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Núm. 930
2016

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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 nature of the pass-through and quantifies historically their short and long-term impact on prices along the distribution chain. The paper uses monthly data from a small open economy and a smooth transition autoregressive vector model estimated by Bayesian methods. The main findings are that pass-through is incomplete, endogenous and then changes over time, nonlinear and asymmetric in the short and long terms to exchange rate shocks and to the state of the economy (i.e., pass-through is nonlinear state-dependent). The three main policy implications of our findings are: Firstly, models used in central banks for policy making need to be adjusted to the incomplete, endogenous, nonlinear and asymmetric nature of pass-through. Secondly, there should not be a specific rule on pass-through on inflation for policy making, even in the short term. Thirdly, uncertainty about pass-through estimates increases rapidly after two years of the shock.

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; Engel, 2002; Adolfson, 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).

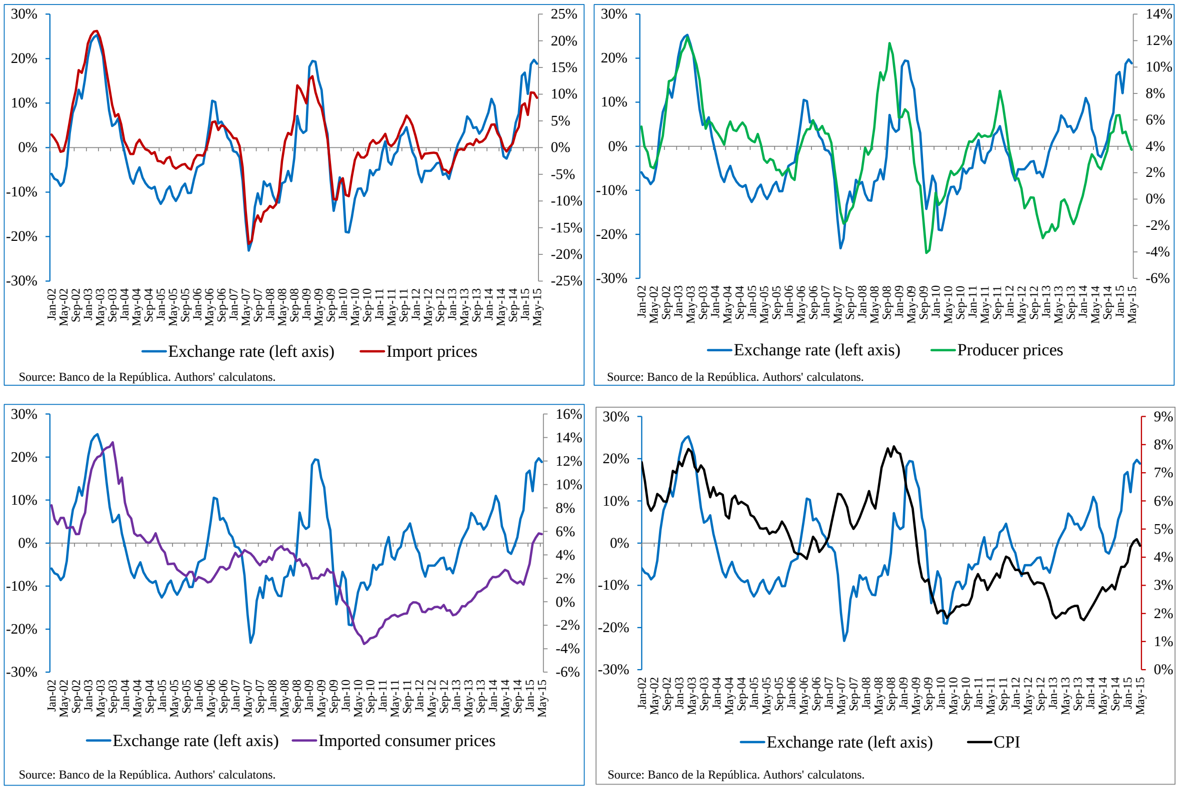
The second reason, which is closely related to the first one, is to determine their inflationary impact and implications for making monetary policy decisions (Ball, 1999; Taylor, 2000; Devereux and Yetman, 2003; Flamini, 2007; Mishkin, 2008; Forbes, 2015; Forbes et al., 2015). If the degree of exchange rate pass-through is complete, its fluctuations, *ceteris paribus*, are transmitted one-to-one to the prices of imported goods, and probably to prices of 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 change their consumption decisions from foreign to local goods or vice versa, whenever the final prices in local currency are modified.

The purpose of this paper is to study the nature of the pass-through of exchange rate shocks on prices along the distribution chain (henceforth PT) and quantify historically their short and long-term impacts. 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 on data of a small open economy. 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 for changes in prices will be also obtained. The paper uses monthly data from a small open economy (Colombia) along with price and trade data from its main trading partners for the period from 2002:7 to 2015:5 (since when floating and inflation-target regimes have been in place).

To give readers context on the Colombian economy and the shocks it may have faced along the sample, we describe some of the statistics related to the main variables of interest: Colombian imported goods correspond to 30% 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 38% of the CPI. Add to this, the time paths of the Colombian nominal effective exchange rate (local currency units per one unit of foreign currencies weighted by trade) and aggregate prices are shown in Figure 1. As can be seen, they show co-movements, in particular for import prices, and have experienced long swings throughout the sample.

Figure 1: Colombian nominal effective exchange rate versus prices
(yearly percentage changes)



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 such as Erceg et al. (2006) does-, it is limited to analyze the nature of the inflationary effects of exchange rate shocks and quantifying historically their impact. Of course, we are aware that the effect of these shocks on prices 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 (see Corsetti et al., 2008a; Bouakez and Rebei, 2008), some recent empirical literature have found for the linear case (see Shambaugh, 2008; Forbes et al., 2015), and we show by decomposing historically the changes in the price indexes.[1] However, in this paper we are interested in what the data reveal about PT, 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. Moreover, we do not mean at all that for monetary policy making is not important to know the type of shock the economy is facing, as pointed out by Engel (2009). What we do mean is that we wish for data to speak up freely.[2] Secondly, the paper does not make the reaction function of the monetary authority explicit in the LST-VAR system; 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 will control for the stance of the monetary policy and its effect on the degree of PT.

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 prices 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

[1] In addition, and for completeness, we will make a digression and carry out an exercise similar to Shambaugh' (2008), but for our nonlinear model, data and econometric approach.

[2] 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 short and long-term parameters) 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 Generalized Impulse Response Functions under such restrictions in the framework of nonlinear models puts them outside of the scope of this paper, rather an open research agenda.

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).[3,4] Thirdly, it goes further to obtain 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 of the exchange rate. As will be clear, this will bring about empirical support to the seminal predictions of the Klein's (1990) on the endogeneity of prices and exchange rates to macroeconomic shocks and offer alternative evidence to the findings of Frankel et al. (2012), Shambaugh (Ibid) and Forbes et al. (Ibid).

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), Engel (2000) and Engel and Rogers (2001), respectively. Thus, the incompleteness of the PT emerges when there are non-competitive

[3] 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 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).

[4] Fernández-Villaverde et al. (2014) list and explain neatly additional justifications for using Bayesian methods in economic and econometric analyses.

market structures along the production or distribution chains, 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; Floden and Wilander, 2006; Takhtamanova, 2008),[5] nominal rigidities (Ball et al., Ibid; Corsetti et al., 2008a), menu costs (Floden and Wilander, 2006; Wolf and Ghosh, 2001), shifts in the composition of country import bundles (Campa and Goldberg, 2005) or increased sensitivity of tradable and nontradable consumer good prices to movements in exchange rates due mainly to a large expansion of imported input use across sectors (Campa and Goldberg, 2006). As for the endogeneity, it arises because the PT depends upon the stochastic underlying macroeconomic structure of the economy (Klein, 1990) or since the exchange rate itself is an endogenous variable, the exchange rate, PT and prices are jointly determined (Klein, Ibid; Devereux et al., 2004; Corsetti et al., 2008a, 2008b).

The nonlinear and asymmetric behavior of the PT is related to the size, sign and nature (transitory versus permanent) of the exchange rate shocks, to their volatility, to price rigidities and to the state of the economy (Borensztein and De Gregorio, 1999; Taylor, 2000; Smets and Wouters, 2002; Devereux and Yetman, 2003; Floden and Wilander, 2006; Corsetti et al., 2008a; Mishkin, 2008; Bussiere, 2013). Lastly, they materialize as a consequence of an inventory management strategy or the duration of price contracts between sellers and buyers. In our paper, the state of the economy is summoned by the historical behavior of CPI inflation (variation, volatility and deviation from central bank's target), 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, growth in price of commodities 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

[5] For instance, some foreign firms set prices of their exports in their own currency ("producer-currency pricing", PCP), while others set prices in the importer country's currency ("local-currency pricing", LCP). In the first case, a local exchange rate movement is expected to pass-through fully on import prices, whereas in the second that may not do so. See Engel (2002) for a deep discussion on the implications of one or another strategy on the degree of exchange rate pass-through and on the macroeconomic adjustment mechanisms.

will roughly capture as said above.[6]

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 and Donayre and Panovska (2016) for Canada and Mexico (see literature review in appendixes A.1.A and A.1.B).[7] These results are independent from the theoretical and empirical approximation used and the country, period and data frequencies analyzed.

The main finding of this paper is that the pass-through is incomplete -as predicted and found by most of the literature-, 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-dependent) and to exchange rate shocks. These results contrast strongly, for example, with those well-known findings by Campa and Goldberg (2005, 2006) for a sample of OECD countries or, in the case of linearity, with Shambaugh' (Ibid) for 16 developed and Emerging countries (Colombia is in his sample) and with Forbes' et al. (Ibid) for UK.

Historically, the accumulated PT on import prices of a 1% positive shock on the variation of the exchange rate ranges from 48% to 52% (proportional to the size of the shock) in the first month and from 55% to 67% in the first year. The equivalent figures on producer, imported consumer and total (CPI) prices range from 18% to 27%, 8% to 14%, 6% to 11% in the first month, respectively, and from 27% to 46%, 19% to 42%, and 13% to 21% in the first year. Finally, and for the same shock, the maximum accumulated PT in four years on import, producer, imported consumer and total (CPI) prices correspond to 75%, 65%,

[6] 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. Unfortunately, we do not have a measure of the "stability," "inflation expectations" or "credibility" of monetary policy to control for. Building them would take us a lot of effort and they would not add up much to the main results this paper brings about.

[7] See Burstein and Gopinath (2013) for a recent overview of the academic literature on PT. Caselli and Roitman (2016) found PT nonlinearities and asymmetries in a sample of 28 Emerging Markets, Colombia among them.

68% and 40%, respectively. When the shock is 10%, the results are puzzling since we found that the larger the shock the smaller the PT, except for import prices. For instance, the respective accumulated PT estimates on the CPI range from 2% to 3%, 5% to 13% and 13% to 33% for the same periods. 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.

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 be 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 after two years of 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 for the PT estimates and the HD of shocks are shown and analyzed in the fifth section. The last part summarizes the conclusions. All aspects related to the implementation of the econometric methodology are left to the appendixes.

2. TRANSMISSION CHANNELS OF EXCHANGE RATE SHOCKS ON INFLATION

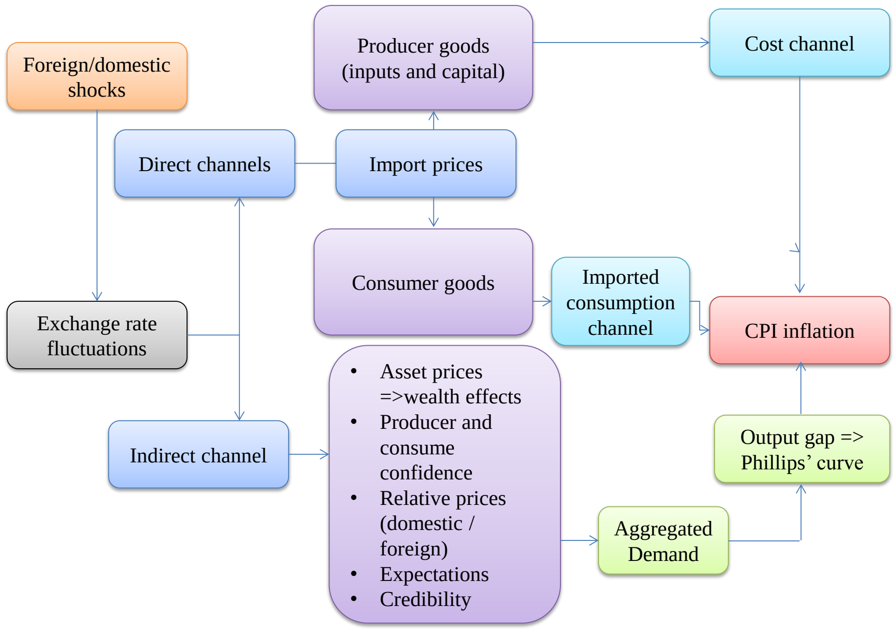
Exchange rate fluctuations manifest themselves on CPI inflation through at least three channels, two of them direct and one indirect (Figure 2). The first channel acts through the direct effect of exchange rate fluctuations on import prices and then on producer prices. For producers, the cost of production changes because many products use imported inputs, and, through the cost channel, so does the CPI.[8] The degree of transmission through 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.

The second channel is the direct effect on prices of imported consumer goods (which may also be 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.

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, inflation expectations and credibility on the monetary authority. Therefore, this way can be called the general equilibrium channel of PT.

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

Figure 2: Transmission channels of exchange rate shocks on prices



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

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 four directions.

Firstly, we introduce marginal costs of foreign exporters 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.[9,10] 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.[11] 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. Finally, we do not include the reaction of monetary policy, for the reasons explained above, which could introduce upward bias to the historical PT estimates.

Hence, price variations at a specific distribution stage in period *t* have different components (see Figure 2): (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, by shocks to mark-ups at each distribution stage, as predicted by the Dornbusch's model in the case of import prices.

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

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

[9] Dornbusch models a foreign firm which optimally fixes its export price with a markup above its marginal cost. In his model the markup is a growing function of its product market share in the domestic country. Unfortunately we could not build a measure of the marginal cost for each of the firms or countries exporting to Colombia, because of data availability. For this reason, we use their whole price index as their marginal cost proxy, once we weight them by the respective monthly trade weight into the Colombian imports.

[10] 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).

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

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

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

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

(8) Inflation of total consumer goods: $\pi_t^{cpi} = E_{t-1}\left(\pi_t^{cpi}\right) + \varphi_1 \varepsilon_t^{\Delta mgc^*} + \varphi_2 \varepsilon_t^{\Delta e} + \varphi_3 \varepsilon_t^{\pi^m} + \varphi_4 \varepsilon_t^{D} + \varphi_5 \varepsilon_t^{S} + \varphi_6 \varepsilon_t^{\pi^{ppi}} + \varphi_7 \varepsilon_t^{\pi^{mc}} + \varepsilon_t^{\pi^{cpi}}$

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 the non-core CPI, 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. $\varepsilon_t^{\pi^m}$, $\varepsilon_t^{\pi^{ppi}}$, $\varepsilon_t^{\pi^{mc}}$ and $\varepsilon_t^{\pi^{cpi}}$ 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 $Y_t = \left(\Delta mgc_t^*, \Delta e_t, \pi_t^m, D_t, S_t, \pi_t^{ppi}, \pi_t^{mc}, \pi_t^{cpi}\right)'$, with a with a vector of structural shocks given by $\boldsymbol{\varepsilon}_t = (\varepsilon_t^{\Delta mgc^*}, \varepsilon_t^{\Delta e}, \varepsilon_t^{\pi^m}, \varepsilon_t^{D}, \varepsilon_t^{S}, \varepsilon_t^{\pi^{ppi}}, \varepsilon_t^{\pi^{mc}}, \varepsilon_t^{\pi^{cpi}})'$.

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 2002:7 and 2015:5. An index weighted by foreign trade was constructed to obtain a nominal effective exchange rate measure of the domestic currency (peso). Trade weights were obtained from the Colombia's main trading partners. Here a rise in the index is a depreciation of the peso. The time series, their sources and some methodological notes are described in Appendix A.2.

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 (8) 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.[12] 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, as well as the robustness exercises implemented, in Appendix A.3.

[12] 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 nonlinearities and asymmetries for extreme values of the variable that describes the transition or state of the economy.

Movements of imported, producer, imported consumer and total consumer prices 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 model is written as (see He et al., 2009):

$$(9) \qquad Y_t = A(L)Y_{t-1} + F(V_{t-d}\,; \gamma, c)B(L)Y_{t-1} + \boldsymbol{\mu}_t \ ,$$

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 $f_j(\cdot) = \{1 + \exp[-\gamma(V_t - c)/\sigma_V]\}^{-1}$ 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.[13] 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 $\gamma \rightarrow \infty$ and $V_t < c$ we are under the regime of $A(L)Y_{t-1}$, while when $\gamma \rightarrow \infty$ and $V_t > c$ we are then under $[A(L) + B(L)]Y_{t-1}$. For finite values of γ, one has a continuum between the two extreme regimes.

