.1.3) can be rewritten as

(A3.1.4) $$e'(\Sigma^{-1} \otimes I_T)e = s^2 + (b - \hat{b})'V^{-1}(b - \hat{b})$$

where $s^2 = y'M_V y$, $M_V = \Sigma^{-1} \otimes (I_T - X^{\theta}(X^{\theta\prime}X^{\theta})^{-1}X^{\theta\prime})$, $\hat{b} = vec((X^{\theta\prime}X^{\theta})^{-1}X^{\theta\prime}Y$ and $V = \Sigma \otimes (X^{\theta\prime}X^{\theta})^{-1}$.

Therefore, the likelihood function of the model is

(A3.1.5) $$L(b, \Sigma, \gamma, c) \propto |\Sigma|^{-T/2} exp\left\{-\frac{1}{2}[s^2 + (b - \hat{b})'V^{-1}(b - \hat{b})]\right\}$$

whose kernel, which is depends on b and the rest of parameters, has the familiar multivariate Normal form.

A3.2 ***Prior distributions***

In order to let data choose between linear and nonlinear models symmetrically, an Inverse-Wishart prior is specified for the variance-covariance matrix Σ. As long as we need to calculate posterior model probabilities in order to compare across different models and, as the dimension of b changes across different model specifications, one should not use flat priors for b to avoid meaningless Bayes factors (Koop, 2003). Thus we use a weakly informative conditional proper prior for b, as is done by Gefang (2012). Thus, the prior for b is assumed as Normal with zero mean and covariance matrix $\underline{V} = \eta^{-1} I_{nk}$, where η is a shrinkage prior distribute Gamma with mean $\underline{\mu_{\eta}}$ (equal 5.6) and degrees of freedom $\underline{\nu_{\eta}}$ (0.25).

Now, the identification problem when $\gamma = 0$ is tackled by setting its prior distribution as nearly non-informative as possible, then a Gamma distribution with mean $\underline{\mu_{\gamma}}$ (equal 2) and degree of freedom $\underline{\nu_{\gamma}}$ (equal 0.1). As for the prior of c, and to avoid just one regimen with few histories, we elicit the prior of c as uniformly distributed between the upper and lower limits of the middle 68% of the observed transition variables.

A3.3 ***Computations of the posterior distributions***

As is recalled by Gefang and Strachan (2010, page 7), the combination of equations (A3.1.3) and the previous equations yields the conditional distribution for Σ as the inverted Wishart with scale matrix $E'E$ and degrees of freedom T and the conditional posterior distribution for the vector b as normal with mean $\bar{b} = \bar{V}V^{-1}\hat{b}$ and variance $\bar{V} = (V^{-1} +$

$\eta I_{nk})^{-1}$. Since no close form is obtained for c and γ, we use the Metropolis within Gibbs strategy for these parameters.

The Gibbs sampling scheme is used to compute the outputs from the posteriors, as follows (Ibid, page 8),

1. Initialize $(b, \Sigma, \gamma, c, \eta) = (b^0, \Sigma^0, \gamma^0, c^0, n^0)$;
2. Draw $\Sigma / b, \gamma, c, \eta$ from $IW(E'E, T)$;
3. Draw $b / \Sigma, \gamma, c, \eta$ from $N(\bar{b}, \bar{V})$;
4. Draw $\gamma / b, \Sigma, c, \eta$ through a Metropolis-Hastings method;
5. Draw $c / b, \Sigma, \gamma, \eta$ from a uniform (c_min, c_max);
6. Draw $\eta / b, \Sigma, \gamma, c$ from $G(\overline{\mu_\eta}, \overline{\nu_\eta})$;
7. Repeat step 2 to 6 for a suitable number of replications, say B.

To avoid the draws from Metropolis-Hastings simulator getting stuck in a local mode, we also tried different starting values for the sampler. The acceptation rates from step 4 we obtain are still under 10% so more work is needed in order to improve them. Convergence diagnostic (still to be computed) indicated that 10,000 effective draws were enough to attain convergence, after 1,500 burnings. The hyperparameters $\underline{\mu_\eta}$ and $\underline{\nu_\eta}$ were calibrated per each transition variable in order to get those acceptation rates.

Appendix A.4 Estimation of the PT coefficient by means of the Bayesian techniques

This appendix summarizes the most important details of the methodology to estimate the effect of a shock to the exchange rate on the different price indexes in the stated nonlinear system (see details, for instance, in Koop (2003) and Lo and Morley (2013)). The generalized impulse response function (GIRF) is defined as the expected deviation caused by a shock on the model's predicted values. Formally, if

(A4.1) $$\mathrm{Y_t} = \mathrm{A(L)Y_{t-1}} + \mathrm{B(L)Y_{t-1}F(V_{t-d}\,; \gamma, c)} + \boldsymbol{\mu}_{\mathrm{t}},$$

in the presence of a shock of magnitude s to the k^{th}-element of the perturbations vector $\boldsymbol{\mu}_t$, the result is:

(A4.2) $$G(j, s, W_{t-1}) = E\left[Y_{t+j} | \mu_{k,t} = s, W_{t-1}\right] - E\left[Y_{t+j} | \mu_{k,t} = 0, W_{t-1}\right],$$

where W_{t-1} denotes the initial conditions (the history or state of the economy). Thus, $G(.)$ is the expected deviation of expected value of Y_{t+j} caused by a shock s from the expected value of Y_{t+j} conditional on the history at time t, W_{t-1}. Then, the PT on a τ horizon is calculated by means of the following procedure (notice we are interested in knowing the degree of PT under the V_{t-d} < *Threshold*, where *Threshold* is the value of parameter c):

