Asymmetric Exchange Rate Pass-Through: Evidence, Inflation Dynamics and Policy Implications for Brazil (1999-2016)

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Abstract: We investigate the existence of an asymmetry in the exchange rate pass-through to the Brazilian consumer price index (CPI). Using a decomposition of the exchange rate series, into appreciations and depreciations of the Brazilian currency during the 1999-2016 period, we estimate Structural Vector Auto-regression (SVAR) models with different identifying restrictions. The results are robust and indicate a relevant asymmetric behavior of the exchange rate pass-through. Estimates indicate a pass-through of 16% in case of depreciation, and of 5.8% in case of appreciation of Brazilian Real (BRL) against the US Dollar. Accordingly, the inflationary effect resulted from a (systematic) depreciation is only partially compensated by a deflationary effect of an (systematic) appreciation of the same magnitude, generating an inflationary bias that may cast doubts on inflation control strategies based solely on inflation targeting. Results provide a case against excess exchange volatility and capital mobility. A stable exchange rate favors price stability.

Resumo: O artigo investiga a existência de repasse cambial assimétrico para o IPCA no Brasil. Usando uma decomposição da taxa de câmbio em apreciações e depreciações durante o período de 1999 a 2016 são estimados modelos SVAR. Os resultados são robustos e indicam existência de um relevante comportamento assimétrico do repasse cambial. As estimativas indicam um repasse de 16% após uma depreciação e de 5,8% após uma apreciação do Real contra o Dólar americano. Desta forma, o efeito inflacionário resultante de uma depreciação (sistemática) é apenas parcialmente compensado por um efeito deflacionário de uma apreciação (sistemática) da mesma magnitude, gerando um viés inflacionário que leva a questionamentos a respeito da estratégia de controle da inflação pelo Regime de Metas de Inflação.

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1. Introduction

Brazil's long experience with high inflation and external shocks to its currency makes Brazilian policymakers, and the public alike, worry about the inflation rate every time one observes excessive movement in the exchange rate markets. In the past, in an inflationary environment, shocks to the exchange rate and depreciations of the Brazilian currency in particular, ended up being passed through to consumer prices. Even though inflation rates have stabilized and the exchange rate pass-through have allegedly declined during the last decade, the transmission of exchange rates shocks to domestic prices remains a concern to the monetary authorities. The exchange rate pass-through is defined as the domestic prices percentage change after a 1% exchange rate variation. Exchange rate fluctuations can affect domestic prices directly or indirectly. Directly, it affects prices of inputs used in domestic production and prices of imported final goods. Thus, the magnitude of direct effects depends on the share of imported goods on domestic consumption and production.

Indirectly, exchange rate fluctuations affect the demand for domestically produced goods that compete with imported goods. Indirect effect depends on the elasticity of substitution between domestic and imported goods. A depreciation of the local currency, for example, raises the internal demand for domestic goods *vis-à-vis* imported goods, while increases the competitiveness of local exports. At a given supply level, a raise in exports may result in inflationary pressures (over domestic inputs and wages). Additionally, administered (or government controlled) prices formally or informally indexed to the exchange rate may also affect domestic inflation.

The literature usually assumes a long-term relationship between price level and exchange rate. Accordingly, it is usually assumed that the exchange rate pass-through is ***symmetric*** – or that the effect of appreciations and depreciations of the local currency (on CPI) have the same magnitude (McCarty, 2007; Gagnon and Ihrig, 2004; Campa and Goldberg, 2005; Choudhri and Hakura, 2006; Kohlscheen, 2010; and for Brazil Belaisch, 2003; Minella et al., 2003; Nogueira, 2007; Araújo and Modenesi, 2010). However, there are several micro and macroeconomic theoretical reasons that justify the possible existence of an ***asymmetric*** exchange rate pass-through – that is, the effect of currency appreciations and depreciations (on CPI) may not have the same magnitude.

This chapter aims at investigating the existence of an *asymmetric* exchange rate pass-through to consumer prices in Brazil. The Brazilian Central Bank (BCB)[2] has adopted the inflation targeting regime in 1999 and uses the Brazilian Consumer Price Index (IPCA).[3] There are many studies estimating the *symmetric* exchange rate pass-through to IPCA. In the international literature, almost all studies that focus on the asymmetry of the pass-through analyses the pass-through to imported prices.