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

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=Δmgc^*, Δe, π^m, D, S, π^{ppi}, π^{mc}, π^{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 GIRFs, which are robust to the ordering of the variables in VAR systems (Pesaran and Shin, 1998; Ewing, 2001).[14] Second, we will introduce an additional identification assumption, which consists on imposing a positive PT and conditioning the accumulated GIRF of the numerator and denominator of equation (10) 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 GIRFs 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 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. This is commonly done by the applied literature on nonlinear models, for instance by Winkelried (2003), González et al. (2010) and Mendoza (2012), who use data of small open economies from Latin American. An alternative, as presented in this paper, is to use Bayesian methods to

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

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.[15,16] 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.[17]

The transition variables are the following ones, according to what the theory presented above suggests: Variation of the CPI inflation ($\Delta\pi^{cpi}$), volatility of inflation ($V(\pi^{cpi})$) and deviation of the CPI inflation from the central bank's target ($D\pi$), 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 (Mq) 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 foreign exporters (or local importers) perceive such changes as transitory, while if it is low, we assume they perceive such changes as permanent.[18]

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[15] 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).

[16] 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)).

[17] 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).

[18] Pollard and Coughlin (2003) state that the effect of the exchange rate volatility on the pass-through will depend on whether prices are set in the exporter's. Thus, under PCP, pass-through is lower when exchange rate volatility increases, because firms do not update prices. On the contrary, under LCP pass-through rises because the updating frequency of firms' pricing increases.

The other transition variables are the output gap (Gy), degree of economic openness ($Opennes$), growth in price of commodities ($\Delta Pcomm$), the interbank interest rate, or 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 increases 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 increases 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 real exchange rate is from its equilibrium, the larger the transmission of nominal depreciation on prices should be in order to restore such equilibrium. Conversely, the further from below the real exchange rate is from its equilibrium, the lower or more neutral the transmission of nominal 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 and trend, it is difficult to make a general prediction, so that we will let data to reveal it. Finally, it is expected that the higher the interbank interest rate is –i.e. the tighter the monetary policy- the lower the PT should be.

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; Donayre and Panovska, 2016):

(10) $$PT_{\tau}^{n}=\frac{\sum_{j=0}^{\tau}\frac{\partial\pi_{t+j}^{n}}{\partial\varepsilon_{t}^{\Delta e}}}{\sum_{j=0}^{\tau}\frac{\partial\Delta e_{t+j}}{\partial\varepsilon_{t}^{\Delta e}}},\ \ n=m,ppi,mc,cpi,$$

where $0\leq PT_{\tau}^{n}\leq 100$. 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. In other words, the PT measures the impact of the exchange rate shock on the respective price level relative to impact on the exchange rate level at τ. 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 1 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).[19] 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.

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

Table 1. Bayes factor for selected models

Model	Transition variable	*p*-lag	*d*-lag	Ln(BF)
VAR	$\Delta(\pi^{cpi})$	3	NA	-1220.2
LST-VAR	$\Delta(\pi^{cpi})$	3	2	-20101.2
VAR	$V(\pi^{cpi})$	3	NA	-2002.7
LST-VAR	$V(\pi^{cpi})$	3	1	-19237.8
VAR	$D\pi$	3	NA	-1015.8
LST-VAR	$D\pi$	3	1	-20179.8
VAR	$\Delta(\Delta e)$	3	NA	-1888.3
LST-VAR	$\Delta(\Delta e)$	3	2	-19540.5
VAR	$V(\Delta e)$	4	NA	-2901.7
LST-VAR	$V(\Delta e)$	4	2	-19429.2
VAR	*Mq*	3	NA	-1098.3
LST-VAR	*Mq*	3	1	-20350.9
VAR	*Gy*	3	NA	-2916.1
LST-VAR	*Gy*	3	1	-20000.0
VAR	*Openness*	3	NA	-4315.4
LST-VAR	*Openness*	3	2	-21615.7
VAR	$\Delta(Pcomm)$	3	NA	-1170.3
LST-VAR	$\Delta(Pcomm)$	3	1	-20731.3
VAR	*IBR*	3	NA	-1586.6
LST-VAR	*IBR*	3	2	-20764.2
VAR	*Trend*	3	NA	-6254.1
LST-VAR	*Trend*	3	2	-22065.7

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

Therefore, data seem to validate an endogenous and nonlinear dynamics of the exchange rate shocks on the price variations 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.

5.2 Estimations of transition functions and their parameters

The estimation of the regression model given by equation (9) 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 2 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 growth of commodities prices ($\Delta Pcomm$).[20] For example, when the transition variable is the volatility of the CPI inflation, the c estimate is 0.44 and the threshold is 0.53, and the number of observations classified in the low regime is 99 and in the high, 53. That is to say, the volatility of CPI inflation has been in the low regime in 65% of the cases along the sample.

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 the time series of the transition variables (top), their smooth transition functions (center) and the time profile of the smooth transition functions (below) in figures A.5.1 to A.5.9 (Appendix A.5).[21]

For the purpose of illustrating the results, the figures for the variation and volatility of the CPI inflation in figures A.5.1 and A.5.2, respectively, are explained. Figure A.5.1 indicates an abrupt transition between the “increases” and “decreases” regimes of the CPI inflation (central chart of Figure A.5.1), which is explained by the relative larger calculated value of the smoothing parameter γ. As said before, in this case the logistic function $f_j(V_t;\gamma,c)$

[20] A possible reason for the result of the first variable is its high volatile.

[21] Given the confidentiality of the measures of the misalignment of the real exchange rate and the output gap series, they are not shown.

seems to approach an indicator function $I(V_t > c)$ and the changes from 0 to 1 could become quite instantaneous at $V_t = c = 0$.

Table 2: Estimated parameters for the selected models

Transition variable	Estimated parameters		# obs. per regime		Threshold		
	γ	C	Low	High		p-lag	d-lag
$\Delta(\pi^{cpi})$	32.11	-12.67	78	74	0.07	3	2
$V(\pi^{cpi})$	1.10	0.44	99	53	0.53	3	1
$D\pi$	6.76	-1.92	87	65	0.29	3	1
$\Delta(\Delta e)$	5.03	-120.69	85	67	0.0	3	2
$V(\Delta e)$	6.92	3.34	86	65	5.72	4	2
Mq	2.23	-11.38	87	65	0.00	3	1
Gy	2.30	-1.35	81	71	0.00	3	1
Openness	5.69	26.37	79	73	36.31	3	2
Δ(Pcomm)	2.10	-30.65	72	80	5.75	3	1
IBR	1.13	4.31	78	74	5.80	3	2
Trend	4.27	225.10	76	76	275.50	3	2

Source: Authors' calculations.

On the other hand, figures A.5.2 shows that the transition between one regime and another of the volatility of CPI inflation 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 the volatility of the inflation rate around 2007. The second one could be due to the impact on the inflation volatility 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, according to monetary authorities, by the domestic positive shock in the domestic price of the agricultural and regulated products and the high and rapid depreciation of the domestic currency (as for the level, the nominal effective exchange rate of the peso depreciated 21% between July 2014 and May 2015, as shown in Figure 1).

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 3.1-6.2 display the degree and dynamics of the PT coefficients on import, producer, imported consumer and total consumer prices as defined by equation (10). Thus, tables show the median of the accumulated PT estimates (in percentage points) on prices at each stage conditional on each of the identified regimes of transition variables, in the presence of positive (depreciation) and negative (appreciation) structural shocks of 1% and 10% to the variation of the nominal effective exchange rate of the local currency. 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 accumulated PT coefficients, as well as its 68% most credible intervals (percentiles 16 and 84), for prices along the distribution chain when there is a positive shock of 10% to the exchange rate change and for both regimes and only three of the transition variables (the other figures are available upon request): Interbank interest rate (*IBR*), *Trend*, and output gap (*Gy*). From those figures the reader can notice not only the statistical significance of the PT estimates and their endogenous and nonlinear nature, but also their rapid increase of their uncertainty after the second year of the shock, since the credible intervals widen. It is worth noting that by definition (see equation (10)), the PT coefficients embed double uncertainty from the corresponding GIRF's estimates for the numerator and the GIRF's estimates for the denominator and the uncertainty coming from the parameter estimation. This may explain the large amplitude of the credible intervals, which make them to overlap, especially for import prices.

The first conclusion we can extract from tables 3.1 to 6.2 is that the degree of PT is incomplete for the data analyzed both in the short and long terms, even for import prices, which are the most connected prices to the exchange rate. This shows evidence against a complete exchange rate transmission even for import prices and 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 size and sign 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. This does not mean that when there is a negative shock – an appreciation of the peso-, the import prices rise. Instead, *ceteris paribus*, these prices fall by the PT estimates reported on the right-hand side of the tables.

From the tables 3.1 to 6.2 one can summarize the minimum and maximum historical degree of the accumulated transmission of exchange rate shocks on prices at each of the distribution stages and at any time period τ (see equation (10)). Thus, the accumulated PT on import prices of a 1% positive shock ranges -across the transition variables- from 48% to 52% (proportional to the size of the shock) in the first month and from 55% to 67% in the first year. The equivalent figures on producer, imported consumer and total consumer prices range from 18% to 27%, 8% to 14%, 6% to 11% in the first month, respectively, and from 27% to 46%, 19% to 42%, and 13% to 21% in the first year. Finally, the maximum accumulated PT at four years on import, producer, imported consumer and total consumer prices correspond to 75%, 65%, 68% and 40%, respectively. Two remarks are needed here. The first is that estimations show neatly how the degree of transmission vanishes along the distribution chain, as shown by Frankel et al. (2012) for a sample of 76 developed, Emerging Market and developing economies. The second is that uncertainty about the PT estimates increases rapidly across time, as is captured by the magnitude of the Bayesian credible intervals after the second year (see figures A.6.1 to A.6.4).[22]

[22] The reader can make the same exercise for the cases of a 10% positive shock or 1% and 10% negative shocks.

Table 3.1 Median estimates of the PT on prices of imported goods

(Percentage points)

Transition Variable	Shock %Points	Positive shock to the exchange rate change				Negative shock to the exchange rate change			
		1 month	6 months	1 year	4 years	1 month	6 months	1 year	4 years
		CPI inflation increases							
$\Delta(\pi^{cpi})$	1	50.0	62.2	64.8	67.6	49.1	62.1	64.5	68.7
	10	49.8	62.0	62.3	64.4	50.1	62.2	62.6	64.5
		CPI inflation decreases							
	1	49.1	62.2	64.5	68.0	49.1	61.7	64.0	67.4
	10	49.8	61.8	62.2	65.2	49.9	61.9	62.0	64.9
		High Volatility of CPI Inflation							
$V(\pi^{cpi})$	1	49.4	65.7	67.2	70.9	48.6	66.9	69.1	71.2
	10	50.4	67.4	67.5	70.4	50.5	67.7	68.2	70.0
		Low Volatility of CPI Inflation							
	1	51.1	58.9	62.2	74.2	49.5	57.0	61.6	76.0
	10	50.8	57.8	59.7	73.6	49.9	56.7	58.7	74.3
		"High" CPI inflation							
$D\pi$	1	50.0	61.5	65.3	70.7	50.0	61.6	65.2	70.9
	10	49.7	61.0	62.8	65.7	50.3	61.8	63.2	66.3
		"Low" CPI inflation							
	1	51.5	62.0	65.4	70.3	50.2	61.5	65.6	69.5
	10	50.5	61.4	63.0	65.5	50.5	61.5	63.0	65.5
		Depreciation / appreciation of the peso increases							
$\Delta(\Delta e)$	1	49.4	62.5	64.7	71.8	49.9	62.6	66.0	73.7
	10	51.1	62.8	63.1	69.7	50.8	62.1	63.2	69.3
		Depreciation / appreciation of the peso decreases							
	1	50.2	61.6	63.6	71.8	51.1	62.4	65.2	72.4
	10	51.0	62.6	63.3	67.7	50.8	62.9	63.4	68.2
		High volatility of the exchange rate							
$V(\Delta e)$	1	50.5	59.6	61.9	64.4	51.2	61.0	63.3	63.5
	10	50.4	61.8	59.8	61.2	50.3	61.4	60.0	61.6
		Low volatility of the exchange rate							
	1	47.6	60.1	64.0	66.1	50.2	60.5	63.0	63.9
	10	48.8	59.2	61.3	64.3	49.3	60.0	62.0	64.8
		Undervalued real exchange rate							
Mq	1	48.2	63.7	64.5	71.9	48.2	63.9	64.4	71.7
	10	48.6	65.2	65.1	72.7	48.6	65.2	65.5	72.4
		Overvalued real exchange rate							
	1	48.0	61.6	62.5	64.0	49.3	62.3	62.5	63.8
	10	48.5	61.2	59.9	60.0	48.7	61.6	60.3	61.3

Source: Authors' calculations.

Table 3.2 Median estimates of the PT on prices of imported goods

(Percentage points)

Transition Variable	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							
	1	49.4	58.5	55.0	47.0	52.6	59.8	56.2	47.2
Gy	10	50.8	58.5	54.7	43.0	51.6	61.1	56.3	52.2
		Negative							
	1	49.1	57.5	54.5	44.7	49.8	56.8	55.3	44.6
	10	50.4	58.7	55.4	43.3	50.0	58.6	55.2	43.7
		High economic openness							
	1	49.8	65.3	65.7	63.8	50.6	65.7	65.2	63.5
Openness	10	51.4	64.7	62.9	62.1	51.1	64.7	62.7	62.6
		Low economic openness							
	1	50.4	65.1	67.0	75.3	49.9	64.8	66.2	74.4
	10	50.6	65.4	66.6	75.6	50.3	65.1	66.3	75.3
		High							
	1	49.3	61.7	63.0	68.8	50.2	62.9	63.2	69.9
Δ(Pcomm)	10	50.5	62.2	60.8	66.2	50.4	62.4	61.2	66.9
		Low							
	1	51.3	63.4	63.6	70.5	49.0	63.0	63.4	69.9
	10	50.5	62.4	60.8	66.8	50.1	62.0	61.1	66.7
		"High"							
	1	49.0	59.8	63.3	55.7	50.0	59.2	63.0	56.3
IBR	10	49.4	61.0	63.9	53.8	49.7	60.7	63.5	54.0
		"Low"							
	1	50.4	60.0	59.6	66.4	49.6	59.8	58.9	65.8
	10	50.1	58.9	57.2	65.0	49.8	59.0	57.3	63.8
		From April 2009							
	1	50.2	64.3	65.4	65.0	51.1	65.4	66.0	65.3
Trend	10	51.1	64.7	64.0	63.8	51.3	64.8	63.9	64.0
		Before April 2009							
	1	51.1	66.1	66.9	73.6	52.8	66.5	66.8	73.5
	10	51.3	65.4	65.9	72.0	52.1	65.8	66.0	72.3

Source: Authors' calculations.

Table 4.1 Median estimates of the PT on prices of producer goods

(Percentage points)

Transition Variable	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 increases							
	1	22.5	31.2	33.1	43.3	22.1	31.7	33.1	43.1
$\Delta(\pi^{cpi})$	10	14.7	22.6	22.1	32.2	15.3	22.8	22.2	31.4
		CPI inflation decreases							
	1	20.3	30.4	32.5	43.1	21.4	31.5	33.0	42.5
	10	14.7	22.5	21.8	32.8	15.6	23.2	22.4	32.3
		High Volatility of CPI Inflation							
	1	20.8	29.2	30.9	58.6	17.8	28.1	29.7	56.0
$V(\pi^{cpi})$	10	15.5	22.2	21.3	45.3	14.6	22.2	22.1	43.7
		Low Volatility of CPI Inflation							
	1	21.6	32.0	36.0	57.4	21.4	32.1	36.0	55.7
	10	16.2	24.3	26.2	50.2	16.0	24.1	26.1	50.5
		"High" CPI inflation							
	1	21.1	29.8	33.2	48.3	19.1	29.1	32.9	48.6
$D\pi$	10	14.2	21.8	22.5	36.9	14.5	22.6	23.8	36.8
		"Low" CPI inflation							
	1	20.6	29.9	34.3	47.5	18.8	29.1	31.8	45.0
	10	14.7	22.2	23.2	33.9	14.7	22.2	23.3	34.6
		Depreciation / appreciation of the peso increases							
	1	21.4	30.4	33.3	46.2	22.5	31.6	35.0	47.0
$\Delta(\Delta e)$	10	15.6	22.8	22.9	34.0	16.4	23.3	23.4	34.1
		Depreciation / appreciation of the peso decreases							
	1	22.8	32.6	33.7	43.7	23.2	32.1	33.3	44.9
	10	15.5	23.1	23.0	33.0	15.4	22.7	22.7	32.7
		High volatility of the exchange rate							
	1	23.0	32.7	35.1	62.6	20.4	28.3	27.1	44.8
$V(\Delta e)$	10	17.7	24.2	23.5	40.0	16.4	21.9	21.8	35.3
		Low volatility of the exchange rate							
	1	22.8	38.0	45.6	58.4	21.1	35.2	42.5	56.7
	10	16.9	29.2	33.4	47.3	16.6	29.1	35.8	47.9
		Undervalued real exchange rate							
	1	22.1	29.6	27.5	30.2	20.9	29.4	28.3	29.4
Mq	10	15.5	21.4	19.6	23.7	15.2	21.7	20.0	23.4
		Overvalued real exchange rate							
	1	21.5	29.9	32.2	40.9	22.8	32.7	34.8	42.4
	10	15.8	23.0	23.0	29.9	16.6	23.7	23.3	30.5

Source: Authors' calculations.