1. Randomly choose a point in the sample where the V_{t-d} < *Threshold* is met. The number of these points will be written *N_lower*.
2. For this point, forecast the model for T periods ahead through simulation, while considering the respective history for the elements of vector V_{t-d} and the observed values brought forward. This forecast is built by using the Bayesian estimates on each effective

step of the Gibbs sampler. With that forecast we get $E\left[Y_{t+j}|\mu_{k,t}=0,W_{t-1}\right]$ for $j = 0,1,..T$.
3. Simulate the model for T periods ahead considering the same history for the elements of vector V_{t-d} from step 2, after subjecting the second element of V_t (corresponding to the devaluation) to a shock (add s in $j=0$ period). With that you get for $E[Y_{t+j} \mid \mu_t = s, W_{t-1}]$ for $j = 0, 1, ..., T$. We considered different values of s.
4. Calculate $G(.)$ in accordance with (A4.2).
5. Compute the PT estimates by equation (12).
6. Return to step 1 each time, use the Gibbs sampler (following the steps stated in Appendix A3.2) and generate a new set of parameters.

With this procedure, there is a resulting total of N trajectories of the PT estimates, considering $V_{t-d} < Threshold$ as initial conditions (for example, that the economy is in a regime of "high" inflation or in recession). Figures A.6.1 to A.6.22 show the median of these trajectories as well as its 68% most credible intervals (percentiles 16 and 84) only for inflations of imported consumer and total consumer goods (the other figures are available upon request). To study the $V_{t-d} > Threshold$ case, the procedure should be repeated by taking this new criteria as the initial condition (step 1). In the simulations presented, shocks were orthogonalized by the *Cholesky decomposition* method, maintaining the order of the variables given by vector Y in equation (11). That is, the foreign marginal cost is the most exogenous variable and CPI inflation the most endogenous one.

By drawing randomly from histories at each regimen and averaging across them, we obtain an estimate and then the median of the PT, which is conditional upon the current state of the economy. Notice that for each of the inflation series, we present two sets of paths for $G(.)$ and PT median estimates, that is, whether the transition variable exhibits a "high" or "low" regime. For instance, whether the Colombian real exchange rate was overvalued or undervalued or the inflation rate was "high" or "low." Additionally, we report the estimated path of $G(.)$ and PT when the shock to the exchange rate was a negative one or ten percent.