Our contribution to the current literature is mostly empirical, and the results help highlighting two important and intertwined theoretical points. Firstly, an asymmetric pass-through may be an additional explanation for downward price rigidity. Secondly, our results provide a strong case against excess exchange rate volatility and capital mobility as supported by the

[2] In Portuguese, *Banco Central do Brasil*.

[3] Calculated by the Brazilian Institute of Geography and Statistics (IBGE) and considered the official inflation index of the country.

Post Keynesian literature. Empirically, we provide evidence on the existence of an ***asymmetric*** exchange rate pass-through to the Brazilian Consumer Price Index. In a departure from the previous literature, we focus specifically on the *asymmetric* exchange rate pass-through to IPCA. We believe that by analyzing the pass-through to a more general price index (the IPCA), we do not restrict ourselves to the possible cost effects of imported prices. Using a decomposition of the exchange rate series into appreciations and depreciations of the Brazilian currency, we estimate Structural Vector Autoregression (SVAR) models and provide estimates of the magnitude of the pass-through in case of appreciations and depreciations of the local currency. Our results support the hypothesis of a strong asymmetry in the exchange rate pass-through for the IPCA.

Our chapter contains three sections besides this introduction and the concluding remarks. Section 2 presents a very brief overview of the recent macroeconomic performance and macroeconomic policy in Brazil. We highlight three stylized facts: 1) the low inflation's sensitivity to the interest rate; 2) the key role of the exchange rate in the monetary policy transmission channel; and 3) the existence of a downward rigidity in the IPCA. Section 3 reviews the literature on the exchange rate pass-through. Finally, we present some implications of the asymmetric pass-through to inflation dynamics and macroeconomic policy.

2. Inflation and Macroeconomic Policy in Brazil: A brief overview

During the 1980s and early 1990s the Brazilian economy presented a process of chronic high inflation. Most economists agreed that inflation had become inertial, as far as the population had incorporated the inflationary memory: (current) prices were indexed to past inflation (Modenesi, 2005, chapters 4-5).

With the adoption of the Real Plan in mid-1994, inflation was put under control. The Real Plan was a price stabilization strategy based on the adoption of a new monetary standard and the implementation of an exchange rate anchor. The plan was successful in controlling inflation. Inflation fell sharply after the launch of the Real Plan, reaching levels that had not been observed for decades in the Brazilian economy (Reis *et al*., 2016, 169-70).

In 1999, a set of policies was adopted, so called *macroeconomic tripod*, based on: inflation targeting regime; floating exchange rate, with high capital mobility; and primary surplus targets. Price stability was pursued by fixing the basic interest rate (*Selic* rate)[4] in line with a Taylor rule. Accordingly, *Selic* rate was set aiming at controlling simultaneously aggregate demand and, though not directly, the exchange rate, which has been the most relevant monetary policy transmission channel. Fiscal policy, in turn, assumed a supporting role, limited to avoiding inflationary pressures and keeping a stable debt/GDP relation (Reis *et al*. 2016, 170-2). This policy was in line with the *New Consensus in Macroeconomics*.[5]