Table 4.2 Median estimates of the PT on prices of producer goods

(Percentage points)

Transition Variable	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	27.0	32.9	29.0	42.8	25.1	30.9	30.1	42.5
	10	16.4	22.2	20.8	32.5	17.3	23.7	22.6	41.8
		Negative							
	1	21.5	27.7	29.7	33.0	20.9	29.8	27.9	30.3
	10	14.9	22.3	20.4	22.7	15.8	23.1	21.3	25.9
		High economic openness							
Openness	1	23.3	31.7	32.2	30.1	21.2	31.2	29.8	28.4
	10	15.2	22.3	20.9	22.4	16.6	23.7	20.9	22.2
		Low economic openness							
	1	24.8	31.4	34.8	43.2	23.7	30.2	33.2	44.2
	10	17.1	22.8	25.5	35.0	16.8	22.4	25.3	34.8
		High							
Δ(Pcomm)	1	25.0	33.2	32.1	44.2	24.4	32.5	31.0	43.2
	10	16.9	23.3	21.6	33.6	17.0	23.5	21.8	33.7
		Low							
	1	24.2	32.5	31.4	43.6	24.9	32.3	31.5	44.6
	10	16.9	23.5	21.8	33.1	16.9	23.4	21.9	34.1
		"High"							
IBR	1	18.8	27.5	26.6	34.9	16.8	25.5	26.1	32.7
	10	14.0	21.8	22.4	33.0	13.6	21.7	21.7	31.8
		"Low"							
	1	21.7	30.0	32.5	65.0	20.6	28.6	31.6	62.7
	10	16.4	21.9	23.7	57.8	16.6	22.0	23.6	56.0
		From April 2009							
Trend	1	17.5	28.4	28.0	27.1	23.1	34.0	35.4	27.6
	10	15.3	22.8	21.5	20.0	16.1	24.2	23.3	21.0
		Before April 2009							
	1	23.9	30.0	33.4	41.5	24.3	29.9	33.4	42.7
	10	17.4	22.5	24.6	32.7	17.2	22.3	24.4	32.6

Source: Authors' calculations.

Second, the estimates reported in the tables show overwhelming evidence and statistical support of the endogeneity of the PT coefficient to state of the economy, which causes it to be quantitatively different across states and change over time.

Third, the evidence indicates the nonlinear nature of the degree of PT. For example, if the volatility of the exchange rate is low, 9% of the 1% depreciation of the peso is transmitted to the CPI in one month and 20% in one year (fifth part of Table 6.1). Meanwhile, if the volatility of the exchange rate is high the transmission goes from 7% to 18% in the same period. Another example for the CPI is that if the interbank interest rate is high, the PT reaches 13% after one year of the 1% shock (fourth part of Table 6.2). On the contrary, if the interbank interest rate is low, the PT reaches 19%. Finally, it is worthy to mention that the size of the PT on the CPI estimated in this paper is higher than those findings by the Colombian literature reported in the introduction (among them, those results from our own research), which may be explained by the size and nature (highly persistent) of the latest exchange rate shock.

Certainly, the nonlinear nature of the PT appears more evident when we increase the size of the exchange rate shock. The results show that the larger the shock the smaller the PT, except for import prices that depends on the state (transition) variable. This is a puzzling result for which we have no answer in this paper but could be solved using micro data. However, notice that our findings do not mean that the impact of a larger exchange rate shock on prices is smaller. For example, let us take the import prices when the transition variable is the change of the CPI inflation and it increases (first part of Table 3.1). A 1% exchange rate shock has an accumulated impact on producer prices of 65 basis points (bp) (1%*65%=65 bp) in the first year. On the other hand, a 10% exchange rate shock has an accumulated impact on the same prices of 620 basis points (10%*62%=620 bp) in the same period.

Table 5.1 Median estimates of the PT on prices of imported consumer goods

(Percentage points)

Transition Variable	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 increases							
$\Delta(\pi^{cpi})$	1	11.3	22.5	30.3	55.2	10.8	21.9	29.9	53.7
	10	4.4	14.0	22.0	44.6	4.4	13.9	21.7	44.5
		CPI inflation decreases							
	1	10.9	22.5	30.6	55.4	10.2	21.2	28.5	53.3
	10	4.7	14.1	22.1	47.1	4.5	13.9	21.5	46.5
		High Volatility of CPI Inflation							
$V(\pi^{cpi})$	1	11.1	21.2	30.9	58.2	11.0	21.0	31.3	59.8
	10	4.5	13.6	22.9	51.4	4.5	13.5	23.0	51.0
		Low Volatility of CPI Inflation							
	1	10.0	22.4	33.7	66.1	9.6	22.0	33.2	66.4
	10	4.2	16.0	26.7	63.6	4.1	16.0	26.9	62.3
		"High" CPI inflation							
$D\pi$	1	12.2	23.6	32.8	60.7	10.7	22.4	32.0	61.1
	10	4.8	14.4	23.3	50.9	4.9	14.4	23.1	51.6
		"Low" CPI inflation							
	1	10.2	21.8	31.3	57.6	11.4	22.5	31.9	59.4
	10	4.2	14.1	22.5	49.6	4.8	14.3	23.2	49.7
		Depreciation / appreciation of the peso increases							
$\Delta(\Delta e)$	1	11.6	22.5	32.4	58.2	11.4	23.5	33.0	59.0
	10	4.5	14.6	23.7	48.5	4.7	14.8	24.2	49.4
		Depreciation / appreciation of the peso decreases							
	1	11.3	22.2	32.0	55.5	12.1	22.6	32.6	56.7
	10	4.6	14.8	24.1	46.1	4.5	14.4	23.8	46.6
		High volatility of the exchange rate							
$V(\Delta e)$	1	8.4	17.8	25.0	36.5	8.4	21.9	29.0	41.7
	10	3.9	13.7	20.9	32.5	3.5	13.4	20.9	31.3
		Low volatility of the exchange rate							
	1	10.2	20.6	27.8	53.0	8.7	20.2	27.5	52.9
	10	4.3	14.1	22.3	46.2	4.3	14.3	21.5	44.0
		Undervalued real exchange rate							
Mq	1	10.3	20.5	28.2	48.0	11.5	20.5	27.3	48.2
	10	4.4	12.9	19.1	37.4	4.5	12.9	19.1	37.3
		Overvalued real exchange rate							
	1	11.4	21.2	30.4	49.1	10.2	20.7	29.9	48.2
	10	4.4	13.4	21.8	38.1	4.2	13.6	22.1	38.3

Source: Authors' calculations.

Table 5.2 Median estimates of the PT on prices of imported consumer goods

(Percentage points)

		Positive shock to the exchange rate change				Negative shock to the exchange rate change			
Transition Variable	**Shock %Points**	**1 month**	**6 months**	**1 year**	**4 years**	**1 month**	**6 months**	**1 year**	**4 years**
					Positive				
	1	10.9	19.9	28.3	57.4	12.3	20.3	26.8	53.1
Gy	10	4.8	10.3	16.0	48.5	4.3	15.1	23.6	55.0
					Negative				
	1	11.2	17.4	21.0	47.9	11.5	17.3	21.4	45.4
	10	4.5	9.7	13.9	41.9	4.2	10.1	14.1	41.9
					High economic openness				
	1	7.8	14.6	21.4	41.8	9.5	16.3	22.3	43.7
Openness	10	3.6	10.0	15.6	34.2	3.5	10.2	16.1	36.5
					Low economic openness				
	1	9.0	24.6	35.3	52.7	8.5	24.5	34.7	51.1
	10	3.6	18.5	28.4	45.4	3.7	18.4	28.2	44.4
					High				
	1	9.3	21.5	31.9	60.0	10.8	22.3	32.9	60.7
Δ(Pcomm)	10	4.2	15.7	26.3	55.2	4.3	15.6	26.0	54.6
					Low				
	1	10.8	22.3	31.8	60.9	10.8	22.5	32.2	60.1
	10	4.5	15.5	26.0	55.0	4.5	15.7	26.4	55.5
					"High"				
	1	14.3	17.5	20.3	30.5	11.9	14.7	18.9	31.7
IBR	10	5.4	8.6	11.2	27.2	5.2	8.4	11.0	27.0
					"Low"				
	1	11.0	27.1	42.2	68.4	10.1	25.4	41.6	67.6
	10	4.4	20.7	37.3	67.1	4.3	20.8	37.6	66.2
					From April 2009				
	1	8.8	14.0	18.9	32.1	8.4	14.5	18.9	33.0
Trend	10	3.3	9.3	13.8	24.6	3.3	9.2	13.5	23.7
					Before April 2009				
	1	9.1	22.5	31.8	44.0	8.6	22.1	31.4	43.1
	10	3.9	16.3	24.9	35.6	3.6	16.6	25.2	36.0

Source: Authors' calculations.

Table 6.1 Median estimates of the PT on prices of total consumer goods

(Percentage points)

Transition Variable	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 increases							
$\Delta(\pi^{cpi})$	1	7.8	12.9	15.9	27.6	8.2	12.7	15.7	28.0
	10	2.9	6.0	7.4	17.2	2.8	6.2	7.3	16.8
		CPI inflation decreases							
	1	8.2	12.6	15.3	28.7	7.7	12.1	15.1	27.2
	10	2.7	6.0	7.3	18.0	2.7	6.0	7.3	17.9
		High Volatility of CPI Inflation							
$V(\pi^{cpi})$	1	8.4	12.1	15.0	38.0	8.0	11.7	14.8	39.1
	10	3.0	6.1	7.8	25.4	3.0	6.2	7.9	24.1
		Low Volatility of CPI Inflation							
	1	6.4	12.0	17.0	39.9	7.0	12.9	18.2	42.8
	10	2.7	6.4	9.8	33.0	2.6	6.4	9.8	32.2
		"High" CPI inflation							
$D\pi$	1	8.6	12.7	16.1	32.3	7.8	12.9	16.0	32.5
	10	2.8	5.9	7.6	20.2	2.9	6.1	7.5	20.1
		"Low" CPI inflation							
	1	7.9	12.4	15.1	30.1	8.5	13.4	16.2	32.3
	10	2.7	6.1	7.8	18.4	2.9	6.1	7.9	19.6
		Depreciation / appreciation of the peso increases							
$\Delta(\Delta e)$	1	8.2	13.5	16.7	31.8	8.2	13.3	16.6	33.0
	10	2.8	6.2	7.9	18.5	2.8	6.2	7.9	18.6
		Depreciation / appreciation of the peso decreases							
	1	8.2	12.8	15.8	29.1	8.7	13.7	16.7	30.8
	10	2.8	6.2	8.1	17.5	2.8	6.5	8.3	18.7
		High volatility of the exchange rate							
$V(\Delta e)$	1	6.7	12.7	18.4	36.1	9.5	13.4	15.3	23.4
	10	3.3	6.6	7.7	18.7	2.9	6.4	7.9	17.0
		Low volatility of the exchange rate							
	1	8.6	14.8	19.7	36.5	7.8	14.0	18.1	36.7
	10	3.4	7.6	10.2	22.7	2.9	7.1	9.3	22.8
		Undervalued real exchange rate							
Mq	1	7.5	11.2	13.3	27.4	7.7	11.8	13.6	27.7
	10	2.8	5.2	6.1	17.9	2.9	5.3	6.1	17.6
		Overvalued real exchange rate							
	1	7.2	11.9	15.1	29.9	7.8	12.3	16.2	30.8
	10	2.5	5.8	7.8	17.4	2.7	6.1	8.1	18.5

Source: Authors' calculations.

Table 6.2 Median estimates of the PT on prices of total consumer goods

(Percentage points)

Transition Variable	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				
	1	8.4	17.2	20.2	32.4	7.4	14.4	17.7	29.2
Gy	10	2.9	8.1	10.4	22.6	2.6	9.8	12.7	26.8
					Negative				
	1	10.7	15.4	16.7	28.7	10.0	14.0	15.2	24.9
	10	2.9	7.2	8.2	19.7	2.8	7.3	8.6	21.3
					High economic openness				
	1	7.8	11.3	12.5	27.6	8.1	11.0	13.5	24.8
Openness	10	3.0	5.4	6.0	17.0	3.3	5.4	6.3	14.9
					Low economic openness				
	1	7.2	15.1	21.1	33.8	7.3	15.3	21.3	33.7
	10	2.8	8.8	13.0	23.9	2.8	8.8	12.8	24.0
					High				
	1	7.2	12.1	15.0	30.0	7.8	12.2	15.1	29.7
Δ(Pcomm)	10	2.4	6.3	8.5	20.3	2.5	6.3	8.5	20.3
					Low				
	1	6.9	11.8	14.3	30.0	6.8	11.6	14.7	30.2
	10	2.4	6.2	8.5	20.1	2.4	6.3	8.5	20.5
					"High"				
	1	10.4	11.8	12.5	22.6	9.5	11.0	11.3	20.1
IBR	10	3.3	5.0	4.8	20.9	2.8	4.6	4.9	19.5
					"Low"				
	1	6.9	14.4	18.9	33.4	6.3	13.6	18.6	33.1
	10	2.5	8.5	12.1	26.2	2.4	8.4	12.4	26.5
					From April 2009				
	1	7.9	11.8	14.3	21.2	7.9	11.2	14.9	23.2
Trend	10	2.4	4.7	5.8	12.9	2.9	4.9	6.1	11.7
					Before April 2009				
	1	6.9	14.9	20.8	34.7	7.4	14.8	20.9	35.1
	10	2.8	8.8	12.7	23.5	2.7	8.8	12.5	23.3

Source: Authors' calculations.

Therefore, our findings for import prices partially confirm, for instance, those of Floden and Wilander (2006) who state that a greater depreciation of the local currency increases opportunity cost of keeping prices fixed so that the transmission on import prices will be larger.[23] On the other hand, our results for the CPI certainly differ from Caselli and Roitman's (2016), since they found that the greater the exchange rate shock the larger the PT.[24] They use local projection techniques to estimate the exchange rate transmission on CPI for a sample of 28 Emerging Markets, Colombia among them. Caselli and Roitman show that for depreciations greater than 10 and 20 percent the pass-through on the CPI is equal to 18 and 25 percent respectively, after one month (and 6% in the linear case). Moreover, they find that for depreciations greater than 20% and that lasts for more than 3 months, the pass-through on CPI touches 32% after 3 months.

Fourth, the PT generally responds differently to the sign of the exchange rate shock; that is, the PT is asymmetric. However, notice that the degree of asymmetry is quite low though, if one compares the sizes of the PT estimates. The reader can review also the findings on asymmetry of the PT in Floden and Wilander (2006) for artificial data, Bussiere (2013) for the G-7 economies and Caselli and Roitman (2016) for a sample of Emerging Markets.[25] To illustrate our results, take import prices when the deviation from the central bank's CPI inflation target is high and select both shocks: 1% and 10% (third part of Table 3.1). The results show that the accumulated PT on import prices is larger in response to appreciations than to depreciations, which coincides with the findings by Floden and Wilander (Ibid). On the other hand, the results for the CPI, when the transition variables are CPI inflation

[23] Since Colombia cannot be characterized as a dollarized economy, the findings of Carranza et al. (2009) do not seem to apply to our results. These authors conclude that depreciations have a negative impact on the degree of PT when economies are dollarized, "because higher internal demand and imported inflation—can be offset or diminished by both the larger financial costs and the balance-sheet effect."

[24] Notice, however, that our definition of PT is very different than Floden and Wilander's and Caselli and Roitman' since they neither 'correct' the PT by the endogenous response of the exchange rate to its own shock (review our equation (10)) nor calculate the accumulated PT.

[25] According to Bussiere, when "the exchange rate depreciates, exporters increase their export prices more than they decrease them when there is an appreciation. This also means that depreciations have a larger effect than appreciations on import prices."

volatility, volatility of the exchange rate and output gap (Table 6.1) are noticeable.

Four 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, the degree of economic openness and the variable *Trend*.