Appendix A.5

Figure A.5.1 Smooth transition function for $\Delta\pi^{cpi}$

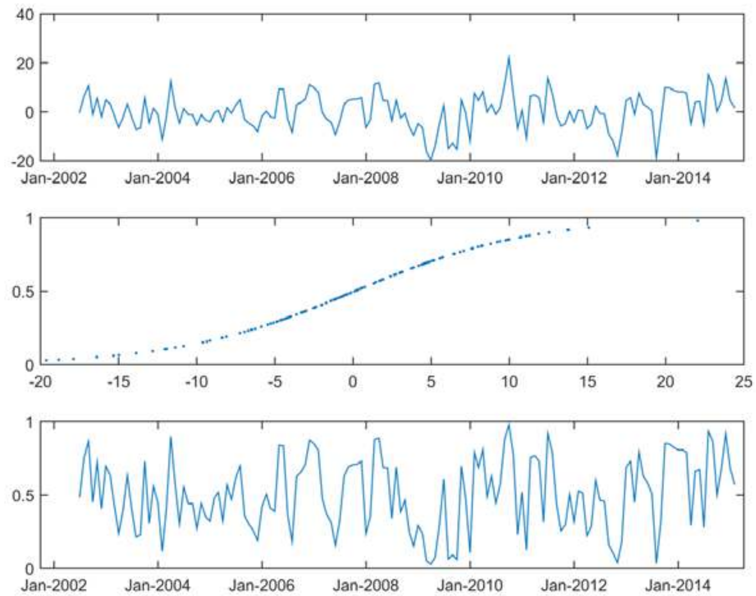


Figure A.5.2 Smooth transition function for $V(\pi^{cpi})$

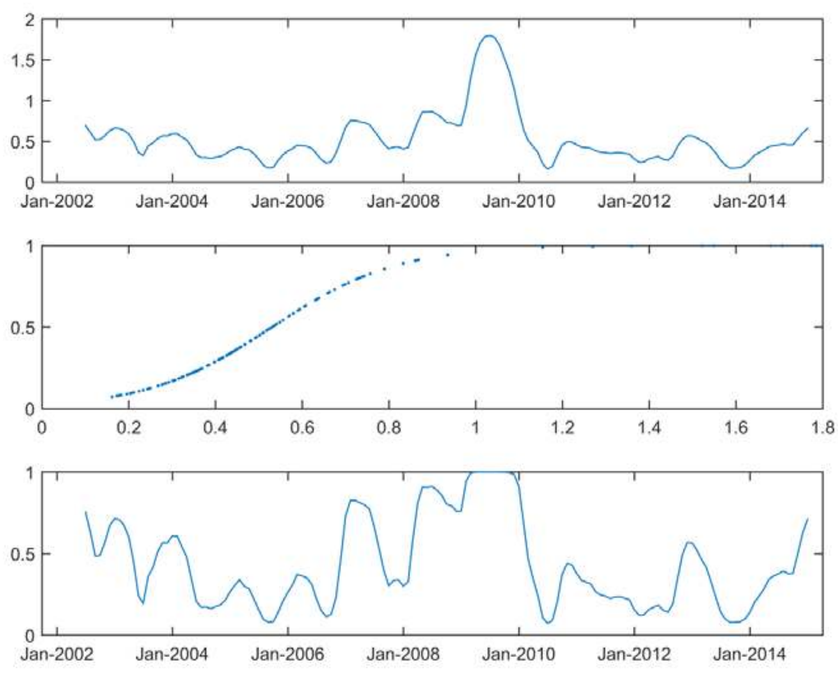


Figure A.5.3 Smooth transition function for $\bar{\pi}^{cpi}$

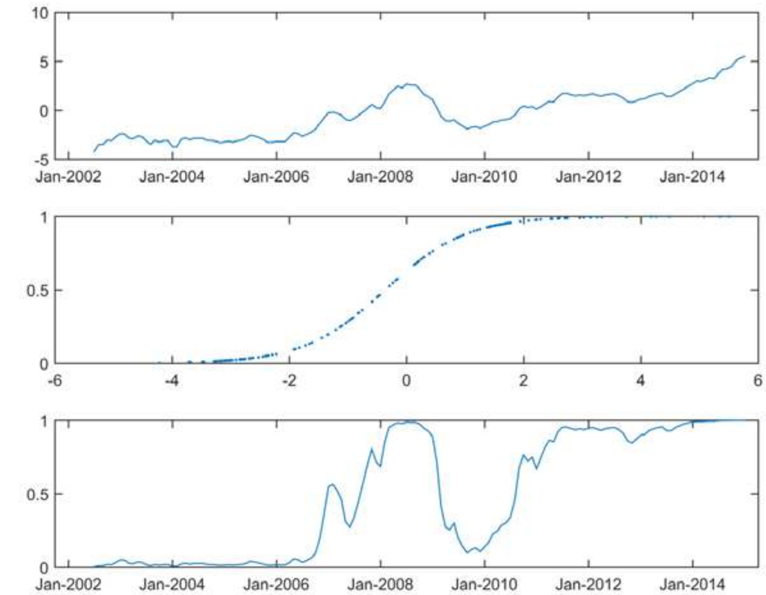


Figure A.5.4 Smooth transition function for $\Delta(\Delta e)$