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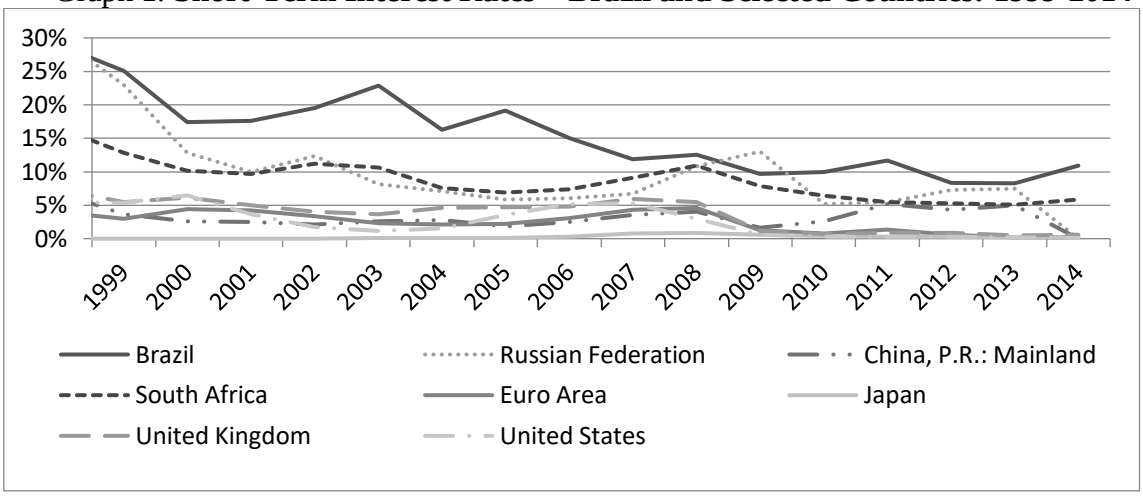
[4] In Brazil, the basic interest rate goes by the acronym (Selic) for *Sistema Especial de Liquidação e de Custódia* (Special System for Settlement and Custody), which is the settlement system for most domestic securities of the Brazilian government.

[5] The New Consensus on Macroeconomics (Blinder, 1981, 1998; Taylor, 1993, 2000; Allsopp e Vines, 2000; Romer, 2000) is associated with the growing popularity of inflation targeting and the resulting acceptance that, even where the regime is not adopted, the main instrument of monetary policy is the (basic) interest rate, and

One should note that since the Real Plan, Brazil set a world record in terms of (real) interest rates, and the BRL was one of the most overvalued currencies during the last two decades (Graph 1). The high interest rates attracted carry trade operations and contributed to an overvaluation of the BRL.[6] In turn, the overvaluation of the BRL facilitated inflation control.

Graph 1. **Short-Term Interest Rates – Brazil and Selected Countries: 1999-2014**



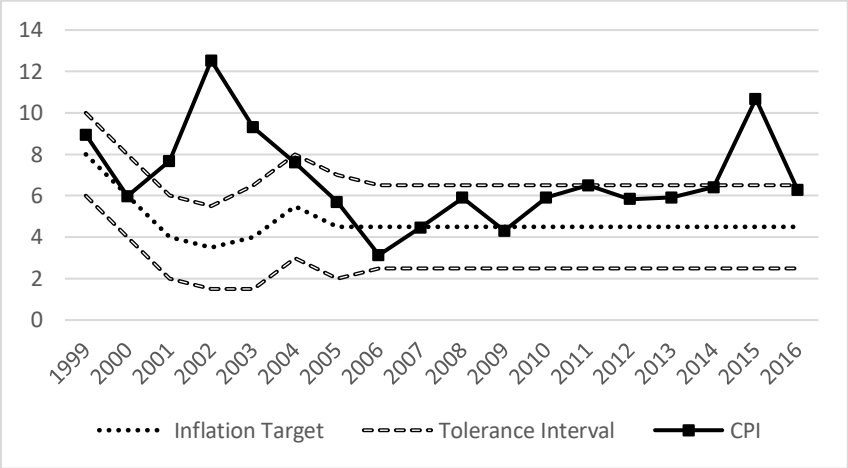
Source: IMF (2016a).

Although Brazil has one of the world's higher interest rates, the BCB has had difficulties meeting its inflation targets (see Graph 2). During 18 years of inflation targeting adoption, upper limit was exceeded in four years (2001, 2002, 2003 and 2015); the center of the target was reached in only three years (2000, 2007 and 2009); and IPCA was below the center of the target only in 2006. During this period, annual inflation averaged around 7%, well above the 4.5% target rate.

no longer the monetary aggregates of some decades ago, influenced by monetarism. The new consensus theoretical core is given by the confluence of monetarism, new classical and real business cycle theories. The natural rate of unemployment (Friedman, 1968) and rational expectations hypothesis are among the two most relevant assumptions shared by this large group of economists. Another fundamental part is the Taylor rule – which holds that the central banks should determine its interest rate aiming at an explicit or implicit inflation target, and at keeping GDP growth near to its potential. We agree with Lavoie that "the only truly new element in the new consensus […] is the rejection of the exogenous supply of money, and the replacement of money growth rule for a real interest rate targeting rule […]" (Lavoie, 2004, p. 23).