With regard to the first variable, the degree of the accumulated PT is almost unanimously higher for all prices and for the short and long terms 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 disagree with the prediction -except for import prices-, i.e., that the degree of PT should be higher when the real exchange rate is undervalued. Indeed, a positive structural shock to the nominal exchange rate should pass through to inflation rapidly so that prices 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? Is it an issue of competitiveness? We do not have an answer for this riddle. The last result is that the PT is consistently lower when the variable *trend* is located after April 2009. Is it related to a structural change on the relationship between prices and exchange rates produced by the 2007-2009 international financial crises? Or is this behavior related with the strengthening of the inflation targeting regime, put in place in Colombia since 2000s, as shown by Mishkin and Klaus Schmidt-Hebbel (2007) for a sample of developed and

Emerging Markets, by Bouakez and Rebei (2008) for Canada, and by Coulibaly and Kempf (2010) and Caselli and Roitman (2016) for samples of Emerging Markets?

In summary, tables 3.1 to 6.2 show that the PT is incomplete, endogenous, nonlinear and asymmetric. In general, the PT is larger when the CPI inflation increases (mainly in the short term), is high and its volatility is low; the depreciation increases and the volatility of the exchange rate is low; the output gap is positive; and the interbank interest rate is low (Table 7).

Table 7. When has PT been higher?

(1% positive exchange rate shock)

Transition variable	Regimen	Prices							
		Import		Producer		Imported consumer		Total consumer	
		1 year	4 years	1 year	4 years	1 year	4 years	1 year	4 years
$\Delta(\pi^{cpi})$	*Increases*	√		√	√			√	
	Decreases		√			√	√		√
$V(\pi^{cpi})$	*High*	√			√				
	Low		√	√		√	√	√	√
$D\pi$	*High inflation*		√		√	√	√	√	√
	Low inflation	√		√					
$\Delta(\Delta e)$	*Increases*	√	---		√	√	√	√	√
	Decreases		---	√					
$V(\Delta e)$	*High*				√				
	Low	√	√	√		√	√	√	√
Mq	*Undervalued*	√	√						
	Overvalued			√	√	√	√	√	√
Gy	*Positive*	√			√	√	√	√	√
	Negative		√	√					
Openness	*High*								
	Low	√	√	√	√	√	√	√	√
Δ(Pcomm)	*High*					√		√	---
	Low	√	√	√	√		√		---
IBR	*High*	√							
	Low		√	√	√	√	√	√	√
Trend	*From April 2009*								
	Before April 2009	√	√	√	√	√	√	√	√

Source: Tables 3.1-6.2. The symbol "---" means that the PT estimates are equal.

A digression: Estimation of the "Pass-through"

This subsection reports the estimates of the "pass-through" according to the methodology proposed in Shambaugh (2008). That is, "rather than focusing on the correlation of exchange rate and prices, I will identify fundamental shocks to the economy and test their effects on exchange rates, consumer prices, and import prices" (Ibid, page 561). Specifically, instead of assuming an exogenous exchange rate shock, as the literature on "notional" pass-through does, we let the exchange rate to be endogenous to structural shocks and then evaluate its corresponding "pass-through".

To illustrate this alternative measure of PT, we re-estimate our nonlinear model by Bayesian methods using our data but redefining equation (10). The "pass-through" is estimated for the CPI, conditional on the high regimes: *CPI inflation increases*, *depreciation/appreciation of the peso increases* and *positive output gap*, only. The shocks are assigned to domestic demand (ε^{D}) -measured by the output gap-, domestic supply (ε^{S}) – measured by the non-core inflation, and foreign supply (ε^{mgc^*}) -captured by the marginal costs of foreign producers of domestic imports-.[26] As stated in the introduction, we do not impose any structural short nor long-term restrictions to our nonlinear system (the motivations were explained in footnote 2).

Thus, let us redefine equation (10) as,

$$(11) \qquad "PT_{\tau}" = \frac{\sum_{j=0}^{\tau} \frac{\partial \pi_{t+j}^{cpi}}{\partial \varepsilon_t^i}}{\sum_{j=0}^{\tau} \frac{\partial \Delta e_{t+j}}{\partial \varepsilon_t^i}}, \qquad i = \varepsilon^D, \varepsilon^S, \varepsilon^{mgc^*}.$$

Figure 3 shows the median accumulated "PT" estimates for the CPI over time, as well as its 68% most credible intervals, following positive foreign supply and domestic demand

[26] Conversely to the Shambaugh's supply shock -a productivity shock-, here a supply shock increases inflation.

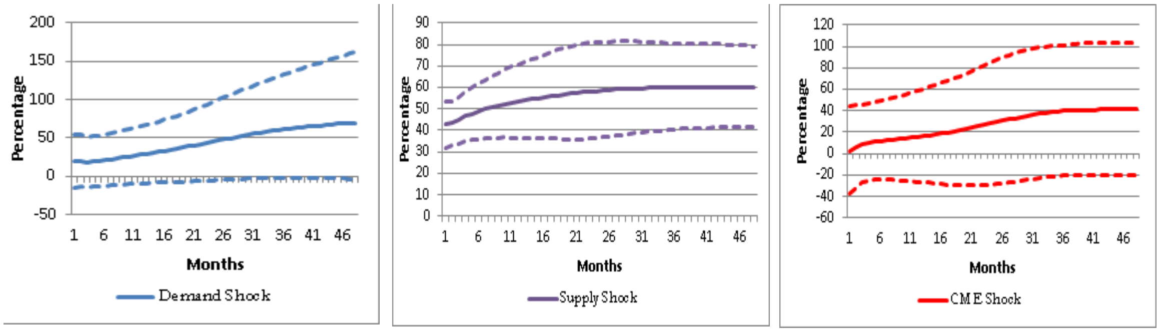
and supply shocks of 1%, under the regimes of the transition variables mentioned.[27] Results revile that the "PTs" are quite similar in size to those reported in Table 1 of Shambaugh (Ibid, page 575) but are not statistically significant, as the credible intervals show, except for the supply shock. Consequently, when the economy faces a supply shock and the exchange rate respond endogenously to it, the "PT" on CPI rises from 44% in the first month to approximately 60% at year four.

Notice that the "PT" estimates are close but not equal to those reported in tables 6.1 and 6.2, which would indicate that pass-through is not only nonlinear state-dependent but also nonlinear shock-dependent. It is worth noting, however, that additional work is required in order to show stronger evidence of this finding for the current data, which would be an advance over Shambaugh's (Ibid) findings and, even, over Forbes et al.' (Ibid).

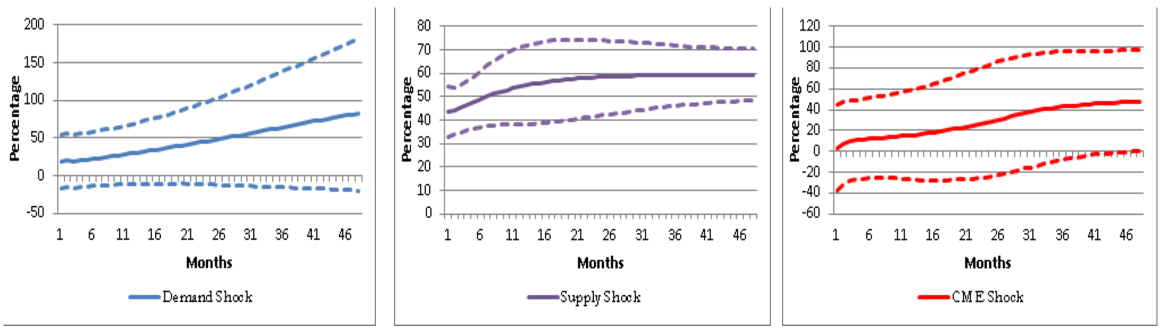
[27] Unfortunately, given the method we use to estimate the PT, which involves the calculation of the GIRFs (see Appendix A.4) , we could not normalize the size of the shocks in order to produce an identical exchange rate movement at time τ, as was done by Shambaugh (Ibid) for the linear case. This difficulty may also help to explain the larger amplitude of the credible intervals.

Figure 3: Path of "Pass-through" on CPI

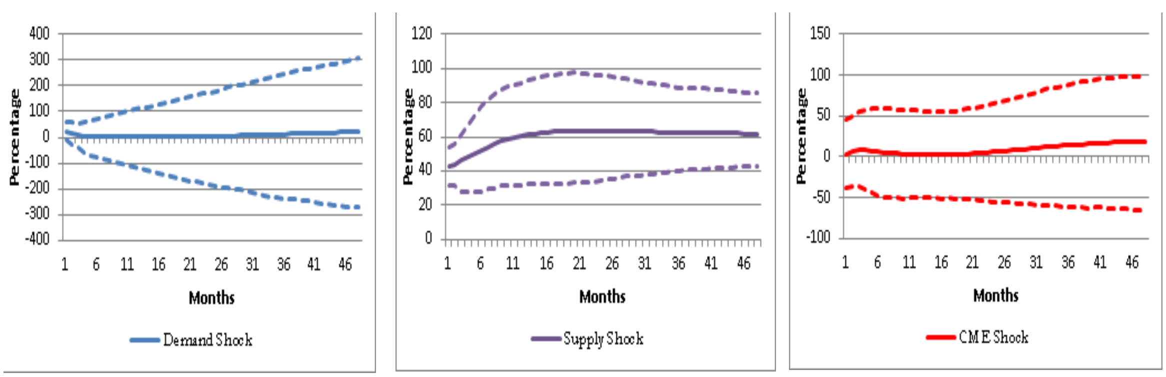
Transition variable: *CPI inflation increases*



Transition variable: *Depreciation/Appreciation of the peso increases*



Transition variable: *Positive output gap*



Source: Authors' calculations.

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 (9) (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 prices at each period of time. Thus, HDs permit us to differentiate which of the structural 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. Accordingly, as we stated in the introduction, the HDs add further evidence to support our conclusions and complements the results reported in tables 3.1 to 6.2.

For multivariate models such as the one considered in this paper and under some structure for the identification of shocks (e.g., Cholesky decomposition), 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),[28] 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.

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

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 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 the price movements 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 prices, but for only five transition variables: variation of the CPI inflation ($\Delta\pi^{cpi}$), variation of the exchange rate change ($\Delta(\Delta e)$), volatility of the exchange rate ($V(\Delta e)$), variation of commodity prices ($\Delta Pcomm$) 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.[29]

[29] 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.

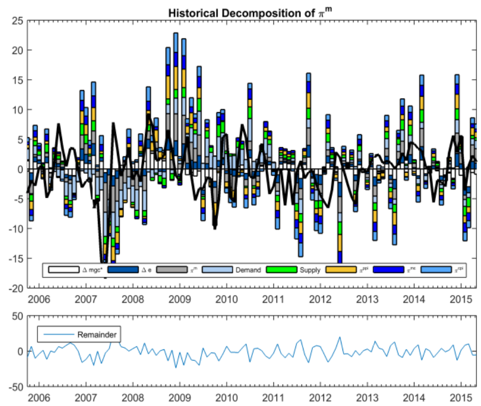
Figures 4 to 7 show the HDs for the inflation of the different prices along the distribution chain conditional on the transition variables mentioned. To illustrate our findings, we explain the results for the inflation of total consumer goods during the last part of the sample (year 2015). Of course, the same reconstruction of their history can be done for each of the prices at each period of time.

Thus, Figure 7 shows that when the transition variable is the variation of the CPI inflation (figure 7(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. Supply and demand shocks appear at the end of the sample as 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.

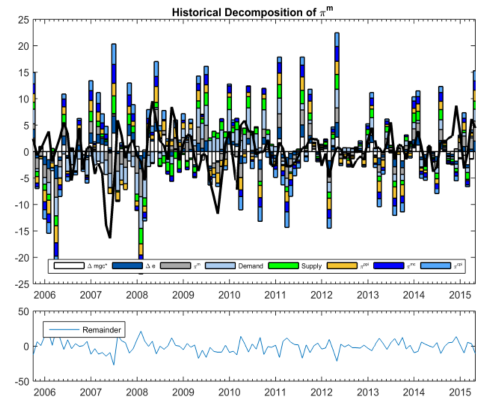
When the transition variable is the variation of the exchange rate change (figure 7(b)), or the growth of prices of commodities (figure 7(d)), the results seem to confirm the upward role played by most of the shocks and the downward role enacted by the external marginal cost shock. Nevertheless, observe that the size of the impact of each of the shocks on CPI inflation depends on the transition variable being in place. Finally, when the transition variable is the interbank interest rate –the operative instrument of the central bank (figure (e))-, supply and demand shocks put negative pressure on CPI inflation, even the exchange rate, while inertial component of CPI inflation put positive pressure.

Figure 4. HD for π^m

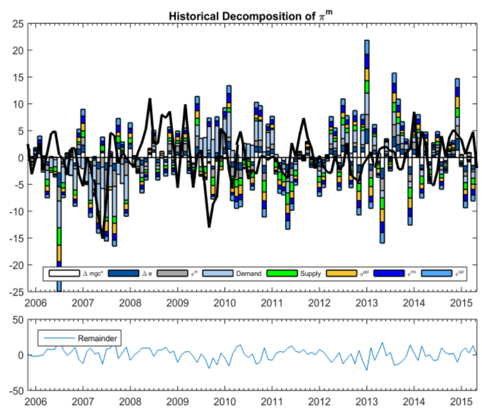
(a) Transition variable: $\Delta(\pi^{cpi})$



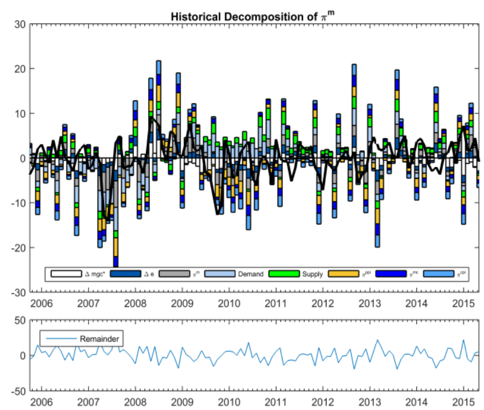
(b) Transition variable: $\Delta(\Delta e)$



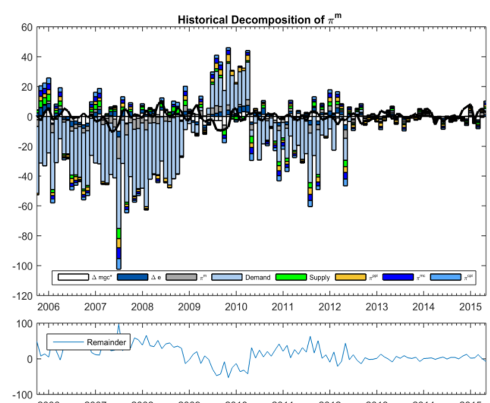
(c) Transition variable: $V(\Delta e)$



(d) Transition variable: $\Delta\, Pcomm$



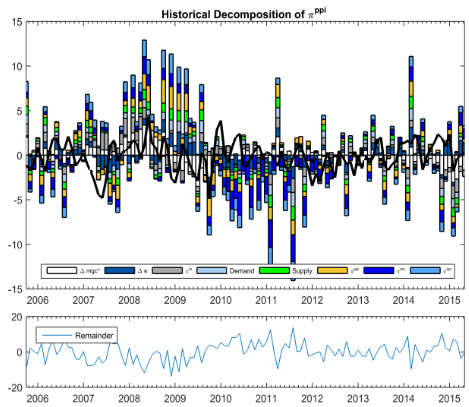
(e) Transition variable: IBR



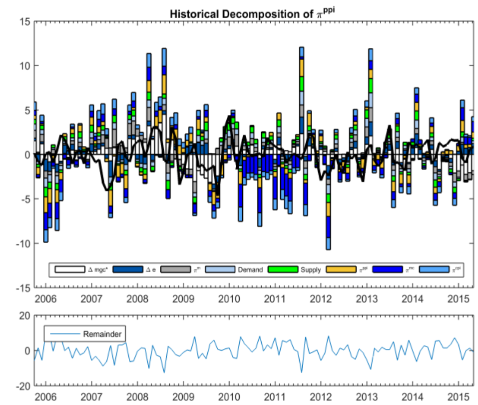
Source: Authors' calculations.