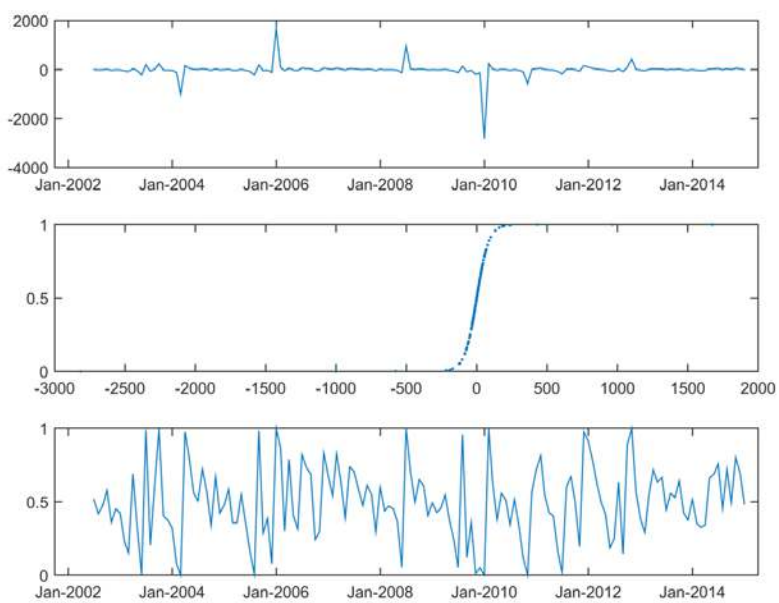


Figure A.5.5 Smooth transition function for $V(\Delta e)$

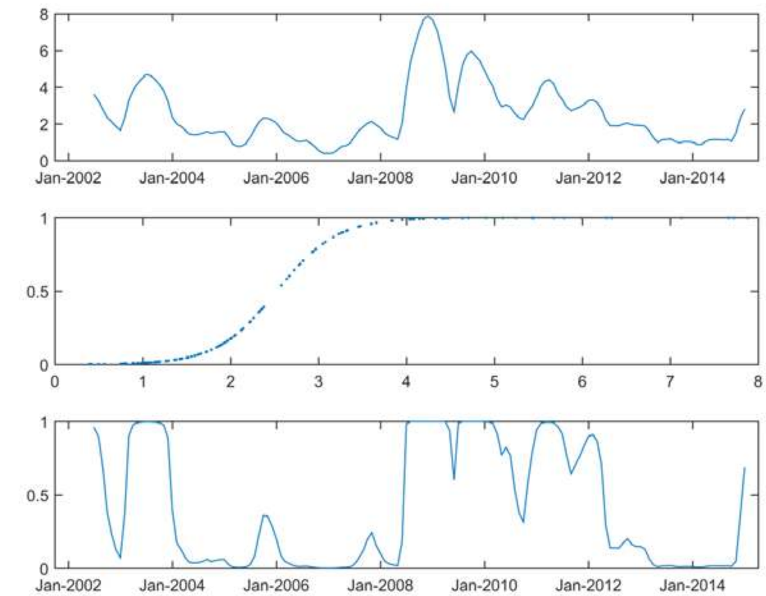


Figure A.5.6 Smooth transition function for Dq

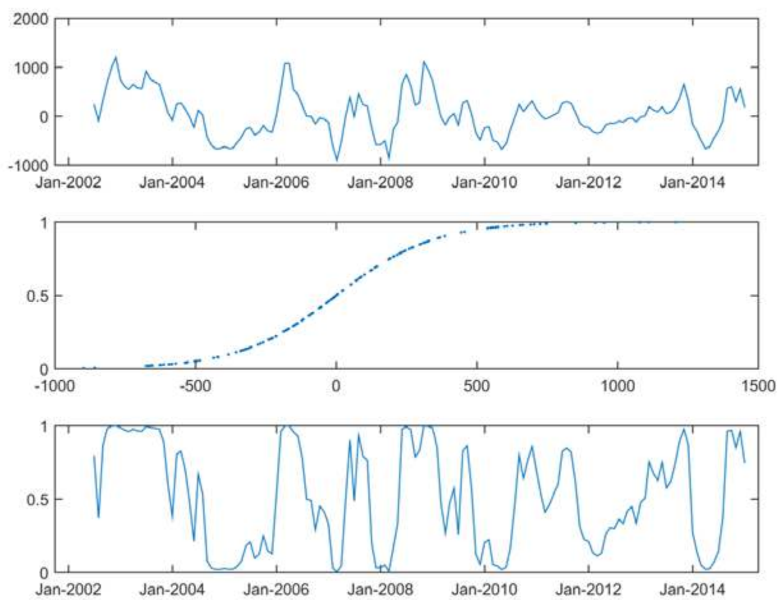


Figure A.5.7 Smooth transition function for Gy

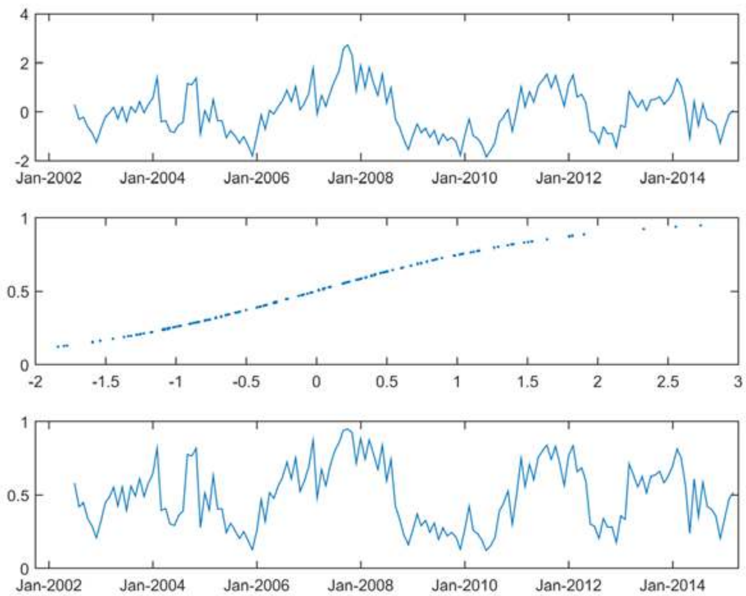


Figure A.5.8 Smooth transition function for $Openness$