[6] For details on the role of foreign exchange derivative market in Brazil, see chapter 11 of this book by Maryse Farhi.

Graph 2. **Inflation (IPCA accumulated in 12 months, %) and Targets: 1999-2016**



Source: IBGE (2016a), BCB (2016a).

In fact, Brazilian inflation has proven rather resilient despite high interest levels set by the BCB (annual inflation rates have been below 5% only in three out of eighteen years period). This suggests there is something *sui generis* in inflation dynamics and in the transmission mechanism of monetary policy which causes Brazilian inflation to not respond – or to remain less sensitive – to contractionary monetary policy.[7] Indeed, an ample set of empirical evidence indicates that the monetary policy transmission mechanism may not be properly functioning. For instance, Modenesi and Araújo (2013) found that the sensibility of the IPCA to the Selic rate is low.

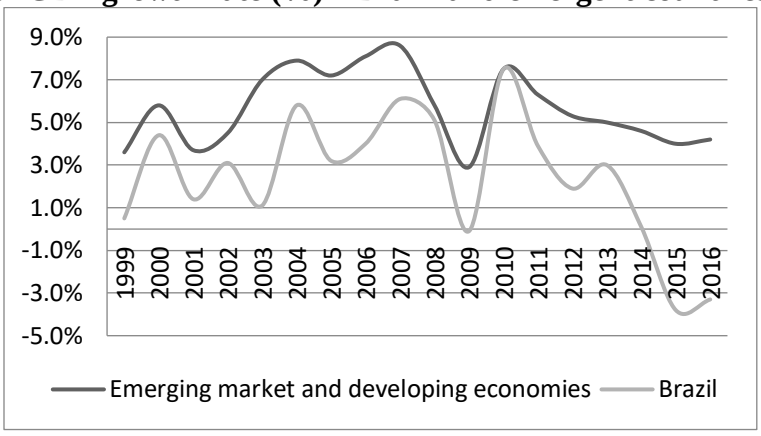
The low sensitivity of the Brazilian inflation to the interest rate level is remarkable and has been widely documented (Modenesi et al., 2017, 206-7). This means that an increase in the Selic rate seems to have limited deflationary impact through the demand channel. For this reason, the BCB – according to the inflation targeting regime – would need to maintain the basic interest rate in excessively high levels in order to meet its inflation targets.

The costs of practicing high levels of interest rate are not negligible. The effect of an increase in the Selic rate on the economic activity level is negative. In response to a rise in interest rate, economy decelerates and employment increases. Monetary rigidity is one of the reasons – although not the sole – for the poor performance of Brazilian economy during analyzed period.[8] The GDP growth rate remained below 6% in the 1999-2016 period (except in 2010, when it exceeded 7.5%), and above 5% in only four years (2004, 2007, 2008, 2010). Such results have proved to be worse than for other emergent countries that have considerably higher growth rates (Graph 3).

[7] According to existing literature (Modenesi and Modenesi, 2012): among the main empirical-institutional features of Brazilian economy that compromises the monetary policy transmission, these are noteworthy: i) non-existence of a *yield curve* for sufficiently long maturity periods; ii) the high share of *administered prices* in the IPCA; iii) existence of a perverse *cost channel*; and iv) the so-called *LFT problem* (Modenesi and Modenesi, 2012). LFT (*Letras Financeiras do Tesouro*, in Portuguese) is a special kind of government bonds that are indexed to Selic.

[8] Even recognizing that Brazil's rates of growth in the 1980's were low, one cannot deny that monetary policy has, at least, constituted a relevant hindrance to the reversal of this situation.

Graph 3. **Real GDP growth rate (%) – Brazil and emergent countries: 1999-2016**



Source: IMF (2016b).

The BRL also appreciates in response to an increase in Selic rate. The high differential between domestic interest rate and foreign rates contributed to the expressive appreciation of the BRL that occurred after 2003, reducing export competitiveness. The BRL is one of the currencies that have appreciated more recently: for instance, in 2011, the average exchange rate was inferior to its value in 1999.