Figure 5. HD for π^{ppi}

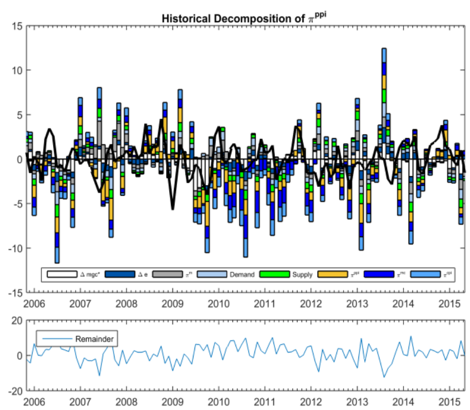
(a) Transition variable: $\Delta(\pi^{cpi})$



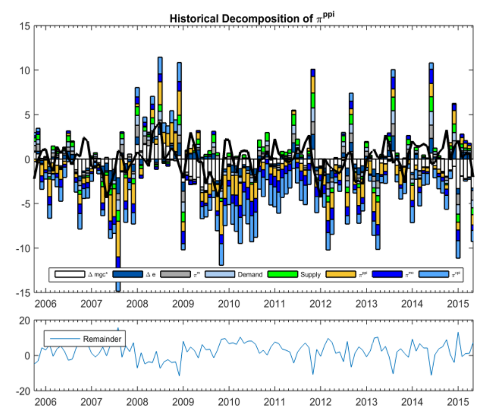
(b) Transition variable: $\boldsymbol{\Delta(\Delta e)}$



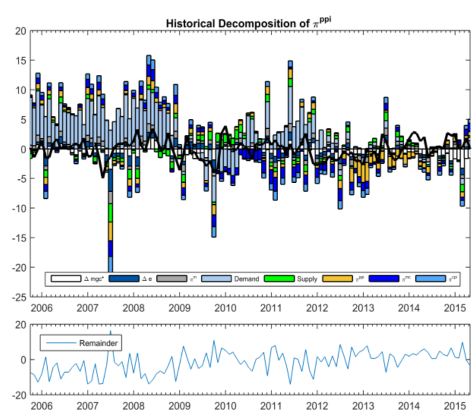
(c) Transition variable: $V(\Delta e)$



(d) Transition variable: $\Delta Pcomm$



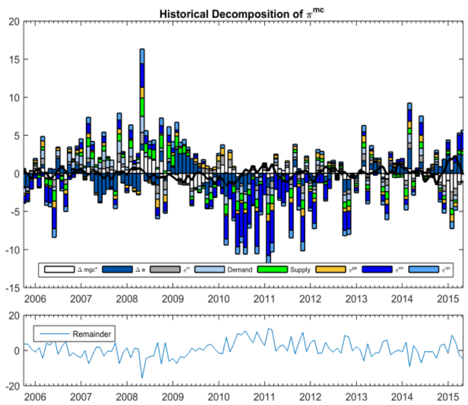
(e) Transition variable: *IBR*



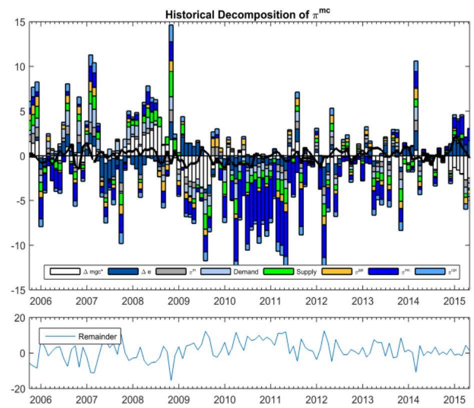
Source: Authors' calculations.

Figure 6. HD for π^{mc}

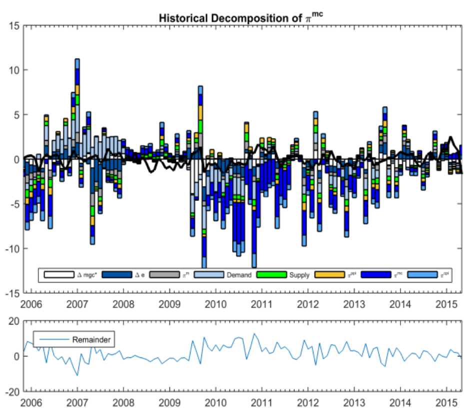
(a) Transition variable: $\Delta(\pi^{cpi})$



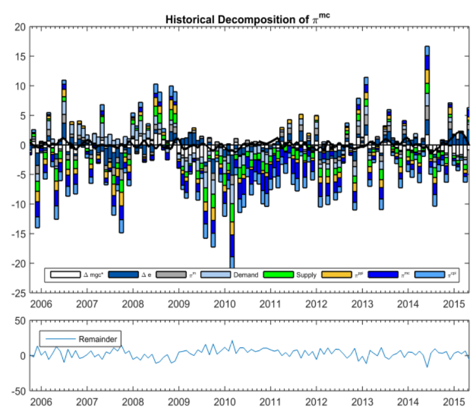
(b) Transition variable: $\boldsymbol{\Delta(\Delta e)}$



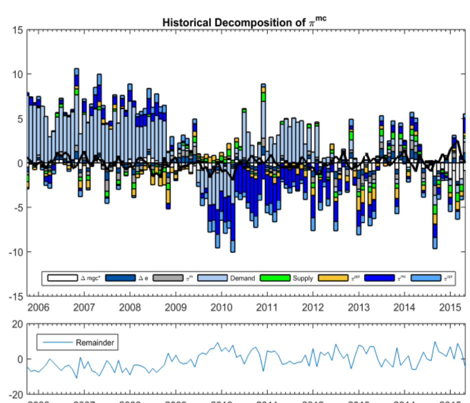
(c) Transition variable: $V(\Delta e)$



(d) Transition variable: *ΔPcomm*



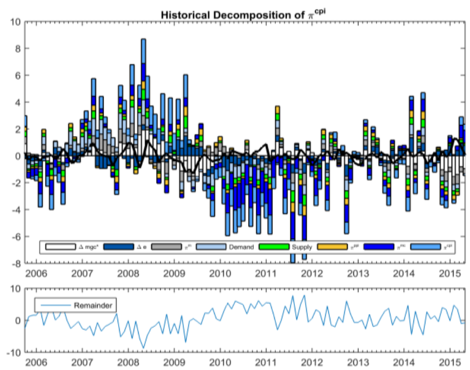
(e) Transition variable: *IBR*



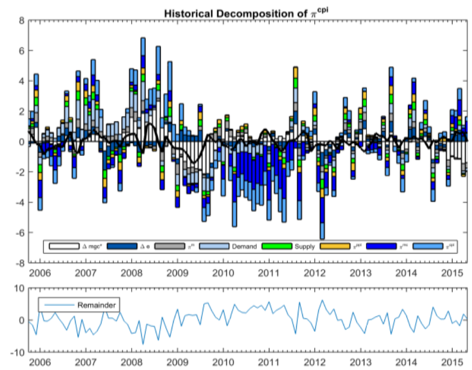
Source: Authors' calculations.

Figure 7. HDs for $\boldsymbol{\pi^{cpi}}$

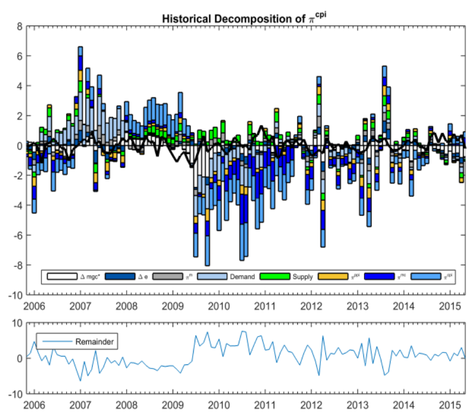
(a) Transition variable: $\Delta(\pi^{cpi})$



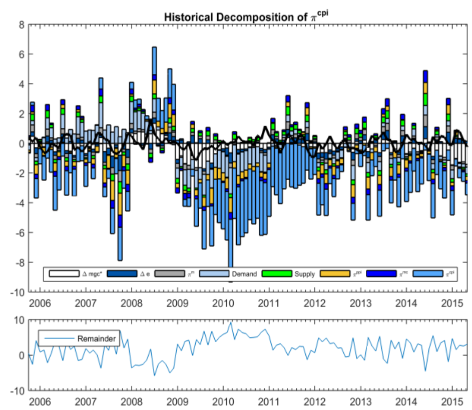
(b) Transition variable: $\boldsymbol{\Delta(\Delta e)}$



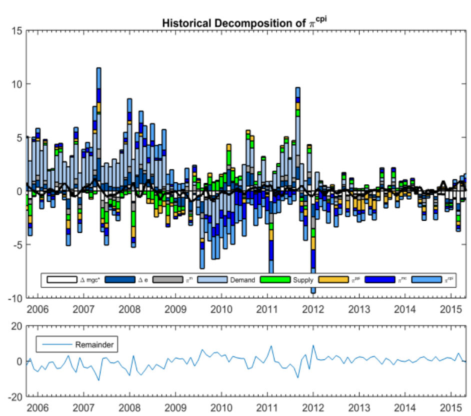
(c) Transition variable: $V(\Delta e)$



(d) Transition variable: $\Delta Pcomm$



(e) 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) for 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 analyze the nature of the pass-through of exchange rate shocks on prices along the distribution chain and quantify historically their short and long-term impacts. 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 on monthly data from a small open economy.

Firstly, the findings showed that the exchange rate pass-through 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 accumulated PT on import prices of a 1% positive shock on the variation of the exchange rate ranges from 43% to 50% in the first month and from 53% to 66% in the first year. The equivalent figures on producer, imported consumer and total consumer prices range from 18% to 27%, 8% to 14%, 6% to 11% in the first month, respectively, and from 27% to 46%, 19% to 42%, and 13% to 21% in the first year. Then, the maximum accumulated PT corresponds to 75%, 65%, 68% and 40%, respectively. When the shock is 10%, the results are puzzling since we found that the larger the shock the smaller the PT, except for import prices. For instance, the respective accumulated PT estimates on the CPI range from 2% to 3%, 5% to 13% and 13% to 33% for the same periods. Finally, it is worth noting that uncertainty about pass-through estimates increases rapidly after two years of the shock.

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-dependent, which complements the recent findings of the literature. Thirdly, we found that PT is nonlinear and responds differently to the size of exchange rate shocks. Also, it responds quite asymmetrically to changes in the sign of the exchange rate shock.

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.

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 be a specific rule on PT on inflation for policy making, even in the short term. 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 very good data and computational capacities. An additional extension is to further 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 in the digression of section 5. With this new research one can show that PT is not only nonlinear state-dependent, but also nonlinear shock-dependent.

REFERENCES

Adolfson, M. (2001). Monetary policy with incomplete exchange rate pass-through. *Sveriges Riksbank Working Paper Series*, No. 127.

……………… (2007). Incomplete exchange rate pass-through and simple monetary policy rules. *Journal of International Money and Finance*, *26*(3), 468-494.

Al-Abri, A. S., & Goodwin, B. K. (2009). Re-examining the exchange rate pass-through into import prices using non-linear estimation techniques: Threshold cointegration. *International Review of Economics and Finance, 18*(1), 142-161.

Aleem, A., & Lahiani, A. (2014). A threshold vector autoregression model of exchange rate pass-through in Mexico. *Research in International Business and Finance, 30*, 24-33.

An, L., & Wang, J. (2012). Exchange rate pass-through: Evidence based on vector autoregression with sign restrictions. *Open Economies Review*, *23*(2), 359-380.

Avdjiev, S., & Zeng, Z. (2014). Credit growth, monetary policy and economic activity in a three-regime TVAR model. *Applied Economics*, *46*(24), 2936-2951.

Bai, J., & Perron, P. (1998). Estimating and Testing Linear Models with Multiple Structural Change. *Econometrica*, *66*(1), 47-78.

---------------------- (2003). Computation and Analysis of Multiple Structural Change Models. *Journal of Applied Econometrics*, *18*(1), 1-22.

Balke, N. (2000). Credit and Economic Activity: Credit Regimes and Nonlinear Propagation of Shocks. *The Review of Economics and Statistics*, *82*(2), 344-349.

Ball, L. M. (1999). Policy rules for open economies. In Taylor, J. B. (ed.), *Monetary policy rules* (pp. 127-156). University of Chicago Press.

Ball, L., Mankiw, N. G., Romer, D., Akerlof, G. A., Rose, A., Yellen, J., & Sims, C. A. (1988). The new Keynesian economics and the output-inflation trade-off. *Brookings Papers on Economic Activity*, *1988*(1), 1-82.

Beckmann, J., Belke, A., & Verheyen, F. (2014). Exchange rate pass-through into German import prices–a disaggregated perspective. *Applied Economics*, *46*(34), 4164-4177.

Ben Cheikh, N. (2012). Asymmetric exchange rate pass-through in the Euro area: New evidence from smooth transition models. *Open-Assessment E-Journal*, *6*(2012-39), 1-28.

Berner, E. (2010). Exchange rate Pass-through: new evidence from German Micro Data. *International Economics*, *124*(4), 75-100.

Blanchard, O., & Quah, D. (1989). The dynamic effects of aggregate demand and supply disturbances. *American Economic Review*, *79*(4), 655-673.

Borensztein, E., & De Gregorio, J. (1999). Devaluation and inflation after currency crises. Mimeo, Research Department, IMF.

Bouakez, H., & Rebei, N. (2008). Has Exchange Rate Pass-Through Declined? Evidence from Canada. *Journal of International Economics*, *75*(2), 249–67.

Burstein, A., & Gopinath, G. (2013). International prices and exchange rates. *NBER Working Paper Series*, No. w18829.

Bussiere, M. (2013). Exchange rate pass-through to trade prices: The role of nonlinearities and asymmetries. Oxford Bulletin of Economics and Statistics, *75*(5), 731-758.

Campa J., & Goldberg, L. (2005). “Exchange rate pass-through into import prices,” *The Review of Economics and Statistics*, *87*(4), 679-690.

-------------------------------- (2006). Pass through of exchange rates to consumption prices: what has changed and why? *Staff Report*, No. 261, Federal Reserve Bank of New York.

Canova, F., & De Nicolo, Y. (2002). Monetary disturbances matter for business fluctuations in G-7. *Journal of Monetary Economics*, *49*, 1131-1159.

Capistrán, C., Ibarra-Ramírez, R., & Francia, M. R. (2011). Exchange Rate Pass-Through to Prices: Evidence from Mexico. *Working Papers*, No. 2011-12, Banco de Mexico.

Carranza, L., Galdon-Sanchez, J. E., & Gomez-Biscarri, J. (2009). Exchange rate and inflation dynamics in dollarized economies. *Journal of Development Economics*, *89*(1), 98-108.

Caselli, F., & Roitman, A. (2016). Non-Linear Exchange Rate Pass-Through in Emerging Markets. *IMF Working Paper*, WP/16/1.

Corsetti, G., & Dedola, L. (2005). Macroeconomics of International Price Discrimination. *Journal of International Economics*, *67*(1), 129–155.

Corsetti, G., Dedola, L., & Leduc, S. (2008a). High Exchange-Rate Volatility and Low Pass-Through. *Journal of Monetary Economics*, *55*(6), 1113-1128.

-- (2008b). International Risk Sharing and the Transmission of Productivity Shocks. *The Review of Economic Studies*, *75*(2), 443-473.

Coulibaly, D., & Kempf, H. (2010). Does Inflation Targeting decrease Exchange Rate Pass-through in Emerging Countries? Documents de travail du Centre d’Economie de la Sorbonne 2010.49.

De Bandt, O., Banerjee, A., & Kozluk, T. (2007). Measuring long run exchange rate pass-through. *Working Paper Series*, No.173, Banque de France.

Devereux, M., & Yetman, J. (2003). Price-setting and exchange rate pass through: Theory and evidence. *Price adjustment and monetary policy: Proceedings of a Conference held by the Bank of Canada*, pp. 347-371.

Devereux, M., Engel, Ch., & Storgaard, P. (2004). Endogenous exchange rate pass-through when nominal prices are set in advance. *Journal of International Economics*, *63*(2), 263-

291.

Donayre, L., & Panovska, I. (2016). State-Dependent Exchange Rate Pass-Through Behavior. *Journal of International Money and Finance*, *64*, 170–195.

Dornbusch, R. (1987). Exchange rates and prices. *American Economic Review*, *77*(1), 93-105.
Engel, Ch. (2000). Long-run PPP may not hold after all. *Journal of International Economics*, *51*(2), 243-273.

------------- (2002). Expenditure Switching and Exchange Rate Policy. NBER Macroeconomics Annual 2002, *17*, 231-272.

-------------- (2009). Pass-Through, Exchange Rates, and Monetary Policy. *Journal of Money, Credit and Banking*, Supplement to Vol. *41*(1).

Engel, Ch., & Rogers, J. (2001). Deviations from purchasing power parity: causes and welfare costs. *Journal of International Economics*, *55*(1), 29-57.

Erceg, Ch., Gust, Ch., & Guerrieri, Luca (2006). SIGMA: A new open economy model for policy analysis. *International Journal of Central Banking*, *2*(1), 1-50.

Ewing, B. (2001). Cross-Effects of Fundamental State Variables. *Journal of Macroeconomics*, *23*(4), 633-645.

Faust, J., & Rogers, J. (2003). Monetary policy's role in exchange rate behavior. *Journal of Monetary Economics*, *50*(7), 1403-1424.

Fernández-Villaverde, J., Guerrón-Quintana, P., & Rubio-Ramírez, J. F. (2014). The new macroeconometrics: A bayesian approach. In O'Hagan, A., & West, M. (Eds.). *The Oxford handbook of applied Bayesian analysis*, OUP Oxford.

Flamini, A. (2007). Inflation Targeting and Exchange Rate Pass-through. *Journal of International Money and Finance*, *26*(7), 1113-1150.