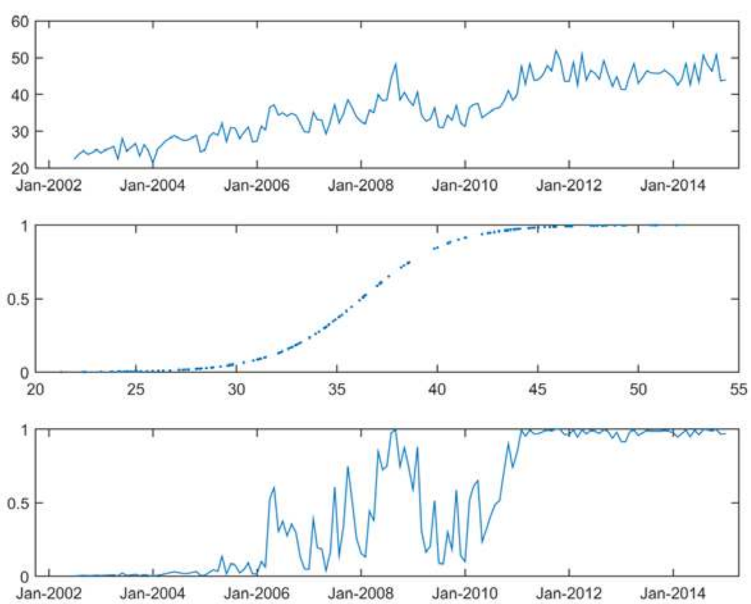


Figure A.5.9 Smooth transition function for $Pcomm$

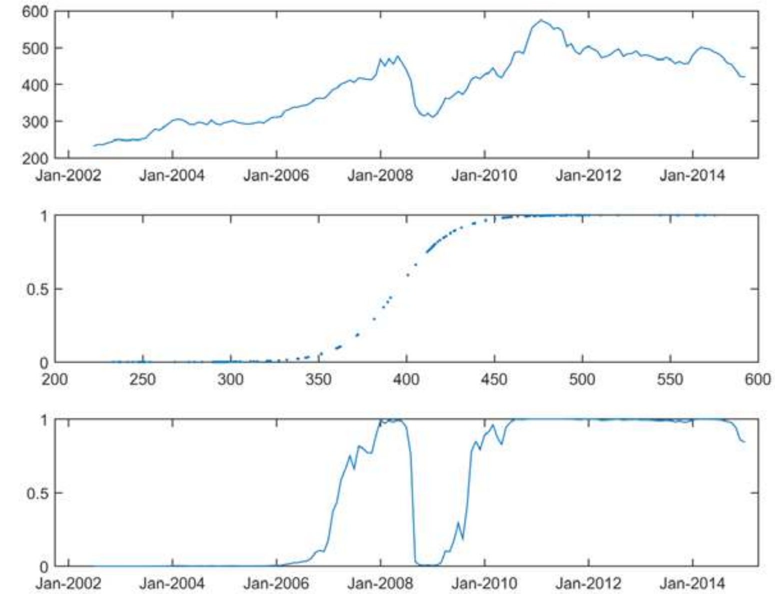


Figure A.5.10 Smooth transition function for IBR

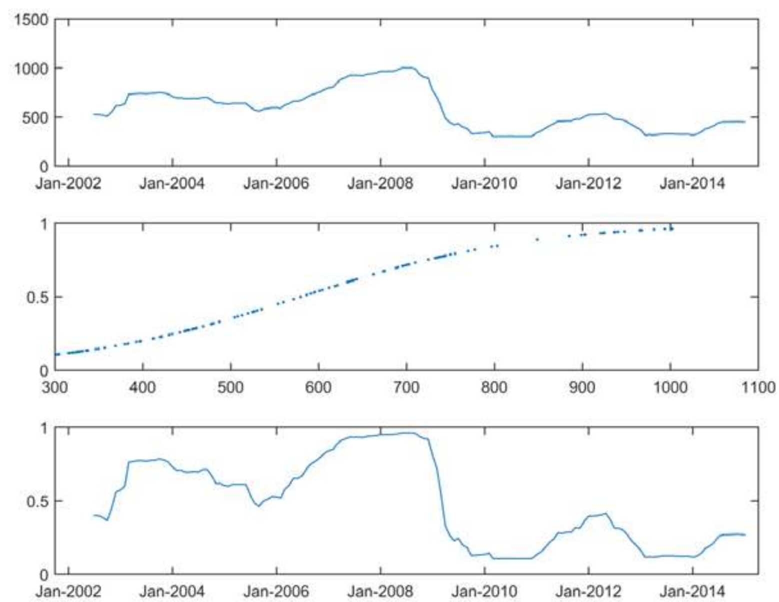
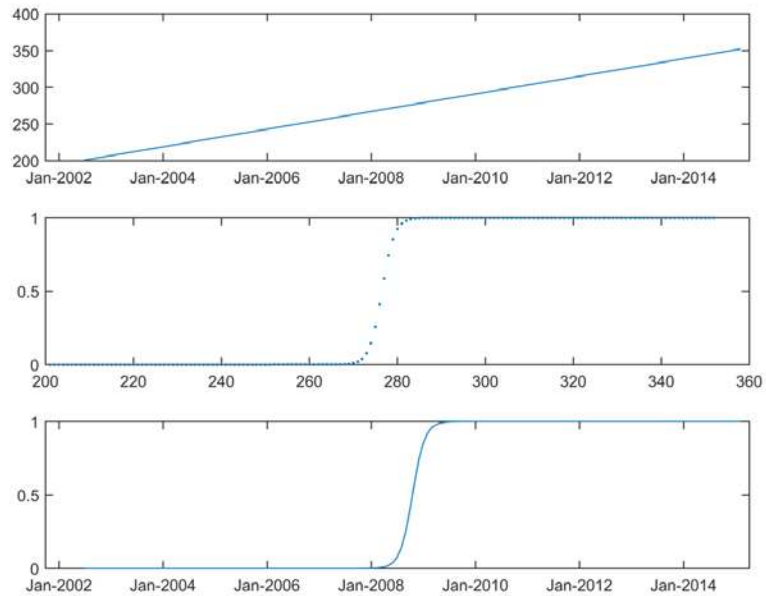


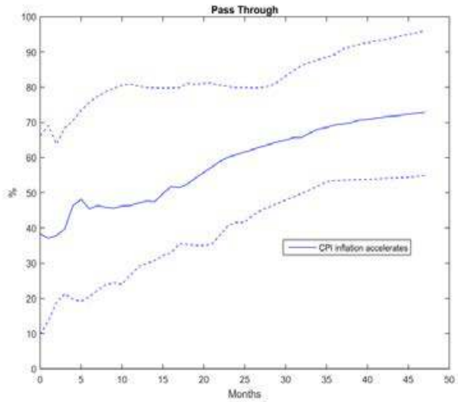
Figure A.5.11 Smooth transition function for $Trend$