It is worth noting that overvaluation of the BRL is not an undesirable byproduct of the high-interest rate policy. On the contrary, the BRL appreciation has been the core of price stabilization strategy, since the Real Plan. Araújo and Modenesi (2010) suggested that exchange rate was more relevant than the economic activity level to explain Brazilian inflation dynamics. In fact, exchange rate has been the most relevant transmission channel of monetary policy (Arestis et al. 2011; Modenesi and Araújo, 2013). This is a second (and well known) stylized fact of Brazilian economy.

Summing up, despite of the extremely high interest rates and strong overvaluation of the BRL, BCB was not able to maintain inflation at expected reasonable levels. In other words, although in relative control, inflation presented downward rigidity. This can be seen as another stylized fact of Brazilian economy after the Real Plan. A common explanation is that the practice of price indexation was not fully eliminated. Some key prices – for instance, some public tariffs, such as public transportation and energy; and also petroleum products and rents – are indexed to past inflation by law. Indeed, administrated inflation (one third of IPCA) drove inflation rates above the target until the early 2007 and after 2015. As a rule, prices in general (and also wages) are also indexed to inflation (in a 12 months basis).[9] Inflation presents a highly inertial component and thus, controlling aggregate demand – via monetary or fiscal policy – has proven to have limited efficacy in curbing inflationary pressures. For instance, in 2017, only after two consecutive years of economic recession and an unemployment rate of 12%, inflation rates finally declined. Note that, in 2015-6 Brazil experienced the most drastic recession of history (Graph 3).

[9] Administered prices represents around 30% of CPI in Brazil. Many of them are (directly or indirectly) indexed to exchange rate. One should note that not all administrated prices are indexed to past inflation.

We provide evidence for yet another reason for IPCA's downward rigidity or inflation resilience: the existence of an *asymmetric* exchange rate pass-through.

3. Review of Literature

3.1 Exchange Rate Pass-through in Brazil

There is a vast literature that estimates the ***symmetric*** exchange rate pass-through in Brazil. Belaisch (2003) estimates VAR models, from July 1999 to December 2002. Model specification follows McCarthy (2007) and uses the exchange rate, IMF oil index price and industrial output index (IBGE).[10] The exchange rate pass-through for consumer prices was estimated at 17% after 12 months.

A group of authors also estimated *symmetric* models with specifications based on Belaisch (2003) and McCarthy (2007): Squeff (2009), Araújo and Modenesi (2010), Souza and Alves (2011) and Nogueira et al. (2013). Other studies also used VAR models with different specifications: Minella et al. (2003), Nogueira (2006), Menezes and Fernandes (2012) and Fraga and Couto (2012). In all these studies, the econometric model is linear and symmetric.

According to literature, exchange rate pass-through has been reduced over time in several countries. Squeff (2009) and Souza and Alvez (2011) divided the analyzed period into two sub-samples. In both studies it was found that the first period (1999-2003) presented a higher exchange rate pass-through than in the second one (2003-2007 and 2003-2009, respectively). It is important to highlight, however, that in both studies the second sub-sample is a period of continuous appreciation of the BRL.

Souza et al. (2013) and Almendra et al. (2015) estimated exchange rate pass-through using State Space models that allowed for time varying parameters.[11] Marodin and Portugal (2015) estimated a Markov Switching Phillips Curve for Brazil from 2000 to 2015. Their results showed evidence of two distinct regimes for the exchange rate pass-through.[12]

Correa and Minella (2010) analyzed the existence of nonlinearities in the Phillips Curve through estimation of a threshold autoregressive model (TAR) with consumer prices, exchange rate and the output gap. The results indicate existence of a non-linear relationship between the exchange rate pass-through and the economic cycle. When the output gap is below the estimated 1.89% threshold, the exchange rate pass-through is not statistically different from zero. However, when the output gap is above the threshold, the estimated pass-through is 9%. Devaluations of the local currency larger than the 2.1% threshold lead to an estimated pass-through of 11% (after three months). Pass-throughs of appreciations (small or large), on the other hand, were not statistically significant.

Carneiro et al. (2004) estimated a backward-looking Phillips curve with a nonlinear specification to the pass-through coefficient for the period from 1994 to 2001. The model

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[10] In the McCarthy (2007) model, inflation is determined by 'supply' shocks, 'demand' shocks and the exchange rate.