Flodén, M., & Wilander, F. (2006). State dependent pricing, invoicing currency, and exchange rate pass-through. *Journal of International Economics*, *70*(1), 178-196.

Forbes, K., Hjortsoe, I., & Nenova, T. (2015). The Shocks Matter: New Evidence on Exchange Rate Pass-Through, Discussion Paper No. 43, Bank of England.

Forbes, K. (2015). Much ado about something important: How do exchange rate movements affect inflation? Speech given at the 47th Money, Macro and Finance Research Group Annual Conference, Cardiff 11 September, Bank of England.

Frankel, J., Parsley, D., & Wei, S. J. (2012). Slow pass-through around the world: A new import for developing countries? *Open Economies Review*, *23*(2), 213-251.

Gali, J., & Monacelli, T. (2000). Optimal monetary policy in a small open economy. Mimeo, Universitat Pompeu Fabra.

Gaytan, A., & González, J. (2006). Structural changes in the transmission mechanism of monetary policy in México: a non-linear VAR approach. *Working Paper Series*, No 2006-06, Banco de México.

Gefang, D. (2012). Money-output Causality Revisited–A Bayesian Logistic Smooth Transition VECM Perspective. *Oxford Bulletin of Economics and Statistics*, *74*(1), 131-151.

Gefang, D., & Strachan, R. (2010). Nonlinear Impacts of International Business Cycles on the UK - A Bayesian Smooth Transition VAR Approach. *Studies in Nonlinear Dynamics and Econometrics*, *14*(1).

Goldfajn, I., & Werlang, S. (2000). The pass-through from depreciation to inflation: a panel study. *Texto Para Discussão*, No. 423, Pontificia Universidad Católica de Río de Janeiro.

González, A., Rincón, H., & Rodríguez, N. (2010). La transmisión de los choques a la tasa de cambio sobre la inflación de los bienes importados en presencia de asimetrías. In M. Jalil and L. Mahadeva (Eds.), *Mecanismos de transmisión de la política monetaria en Colombia*, Universidad Externado de Colombia y Banco de la República, Colombia.

Granger, C. W., & Teräsvirta, T. (1993). *Modeling nonlinear economic relationships*, Oxford University Press, New York.

He, C., Teräsvirta, T., & González, A. (2009). Testing parameter constancy in stationary vector autoregressive models against continuous change. *Econometric Reviews*, *28*(1-3), 225-245.

Ito, T., & Sato, K. (2008). Exchange Rate Changes and Inflation in Post-Crisis Asian Economies: Vector Autoregression Analysis of the Exchange Rate Pass-Through. *Journal of Money, Credit and Banking*, *40*(7), 1407-1438.

Kılıç, R. (2010). Exchange-rate pass-through to import prices: nonlinearities and exchange rate and inflationary regimes. *TÜSİAD-Koç University Economic Research Forum Working Paper Series*, No. 1033.

Klein, M. (1990). Macroeconomic aspects of exchange rate pass-through. *Journal of International Money and Finance*, *9*(4), 376-387.

Koop, Gary (2003). *Bayesian Econometrics*, John Wiley & Sons Ltd, England.

Koop, G., Pesaran, M. H., & Potter, S. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics*, *74*(1), 119-147.

Koop, G., & Potter, S. (1999). Bayes factors and nonlinearity: Evidence from economic time series. *Journal of Econometrics*, *88*(2), 251-81.

Krugman, P. (1986). Pricing to market when the exchange rate changes. *NBER Working Paper Series*, No. 1926.

Lo, Ming C., & Morley, J. (2015). Bayesian analysis of nonlinear exchange rate dynamics and the purchasing power parity persistence puzzle. *Journal of International Money and Finance*, *51*, 285-302.

Luukkonen, R., Saikkonen, P., & Teräsvirta, T. (1988). Testing linearity against smooth transition autoregressive models. *Biometrika*, *75*(3), 491-499.

Marazzi, M., Sheets, N., Vigfusson, R., Faust, J., Gagnon, J., Marquez, J., Martin, R., Reeve, T., & Rogers, J. (2005). Exchange rate pass-through to U.S. import prices: Some new evidence. *International Finance Discussion Papers*, No. 833, Board of Governors of the Federal Reserve System.

McCarthy, J. (2007). Pass-through of Exchange Rates and Import Prices to Domestic Inflation in Some Industrialized Economies. *Eastern Economic Journal*, *33*(4), 511-537

Mendoza, O. (2004). Las asimetrías del pass-through en Venezuela, *Serie Documentos de Trabajo*, No. 62, Banco Central de Venezuela.

Mendoza, O. (Ed.) (2012). *Efecto Transferencia (pass-through) del Tipo de Cambio sobre los Precios en Latinoamérica*, Banco Central de Venezuela.

Mihailov, A. (2009). Exchange rate pass-through to prices in macrodata: A comparative sensitivity analysis. *International Journal of Finance and Economics*, *14*(4), 346-377.

Miller, S. (2003). Estimación del Pass-Through del Tipo de Cambio a Precios: 1995-2002. *Revista de Estudios Económicos*, No. 10, Banco Central de Reserva del Perú.

Mishkin, F. (2008). Exchange Rate Pass-Through and Monetary Policy. *NBER Working Paper Series*, No. 13889.

Mishkin, F., & Schmidt-Hebbel, K. (2007). Does Inflation Targeting Make a Difference? *NBER Working Paper Series*, No. 12876.

Monacelli, T. (2003). Monetary policy in a low pass-through environment. *Working Paper Series*, No. 227, European Central Bank.

Nogueira Júnior, R. P., & León-Ledesma, M. (2008). Exchange rate pass-through into inflation: The role of asymmetries and non-linearities. *Department of Economics Discussion Paper*, No. 8, University of Kent.

Obstfeld, M. (2001). International Macroeconomics: Beyond the Mundell-Fleming Model. Center for International and Development Economics Research. UC Berkeley: Center for International and Development Economics Research. Retrieved from: http://escholarship.org/uc/item/6796n8s0

Obstfeld, M., & Rogoff, K. (1995). Exchange rate dynamics redux. *Journal of Political Economy*, *103*(3), 624-660.

Otani, A., Shiratsuka, S., & Shirota, T. (2006). Revisiting the decline in the exchange pass-through: further evidence from Japan's import prices. *Monetary and Economic Studies*, *24*(1), 61-75.

Ozkan, I., & Erden, L. (2015). Time-varying nature and macroeconomic determinants of exchange rate pass-through. *International Review of Economics and Finance*, *38*,56-66.

Parra, J. C. (2010). La sensibilidad de los precios del consumidor a la tasa de cambio en Colombia: una medición de largo plazo. In M. Jalil and L. Mahadeva (Eds.), *Mecanismos de transmisión de la política monetaria en Colombia*, Universidad Externado de Colombia y Banco de la República.

Pesaran, H., & Shin, Y. (1998). Generalized impulse response analysis in linear multivariate models. *Economic Letters*, *58*(1), 17-29.

Pollard, P. S., & Coughlin, C. C. (2004). Size Matters, Asymmetric Exchange Rate Pass-Through At The Industry Level. *Working Paper Series*, 2003-029B. Federal Reserve Bank of St. Louis.

Ramírez, Cinthya (2005). Exchange rate pass-through and inflation targeting in Latin America, *Mémoire*, Université de Genève, Institut Universitaire De Hautes Etudes Internationales.

Rincón, Hernán (2000). Devaluación y Precios Agregados en Colombia, 1980-1998. *Desarrollo y Sociedad*, No. 46, Centro de Estudios para el Desarrollo (CEDE), Universidad de los Andes, Colombia.

Rincón H., Caicedo, E., & Rodríguez, N. (2005). Exchange rate pass-through effects: A disaggregate analysis of Colombian imports of manufactured goods. *Ensayos Sobre*

Política Económica, No. 54, Banco de la República.

Rincón, H., & Rodríguez, N. (2015). Transmisión de las variaciones de la tasa de cambio a la inflación. *Carta Financiera*, ANIF, No. 169, 40-47.

Rodríguez, N., Rojas, B., & Patiño, M. (2006). Estimación del efecto pass-through para la economía paraguaya. *Documento de Trabajo GEE*, No. 4, Banco Central del Paraguay.

Rowland, Peter (2003). Exchange rate pass-through to domestic prices: The case of Colombia. *Borradores de Economía*, No. 254, Banco de la República.

Sekine, T. (2006). Time-varying exchange rate pass-through: Experiences of some industrial countries. *BIS Working Papers*, No. 202, Bank for International Settlements.

Shambaugh, Jay (2008). A new look at pass-through. *Journal of International Money and Finance*, *27*(4), 560-591

Shintani, M., Terada-Hagiwara, A., & Yabu, T. (2013). Exchange rate pass-through and inflation: A nonlinear time series analysis. *Journal of International Money and Finance*, *32*, 512-527.

Smets, F., & Wouters, R. (2002). Openness, Imperfect Exchange Rate Pass-through and Monetary Policy. *Journal of Monetary Economics*, *49*(5), 947-981.

Takhtamanova, Y. (2008). Understanding Changes in Exchange Rate Pass-Through. *Working Paper Series*, No. 2008-13, Federal Reserve Bank of San Francisco.

Taylor, John (2000). Low inflation, pass-through, and the pricing power of firms. *European Economic Review*, *44*(7), 1389-1408.

Teräsvirta, T. (1994). Specification, Estimation, and Evaluation of Smooth Transition Autoregressive Models. *Journal of the American Statistical Association*, 89(425), 208-218.

Van Dijk, D., Teräsvirta, T., & Franses, P. (2002). Smooth Transition Autoregressive Models – A Survey of Recent Developments. *Econometric Reviews*, *21*(1), 1-47.

Winkelried, Q. (2003). ¿Es asimétrico el pass-through en el Perú?: Un análisis agregado. *Revista Estudios Económicos*, No. 10, Banco Central de Reserva del Perú.

Wolf, H. C., & Ghosh, A. R. (2001). Imperfect exchange rate pass-through: strategic pricing and menu costs. *CESifo Working Paper*, No. 436.

Appendix A1.A International literature on PT

Authors	Year	**Freq.**[1]	**Sample**	**Countries**	**Econ. model**	**Approach**[2]	**Variables**[3]	**Inflation**[4]
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:_
Ozkan & Erden	2015	M	1980-13	88	Panel-Kalman Filter DCCGARCH- Panel threshold	L	L & Diff	CPI: ↑
Donayre & Panovska	2016	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 A1.B Colombian literature on PT

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
- First elaborated study written on exchange rate pass-through in Colombia. - Paper showed that 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.							
Rowland	**2003**	M	1983-2002	VAR, VEC	LR	L and Diff	Pm; W; CPI
- Paper found that 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. - According to the author, an exchange rate shock had little impact on consumer price inflation.							
Rincón et al.	**2005**	M	1995-2002	VEC	LR	Diff	Pm
- Paper made a disaggregate analysis and estimated the PT for import prices of a sample of the sectors in the Colombian manufacturing industry. - It 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.							
Ramirez[5]	**2005**	M	1980-2004	ARDL, RR	LR	Diff	Pm; W
- Paper compares PT estimates of Colombia and other Latin American countries. - It 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. - Paper showed that the country for which the clearest evidence of changes in the PT induced by IT was Brazil.							
Parra	**2010**	Y	1994-2005	Calibration	Elasticity	L	Pm; Pt; Pnt; CPI
- Paper shows the disconnection between the nominal exchange rate and domestic inflation, which is explained by the presence of margins of distribution and marketing on the imported goods. - It concludes that on average a 1% nominal devaluation of the local currency would imply a 0.28 increase in the CPI.							
González et al.	**2010**	Q	1985-2007	LST-VAR	NL	Diff	Pm
- It showed that the PT on whole import prices was incomplete not only in the short term but also in the long term. - Estimations showed that the PT coefficient was between 0.06 and 0.58. - Paper 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. - 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.

Rincón and Rodríguez	**2015**	Q	1985-2014	LST-VAR	LR	Diff	Pm; W; CPI

- It concludes that PT on CPI was 0.04 in the first year, using a linear VAR model.

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.

Appendix A.2. Data and sources

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

- Mgc*: Trade weighted measure of the foreign countries' marginal costs. Foreign countries are the main exporters to Colombian: USA, Canada, Japan, UK, Germany, Netherlands, Spain, France, Italy, Belgium, Switzerland, Sweden, Mexico, Panama, Venezuela, Ecuador, Peru, Brazil, Chile, and Argentina. The monthly producer price index of each of these countries was used as their marginal cost proxy. Then, the price indexes were weighted by the respective monthly import weight into the Colombian imports. Source: Banco de la República, International Financial Statistics (IMF) and home pages from the respective central banks (unpublished statistics).
- E: Nominal effective exchange rate index. It is weighted using imports from the Colombian's main trading partners. Source: *Banco de la República* (unpublished statistics).
- P^{m}: Price index of imported goods. Not seasonally adjusted (2014=100). Source: *Banco de la República* (http://www.banrep.gov.co/es/ipp).
- S: Non-core CPI. Source: *Banco de la República* (unpublished statistics).
- P^{ppi}: Producer price index (2014=100). Not seasonally adjusted. Source: *Banco de la República* (http://www.banrep.gov.co/es/ipp).
- P^{mc}: Main imported goods of the Consumer Price Index. Not seasonally adjusted. Source: *Banco de la República* (unpublished statistics).
- P^{cpi}: Consumer Price Index (2008=100). Not seasonally adjusted. Source: *Banco de la República* (http://www.banrep.gov.co/es/ipc).
- Annualized monthly inflation (π_t^l) = ln (I_t) - ln (I_{t-12}), I= P^{m}, P^{ppi}, P^{mc}, P^{cpi}. Source: Own calculations.
- $\Delta\pi^{cpi}_t$: Change of the annualized monthly CPI inflation = ($\pi^{cpi}{}_t$/ $\pi^{cpi}{}_{t-1}$) - 1. Source: Own calculations.
- V($\pi^{cpi}{}_t$): Volatility of the annualized monthly CPI inflation. It is calculated as the standard deviation of π_t using a moving window of twelve months. Source: Own calculations.
- $D\pi_t$: Deviations of the annualized monthly CPI inflation from central bank's CPI inflation target. Source: Own calculations.

- Δe_t: Annualized monthly variation of the exchange rate = ln (E_t) - ln (E_{t-12}). Source: Own calculations.
- $\Delta(\Delta e_t)$: Change of the Annualized monthly variation of the exchange rate = $(\Delta e_t/\Delta e_{t-1}) - 1$. Since the series presented outliers, we adjusted it taking centered moving averages of order three. Source: Own calculations.
- $V(\Delta e_t)$: Volatility of the exchange rate. It is calculated as the standard deviation of Δe using a moving window of twelve months. Source: Own calculations.
- Mq: Measurement of misalignment of the real exchange rate: It is calculated as the difference between the quarterly real exchange rate index taken from the central bank statistics (when it increases it depreciates) and the quarterly estimated "equilibrium real exchange rate" made by the Real Exchange Rate Team of the central bank's Research Department. The latter is a quarterly simple average of four estimates of the equilibrium real exchange rate: i) The filtered value of the real exchange rate using the Hodrick and Prescott filter; ii) the fitted value of a structural VEC model of the real exchange rate on real variables such as net foreign assets, terms of trade and an indicator of the Colombian trade openness; iii) the fitted value of a VEC model of the real exchange rate on real variables such as net foreign assets, terms of trade, public expenditures and relative productivity between Colombia and USA; and iv) the estimated of the "fundamental equilibrium exchange rate" according to the methodology developed by the International Monetary Fund. To obtain the monthly series we interpolated the quarterly "misalignment" series using the "DISAGGREGATE.SRC" procedure (by Tom Doan, Estima). Source: *Banco de la República* and own estimations (unpublished statistics).
http://www.banrep.gov.co/es/series-estadisticas/see_ts_cam_itcr.htm%23itcr
- Gy: Measurement of the output gap. It is the average of five models that are estimated and updated quarterly for the Colombian Inflation Report. These are: A simple HP filter; a survey data based on principal component estimates; two New Keynesian models, one with adaptive expectations and the other with rational expectations; and a production function approach. All estimates that rely on statistical filters include out of sample forecasts to ameliorate the optimal filtering end of sample problem. The average serves as a prior at several points of time for a HP filter, in order to take all estimates to quarterly frequency. The centered moving average of this HP filter with priors is the official output gap estimate, which feeds the forecasting and policy analysis models. To obtain the monthly series we interpolated the quarterly "output gap" series using the "DISAGGREGATE.SRC" procedure (by Tom Doan, Estima). Source: *Banco de la República* and own estimations (unpublished statistics).
- Openness: Indicator of the country's trade openness. It is calculated as the ratio between total monthly imports plus exports and the GDP. Sources: National Department of Statistics (DANE), *Banco de la República*, and own calculations (unpublished statistics).
- Pcomm: Commodity price index. Correspond to CRB BLS Spot Index (1967=100)-PRICE INDEX (CRBSPOT). Source: Datastream.
- IBR: Colombian interbank interest rate (TIB). Source: *Banco de la República* http://www.banrep.gov.co/es/tib.