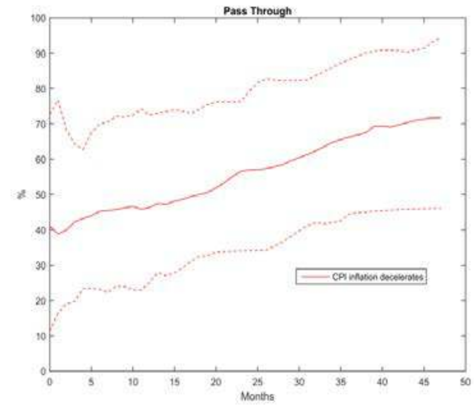
APPENDIX A.6

Figure A.6.1 PT on inflation of imported goods

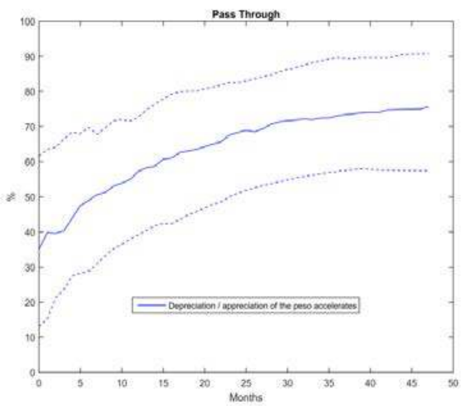
$\Delta\pi^{cpi}$ - *Accelerate*



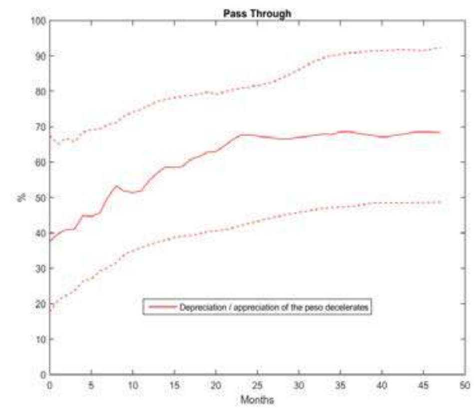
$\Delta\pi^{cpi}$ - *Decelerate*



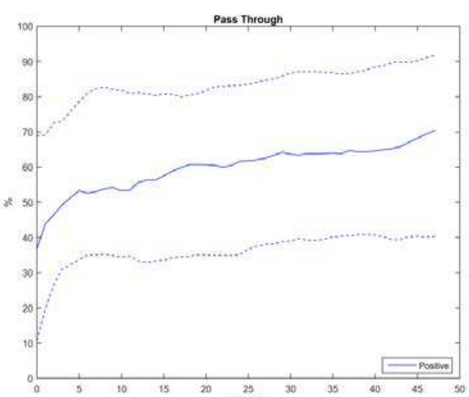
$\Delta(\Delta e)$ - *Accelerate*



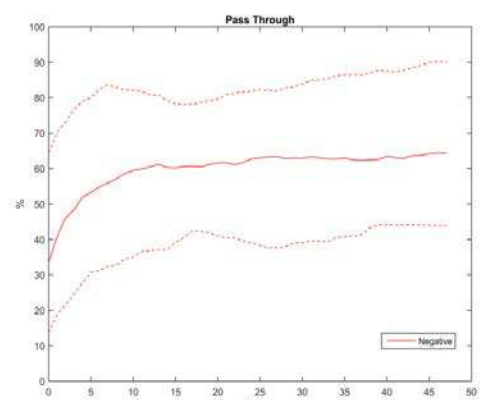
$\Delta(\Delta e)$ - *Decelerate*



Gy - *Positive*



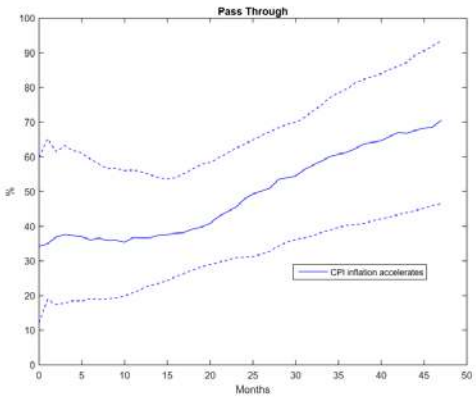
Gy - *Negative*



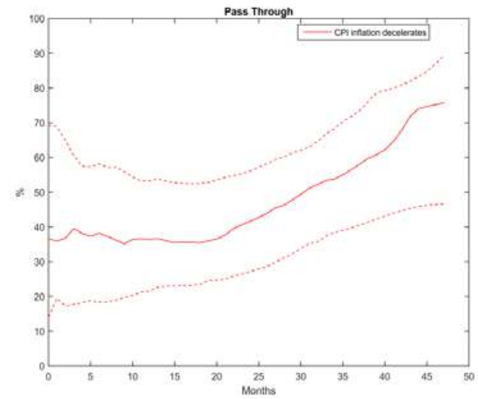
Source: Authors' calculations.