[11] One should conclude, that in both studies, the results showed that exchange rate pass-through was higher during periods of depreciation of the local currency than in periods of appreciation.

[12] Under the so-called 'normal' regime, the pass-through to consumer prices was not statistically significant. Comparatively, the expected pass-through under a 'crisis' regime is of 10%. 'Crisis' periods occurred from 2000 to 2003 and in 2015, years in which the BRL depreciated. The 'normal' cycle extends from 2003 to 2014, years of continuous appreciation of the local currency (except for July to November 2008).

considers different components of consumer price index (industrialized, services and food) and the exchange rate and unemployment rate as determinants of inflation. The nonlinear specification presented a pass-through of 5.6% for 1999, 6% for 2000 and 7.7% for 2001. The empirical evidence obtained by the authors also suggested the existence of different nonlinear pass-through mechanism among different price groups.

Most international econometric studies estimate exchange rate pass-through to import prices and to producer prices. Only a few studies focus consumer prices.[13] Results, in general, present evidences of asymmetric exchange rate pass-through, although the direction and magnitude vary from country to country and with the industry analyzed.

Although it is possible to use nonlinear estimation methods most studies estimates autoregressive distributed lag (ARDL) and vector autoregressive (VAR) models and decompose the exchange rate series in two new variables, one for appreciation observations and another for depreciations.

Summing up, there are many studies estimating the *symmetric* exchange rate pass-through to consumer price in Brazil. In the international literature, studies that focus on the asymmetry of the pass-through usually use imported prices. Our main contribution is to provide evidence on the existence of an *asymmetric* exchange pass-through to consumer price in Brazil. We innovate by using a decomposition of the exchange rate series into appreciations and depreciations of the BRL.

3.2. Asymmetric Exchange Rate Pass-through: Theory

According to existing theoretical literature, asymmetric exchange rate pass-through is usually understood to mean that domestic currency appreciations and depreciations have different magnitude impact over prices.[14]

As Webber (1999) notes, the theoretical literature offers three groups of explanations for asymmetry: (i) marketing constraints, formulated by Foster and Baldwin (1986) and Knetter (1994); refers to the case where exporters are unable to raise their sales in face of an increased demand for imports as a result of a fall in price caused by an appreciation of the local currency (this situation results in exchange rate pass-through after devaluations greater than after appreciations); (ii) production technology switching; if the producing firm has the possibility to buy its inputs not only domestically but also to import, appreciations may result in a higher exchange rate pass-through than depreciations (Ware and Winter, 1988); and (iii) market share objectives; this possibility is usually alluded by Pricing to Market literature, notably by Froot and Klemperer (1989), Marston (1990) and Krugman (1987). It happens when the exporting firms are trying to set the lowest possible price in the importer currency, in order to increase sales and market share. In this case, exchange rate pass-through after appreciations is higher than after depreciations.

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[13] For instance, Brun-Aguerre (2017), Pollard and Coughlin (2004), Herzberg *et al. (*2003), Bussiere (2013), Webber (1999b), Wickremasinghe and Silvapulle (2004), Campa *et al.* (2008), Alvarez *et al.* (2008), Gil-Pareja (2000), and Karoro et al. (2009), estimate asymmetric exchange rate pass-through to import prices. Khundrakpam (2007) employ producer prices. Mihaljek and Klau (2008), Przystupa and Wróbel (2009), Delatte and López-Villavicencio (2011) utilize asymmetric exchange rate pass-through to consumer prices. All these papers decompose the exchange rate in appreciations and depreciations.

[14] Sometimes it also refers to the speed that exchange rate fluctuations affect prices.

Thus, two of the three theoretical reasons found in literature lead to a higher pass-through after a currency appreciation rather than after a depreciation. It is, however, generally believed that prices are rigid downward due to firms being more likely to increase their mark-up than to reduce it. In this case, the effects over prices after a depreciation of the currency would be greater than after an appreciation. Therefore, literature on downward rigidity of prices and asymmetric price transmission also apply to asymmetric exchange rate pass-through.