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 $B = (A_0, A_1, \dots, A_p, B_0, B_1, \dots, B_p)'$ and $x^{\theta} = I_n \otimes X^{\theta}$, $X^{\theta} = \left[x_1^{\theta\prime}, \dots, x_T^{\theta\prime}\right]'$, with $x_t^{\theta} = [x_t \;\; F(z_{t-d})x_t]$ and $\theta = (\gamma, c)'$, But model (A3.1.1) can be vectored and transformed into,

(A3.1.2) $$y = x^{\theta}b + e,$$

where $y = vec(Y)$, $b = vec(B)$ and $e = vec(E)$. Given that errors terms are assumed to be Gaussian 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 depends on *b* and the rest of parameters, has the familiar multivariate conjugate posterior normal form.

A3.2 ***Prior distributions***

In order to choose the prior distributions -as long as one needs to calculate posterior model probabilities (Bayes Factors) to compare across different models-, and given that the dimension of b changes across different model specifications, one should not use (complete) 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 distributed as Gamma with mean $\underline{\mu_{\eta}}$ (equal 5.6) and degrees of freedom $\underline{\nu_{\eta}}$ (0.25). Additionally, an Inverse-Wishart prior is specified for the variance-covariance matrix Σ.

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.

As is required by formal Bayesian analysis, we implemented robustness exercises on the priors. Since the most sensitive one is the prior distribution for η, the parameters $\underline{\mu_\eta}$ and $\underline{\nu_\eta}$ were calibrated so that they yielded suitable acceptance rates of the Metropolis algorithm, as well as that the simulated PTs met the restriction $0 \leq PT_\tau \leq 100$ in most of the draws.

In addition, as the degrees of freedom $\underline{\nu_\eta}$ plays an important role on both the acceptance rates and on meeting the size restriction of the simulated PTs, we decided to assign them values consistent with an uninformative prior distribution, as recommended by Gefang (2012), since results were sensitive to their variations up to the order of 10^{-4}.

On the other hand, the coefficients that characterize the prior distributions of the variance-covariance matrix Σ, the smoothing parameter γ, and the location parameter c fail to have great influence on the acceptance rates or the Pass-through estimates.

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. Convergence diagnostic indicated that

25,000 effective draws were enough to attain convergence, after 5,000 burnings. The hyperparameters $\underline{\mu_\eta}$ and $\underline{\nu_\eta}$ were calibrated per each transition variable in order to get the best 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 (2015)) as stated by equations (9) and (10). 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) $$\mathrm{Y_t} = \mathrm{A(L)Y_{t-1}} + \mathrm{B(L)Y_{t-1}F(V_{t-d}\,;\gamma, c)} + \boldsymbol{\mu}_t,$$

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):

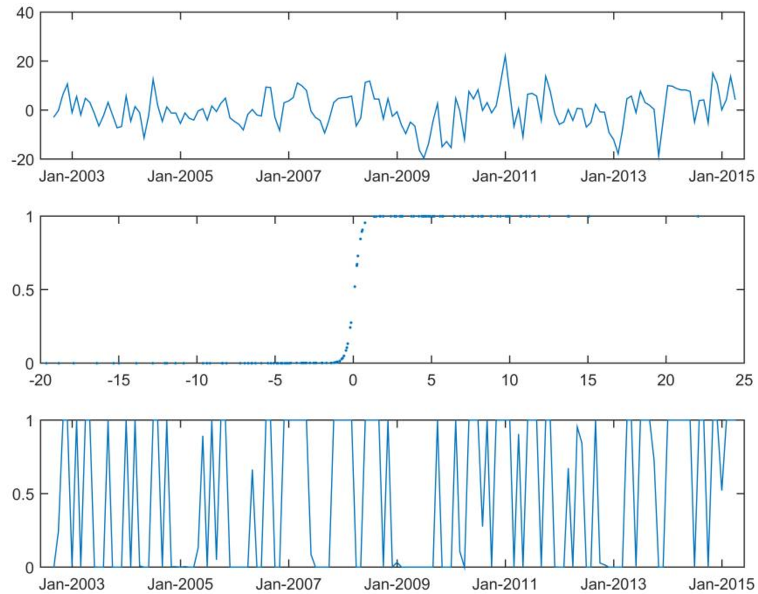
1. Randomly choose a point in the sample where the $V_{t-d} < Threshold$ is met. The number of these points will be written *N_lower*.
2. For this point, forecast the model for T periods ahead through simulation, while considering the respective history for the elements of vector V_{t-d} and the observed 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 (10).
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.

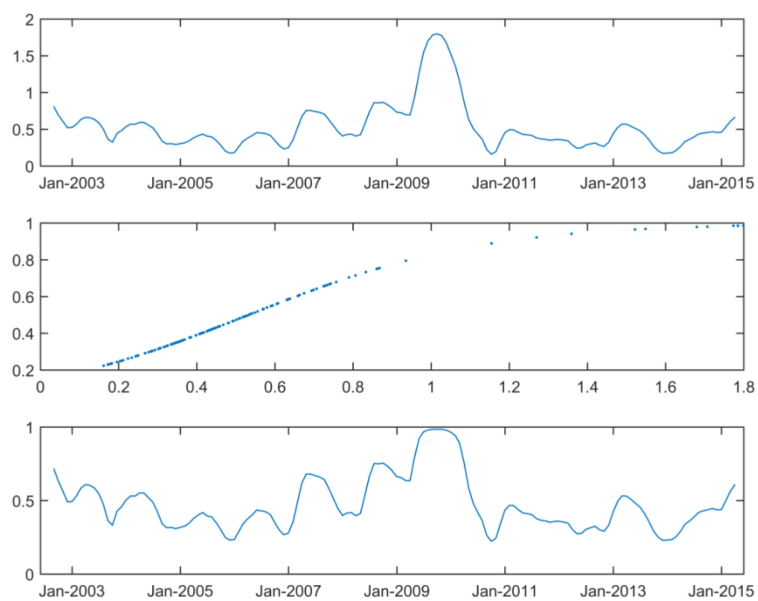
By drawing randomly from histories at each regimen and averaging across them, we obtain an estimate and then the median of the PT, which is conditional upon the current state of the economy. Notice that for each of the inflation series, we present two sets of paths for $G(.)$ and PT median estimates, 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

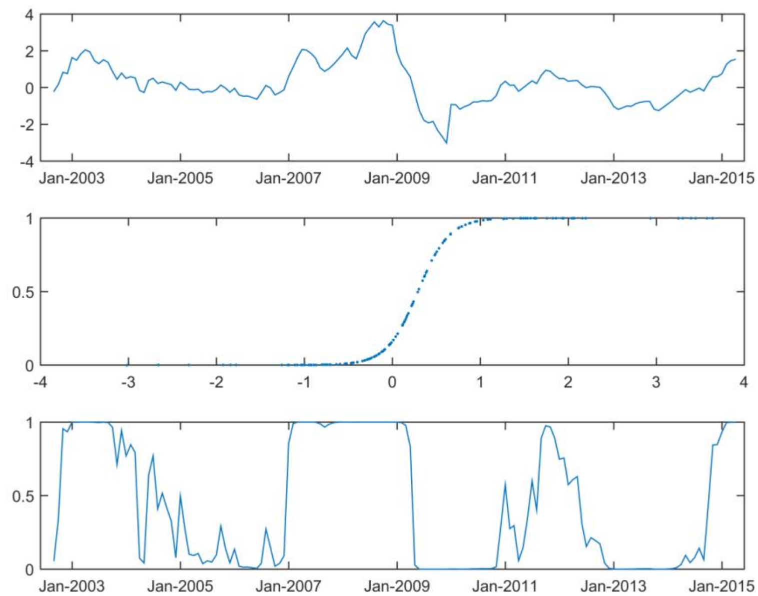
Graph A.5.1 Transition variable, smooth transition function and time profile for $\Delta(\pi^{cpi})$.



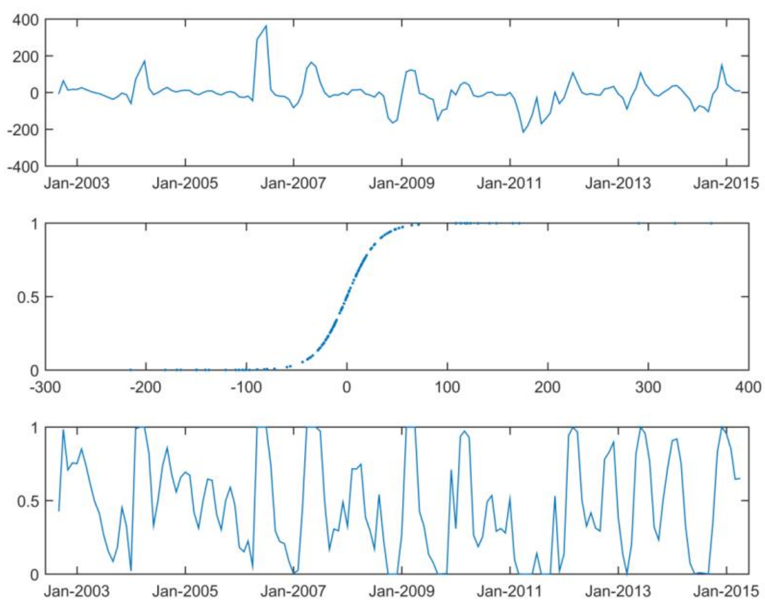
Graph A.5.2 Transition variable, smooth transition function and time profile for $V\,(\pi^{cpi})$



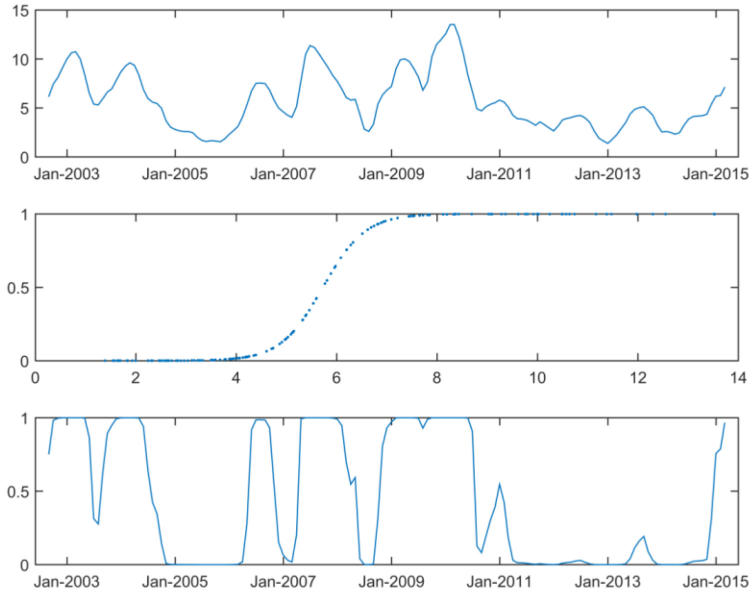
Graph A.5.3 Transition variable, smooth transition function and time profile for $D\pi$



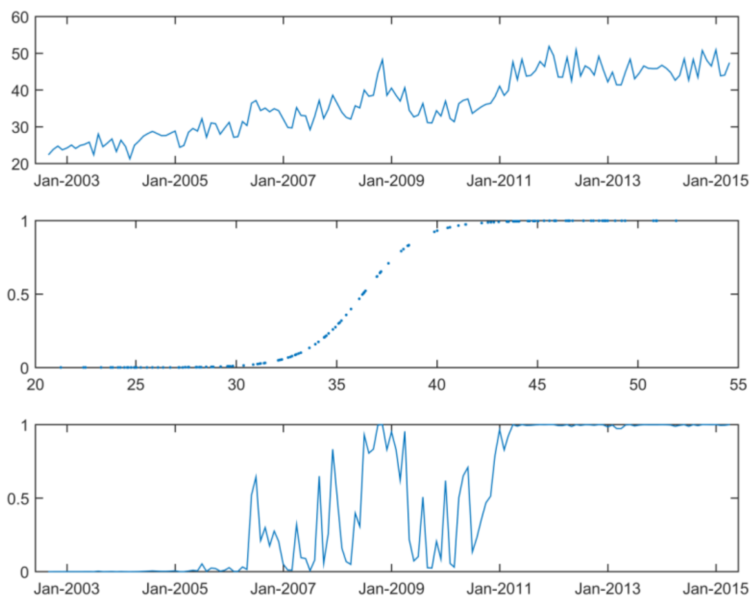
Graph A.5.4 Transition variable, smooth transition function and time profile for $\Delta(\Delta e)$



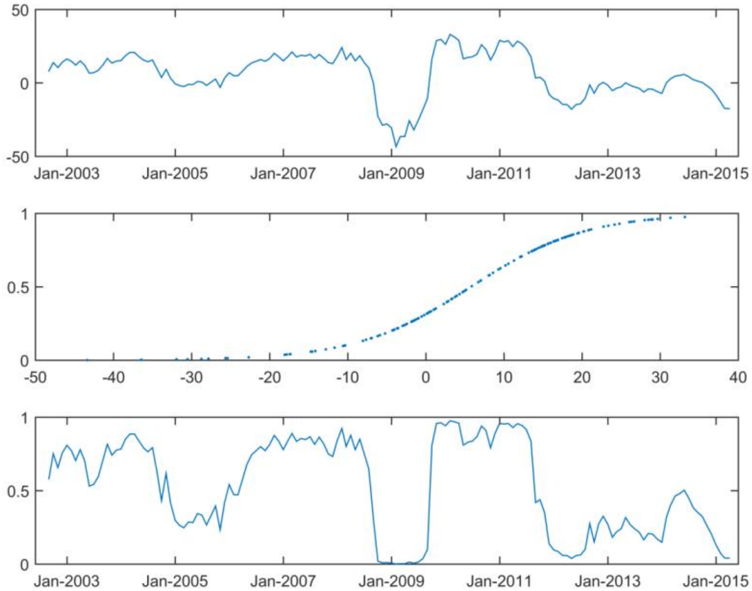
Graph A.5.5 Transition variable, smooth transition function and time profile for $V(\Delta e)$



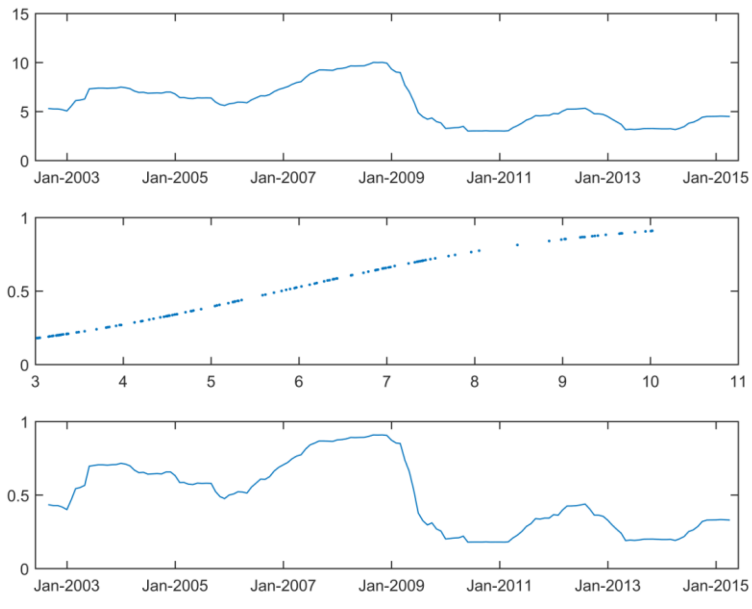
Graph A.5.6 Transition variable, smooth transition function and time profile for $Openness$.