Figure A.6.2 PT on inflation of producer goods

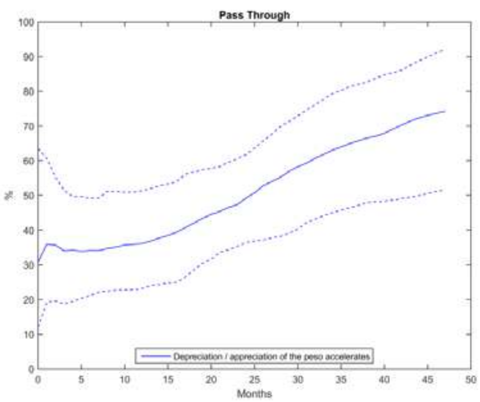
$\Delta\pi^{cpi}$ - *Accelerate*



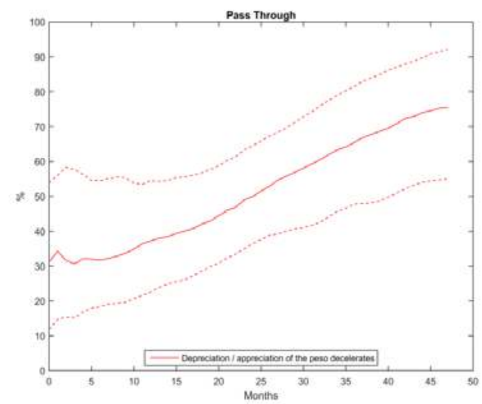
$\Delta\pi^{cpi}$ - *Decelerate*



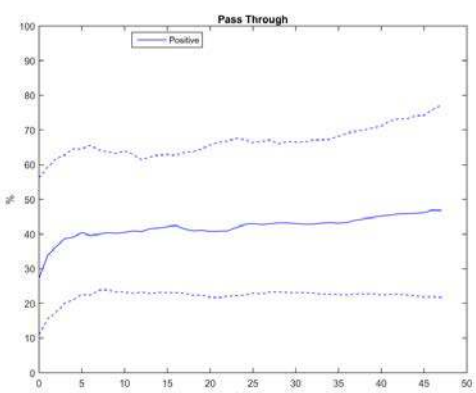
$\Delta(\Delta e)$ - *Accelerate*



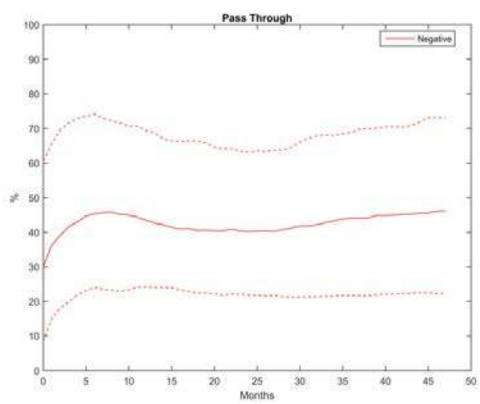
$\Delta(\Delta e)$ - *Decelerate*



Gy - *Positive*



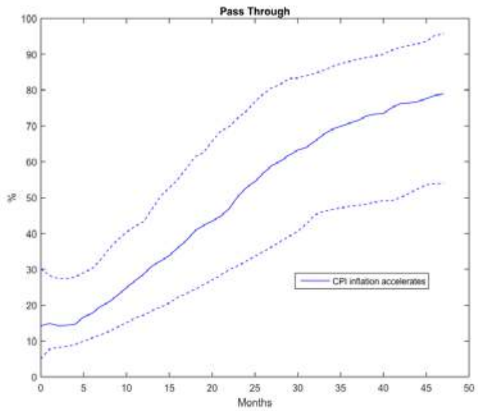
Gy - *Negative*



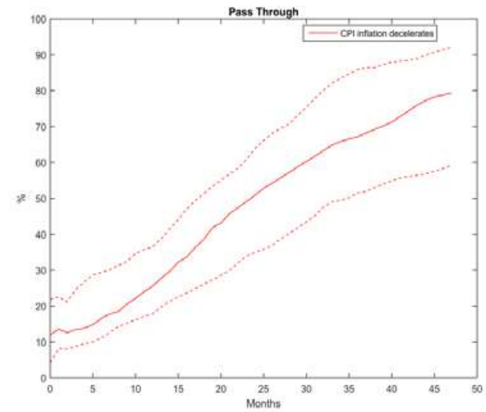
Source: Authors' calculations.