From a macroeconomic perspective, the exchange rate pass-through may be asymmetric if the Monetary Authority is concerned with inflationary pressures arising from exchange rate movements and reacts more strongly after a currency devaluation than after an appreciation (Delatte and Villavicencio, 2011). Furthermore, the exchange rate pass-through may depend on the level of economic activity. In periods of economic recessions, for example, the effects of a depreciation in raising prices may be smaller than the effects of an appreciation in reducing domestic prices (Goldfajn and Werlang, 2000).

In general, literature suggests that price adjustments to exchange rate fluctuations depend on market structures and firm pricing strategies, which will differ from industry to industry and from country to country.[15] The existence and direction of asymmetric exchange rate pass-through to prices may not be asserted *a priori*. Generally, industries producing homogeneous and globally marketable products should present a higher pass-through and less possibility of asymmetry, whereas industries whose products are more differentiated and where market structure is less competitive have greater possibility of presenting asymmetries and nonlinearities.

4. Asymmetric Exchange Rate Pass-through: empirical evidence from Brazil (1999-2016)

4.1. Data Base

The econometric model estimated is based on Belaisch (2003) and Araújo and Modenesi (2010), and own elaboration as above, and is extensively used in the Brazilian exchange rate pass-through literature. Inflation is determined by its lags and three other factors: i) aggregate demand (or level of economic activity) as measured by industrial output; ii) aggregate supply conditions, a commodity price index is used as proxy; and (iii) the nominal exchange rate.

Intuition behind this equation is simple. Inflation dynamics depends on three components: i) aggregate demand; ii) supply (or cost) conditions; and iii) the exchange rate. In line with Vernengo (2006), this equation comprises both orthodox and heterodox theories of inflation. Friedman (1968), an exponent of orthodox theory, emphasizes demand pressures (resulting from excessive money supply). Davidson (2003), a prominent Post Keynesian author, advocates cost-push inflation pressure. Finally, there is a lot empirical evidence showing that exchange rate plays a significant role in inflation dynamics (Taylor, 2001), particularly in emerging economies (see for instance, Silva and Vernengo, 2008-2009).

[15] According to Goldfajn and Werlang (2000), Calvo and Reinhart (2000) and Frenkel et al (2005), ERTP is higher for the emerging countries than for developed countries. Additionally, in emerging countries, with currencies placed at the lower end of the currency hierarchy, exchange rate is prone to be more volatile (Paula et. al, 2017).

All variables are monthly observations for the period from August 1999 to June 2016 and are used in first difference of logarithms. August 1999 was chosen as the starting period for two reasons. Firstly, inflation targeting regime was officially established in Brazil in June 1999. Secondly, there is a major methodological break in the IPCA in August 1999 when components weights were updated. The variables used are described below (and plotted in the Appendix):

i) CPI: Consumer price index, measured by IBGE and used in Brazilian IT Regime
ii) Y: industrial output (*quantum*) measured by IBGE as proxy for aggregate demand.
iii) COMM: a commodities price index, constructed with IMF commodities prices data using method proposed by the Brazilian Institute for Applied Economic Research (IPEA) (Nonnenberg and Lameiras, 2005) as proxy for aggregate supply conditions.
iv) ER: Exchange rate BRL/USD, monthly average provided by BCB.

The industrial output index was chosen as a proxy due to non-availability of a monthly series suitable for economic activity at the aggregate level. Although industrial output is frequently used in the Brazilian econometric literature, it should be noted that this indicator has limitations because it represents only about 30% of the Gross Domestic Product (GDP).
A commodities price index was calculated using a method proposed by IPEA (Nonnenberg and Lameiras, 2005). Commodity prices from IMF database were weighted according to the Brazilian production structure measured by the producer price index (PPI) provided by Fundação Getulio Vargas (FGV).
Usually the Brazilian exchange rate pass-through econometric literature uses IMF's commodities index. It is an important remark, however, that in IMF's index the oil prices share is higher (53.6%) than in COMM index (18%). Also, food and beverage share in IMF's index is lower (13.8%) than in COMM index (48%).
The commodity price index can be a proxy for international cost conditions. An increase in commodities prices can be interpreted as a supply shock leading to inflationary pressures (Araújo and Modenesi, 2010). Furthermore, given the high share of commodities in Brazil's exports, an increase in commodities prices may imply higher profit for exporters and a positive demand shock. In other words, external variables (exchange rate and commodities prices) may represent supply shocks (via costs) and demand shocks (via exports). In both cases, an increase in commodities prices is expected to have a positive effect on consumer prices leading to inflationary pressures.
The exchange rate series was decomposed into two series based on period-to-period price variations, as presented in the appendix. The currency devaluation series presents only **positive** exchange rate variations whereas the currency appreciation series presents only **negative** exchange rate variations. One should note that a decrease in exchange rate (BRL/USD) is equivalent to an appreciation of BRL.