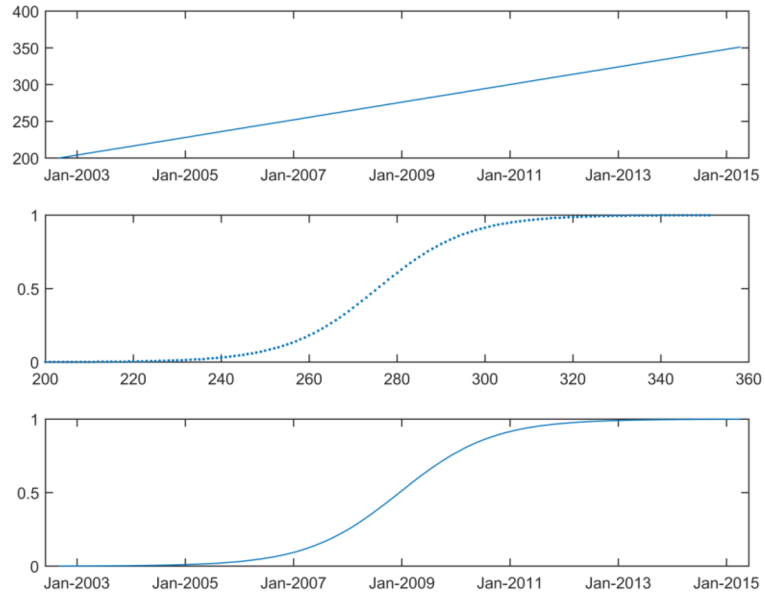
Graph A.5.7 Transition variable, smooth transition function and time profile for *ΔPcomm*



Graph A.5.8 Transition variable, smooth transition function and time profile for *IBR*



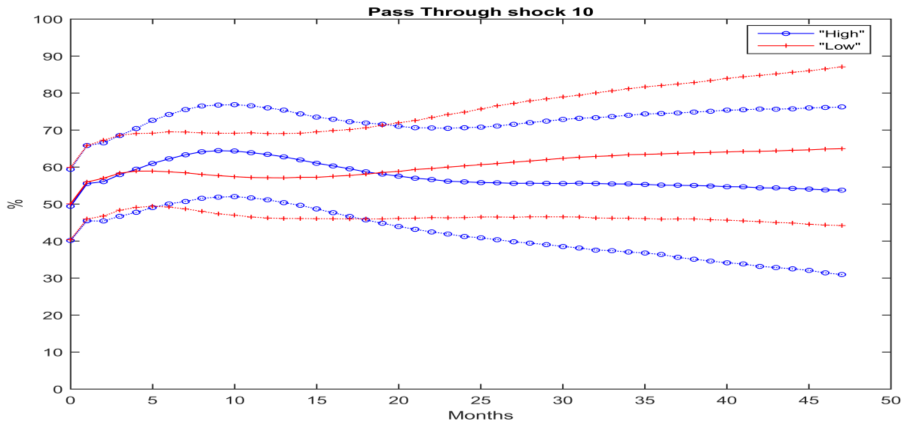
Graph A.5.9 Transition variable, smooth transition function and time profile for *Trend*



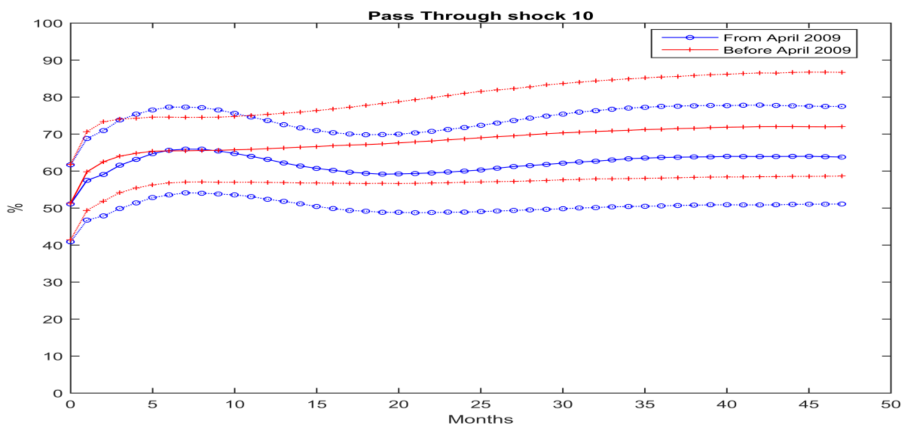
APPENDIX A.6

Figure A.6.1 Path of the PT on import prices

Transition variable: Interbank interest rate (*IBR*)



Transition variable: Trend (*Trend*)



Transition variable: Output gap (*Gy*)

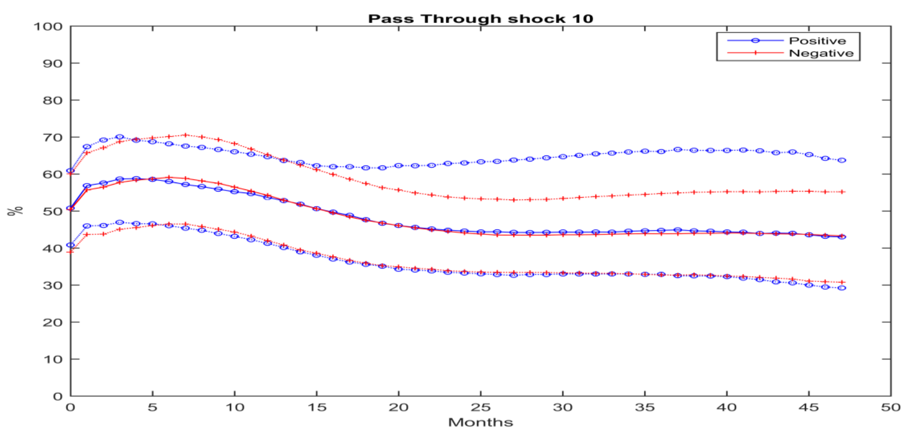
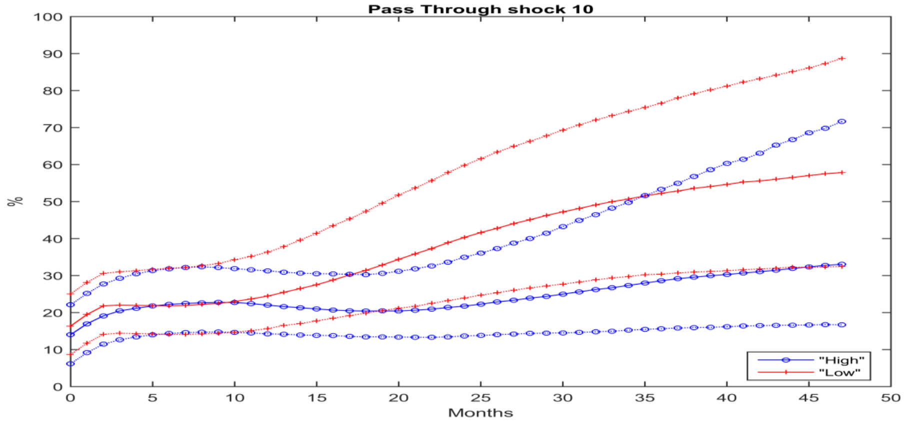
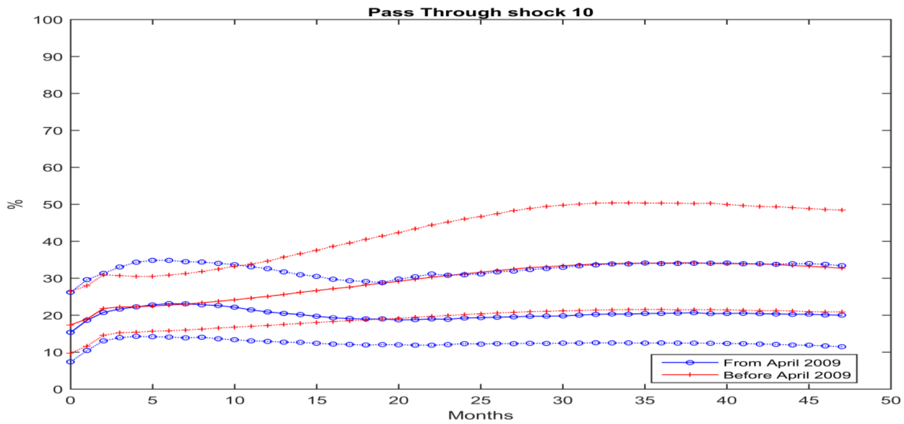


Figure A.6.2 Path of the PT on producer prices

Transition variable: Interbank interest rate (*IBR*)



Transition variable: Trend (*Trend*)



Transition variable: Output gap (*Gy*)

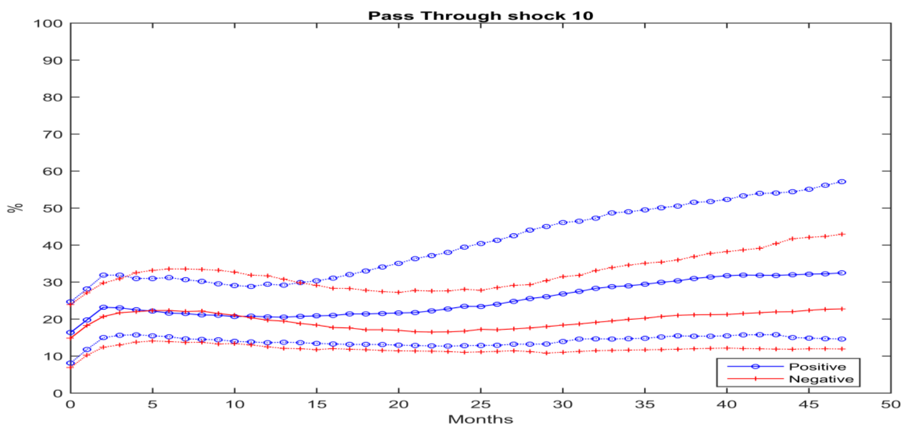
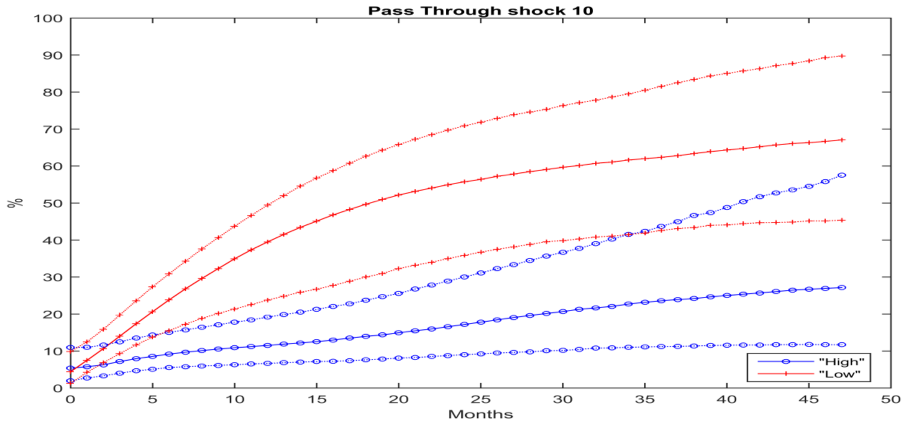
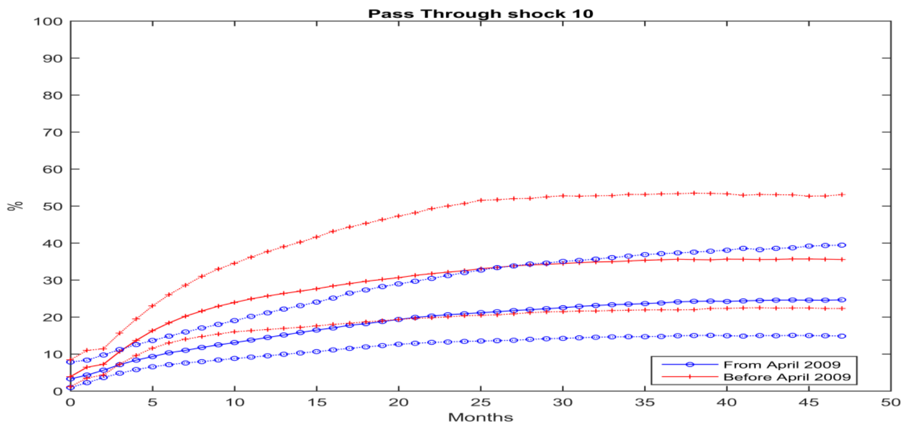


Figure A.6.3 Path of the PT on imported consumer prices

Transition variable: Interbank interest rate (*IBR*)



Transition variable: Trend (*Trend*)



Transition variable: Output gap (*Gy*)

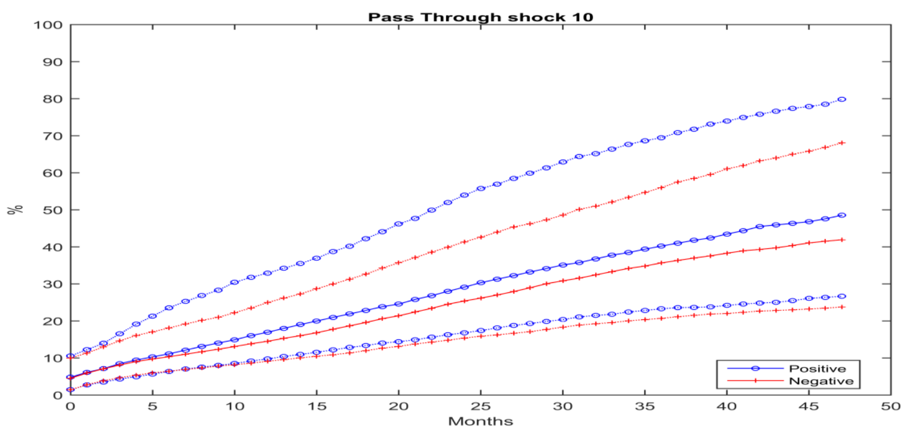
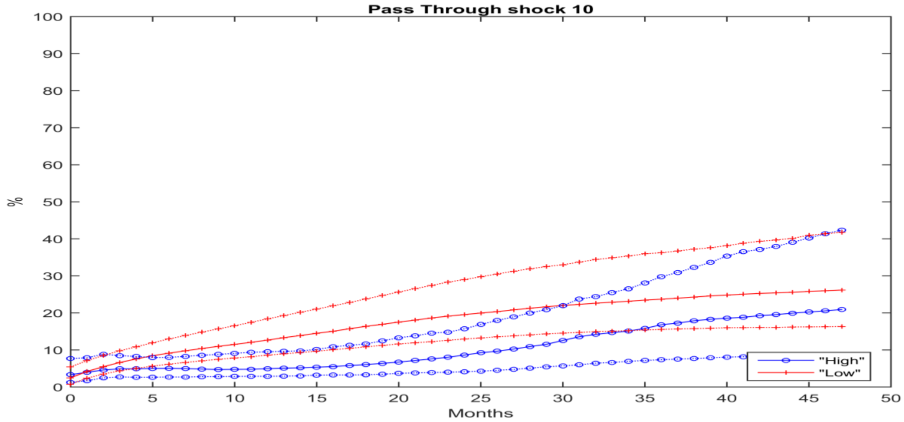
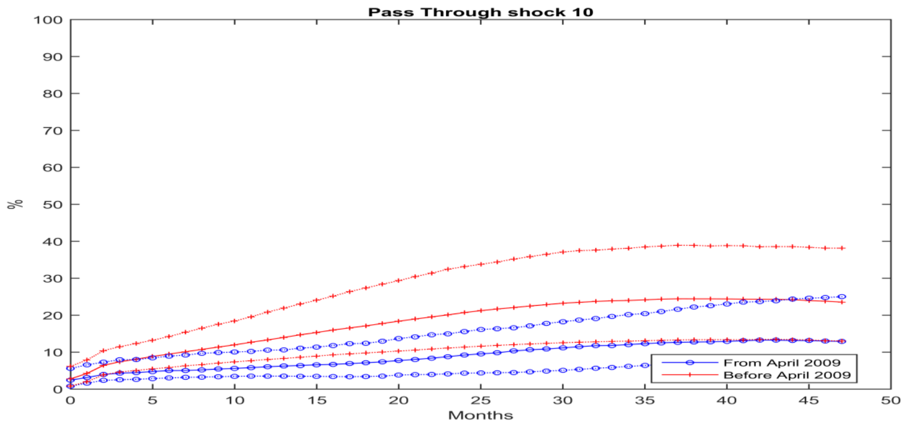


Figure A.6.4 Path of the PT on CPI

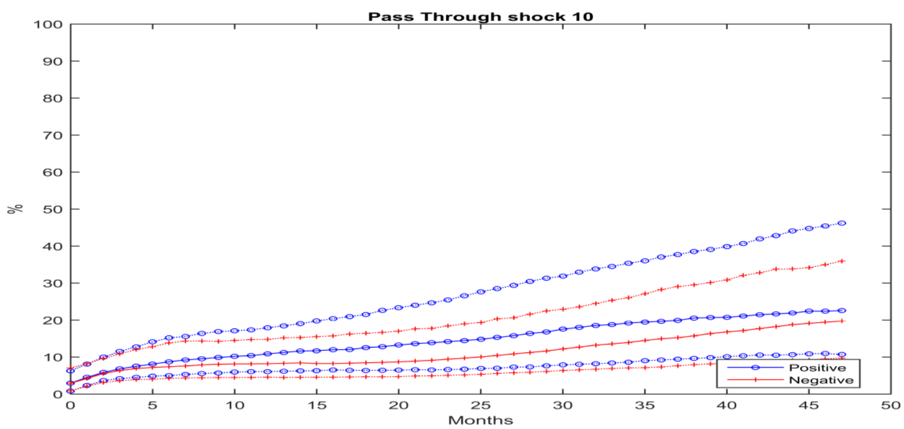
Transition variable: Interbank interest rate (*IBR*)



Transition variable: Trend (*Trend*)



Transition variable: Output gap (*Gy*)

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