Figure A.6.1 PT on inflation of imported consumer goods

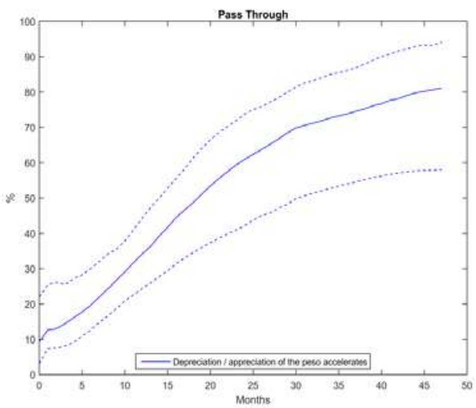
$\Delta\pi^{cpi}$ - *Accelerate*



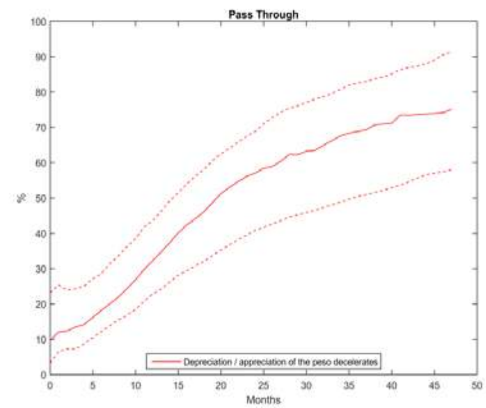
$\Delta\pi^{cpi}$ - *Decelerate*



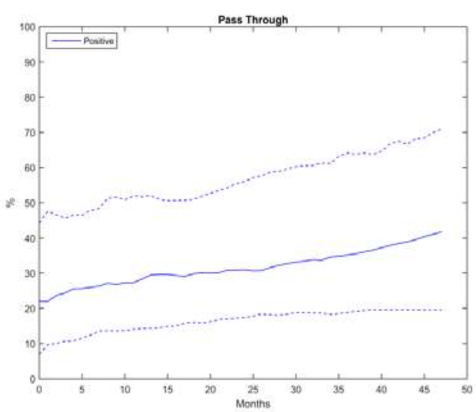
$\Delta(\Delta e)$ - *Accelerate*



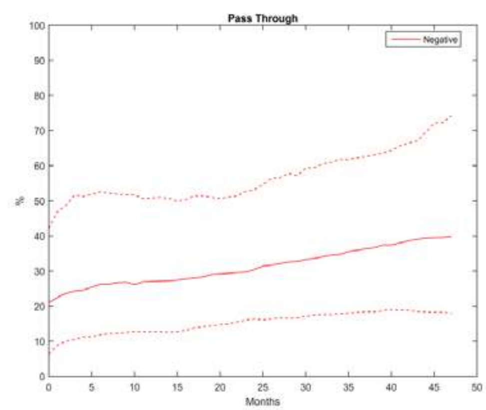
$\Delta(\Delta e)$ - *Decelerate*



Gy - *Positive*



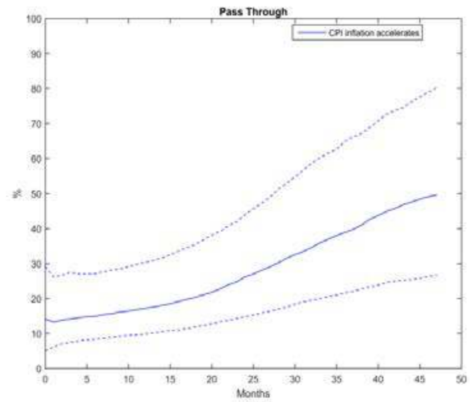
Gy - *Negative*



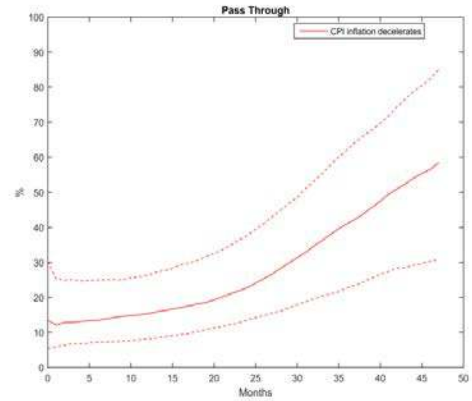
Source: Authors' calculations.

Figure A.6.1 PT on total consumer goods

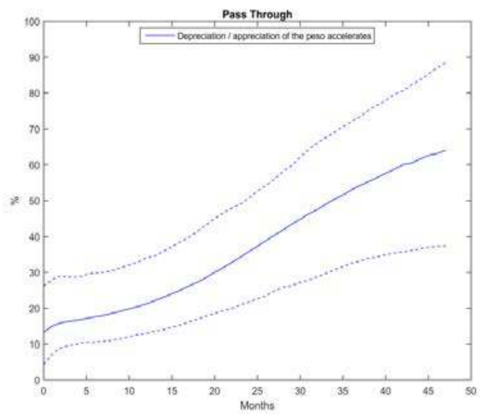
$\Delta\pi^{cpi}$ - *Accelerate*



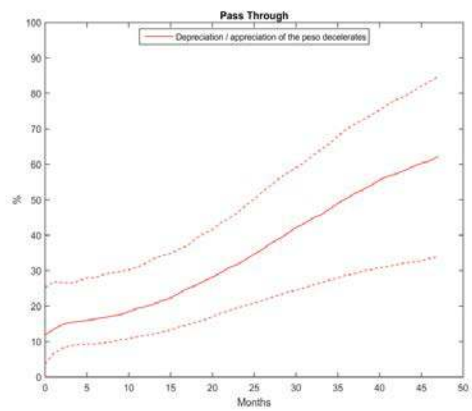
$\Delta\pi^{cpi}$ - *Decelerate*



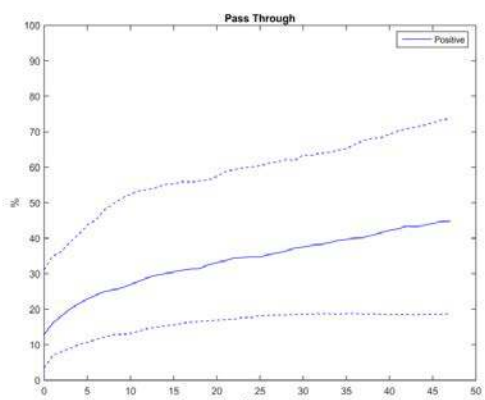
$\Delta(\Delta e)$ - *Accelerate*



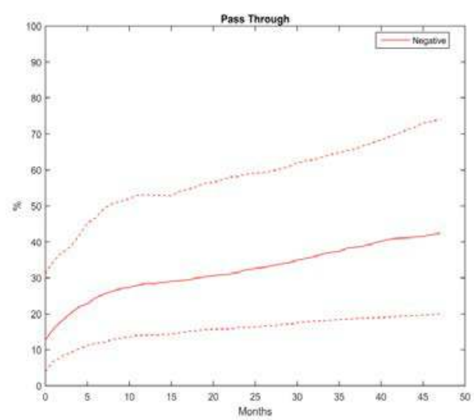
$\Delta(\Delta e)$ - *Decelerate*



Gy - Positive



Gy - Negative



Source: Authors' calculations.