4.2. Econometric Estimation and Results

As most macroeconomic variables are inter-related, an autoregressive system (VAR) is the benchmark model widely used by macroeconomists. In VAR models, macroeconomic variables may be all treated as endogenously determine.[16]

Two SVAR models were estimated, a symmetric and an asymmetric model.[17]

i) Symmetric: $Y_t = (\Delta CPI_t, \Delta ER_t, \Delta COMM_t, \Delta Y_t)'$

ii) Asymmetric: $Y_t = (\Delta CPI_t, \Delta ER_t^+, \Delta ER_t^-, \Delta COMM_t, \Delta Y_t)'$

Where CPI is the consumer price index; ER is the exchange rate; ER_t^+, increases in exchange rate (BRL/USD), equivalent to depreciations of Brazilian currency; ER_t^- decreases in exchange rate (BRL/USD), equivalent to appreciations of Brazilian currency; COMM is the commodities price index and Y is industrial output, as described previously.

Model specification in SVAR context involves selecting lag order and imposing restrictions on SVAR parameters in order to estimate impulse response functions and variance decomposition. Details about SVAR identification are presented in appendix.

The criterion to impose restrictions was the analysis of the error correlation matrix and the selection of the pairs of variables with high correlation errors. Then restrictions were imposed only for the selected pairs: i) commodities prices contemporaneously affect all other variables; ii) exchange rate contemporaneously affects industrial output and consumer prices iii) industrial output contemporaneously affects consumer prices.

The selection of the lag order was used to find the most parsimonious model with well-behaved residues that satisfied the stability condition, i.e. that the characteristic polynomial inverse roots lie inside the unit circle.[18] The symmetric and asymmetric models were estimated with the same number of lags so that results could be directly compared.

Wald coefficient restriction tests were performed for the asymmetric model to test the hypothesis that local currency depreciations coefficients are statistically different from currency appreciations coefficients. Two different specifications of the Wald test were implemented, as presented in the appendix, and for both of them test statistics reject the null hypothesis that coefficients are equal at conventional significance levels. Therefore, results indicate the existence of asymmetry, i.e. that exchange rate devaluations have different effects on inflation than exchange rate appreciations.

Variance decomposition analysis can be used for interpreting the interrelated dynamic in SVAR models. This method estimates the amount of variation in each of the endogenous variables in the system of equations due to exogenous shocks in each of the other endogenous variables over some period. Thus, the variance decomposition provides information about the relative importance of shocks in affecting the variables in the SVAR.[19]

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[16] "Most recent empirical studies of monetary policy and real economic activity have adopted a vector autoregression (VAR)" (Walsh, 2003, 24).

[17] For details on the SVAR models used, and the decomposition of the exchange rate series (*ER)* into ER^+ and ER^- see appendix.

[18] Residuals that are not autocorrelated, nor heteroskedastic, and are normally distributed. For residual autocorrelation Portmanteau and Lagrange Multiplier tests were performed. For residual normality, the multivariate Jarque-Bera and White's test for heteroskedasticity of residuals.

[19] The same structural factorization used to calculate impulse response functions was used in variance decomposition.

In table 1, the second column contains the forecast error of the variable at the given forecast horizon. The remaining columns give the percentage of the forecast variance due to each shock with each row adding up to 100.

Table 1 shows variance decomposition of the symmetric and asymmetric models. For the symmetric model, the results show that exchange rate shocks are the major factor affecting consumer price variations. Commodity prices are the second most relevant factor, although its share after 12 periods in consumer price variations (2.1%) is much lower than the exchange rate (26.6%). Industrial output is the least relevant factor with only 1% of the consumer price variance being explained by its shocks.

For the asymmetric model (lower part of Table 1), results indicate that shocks to commodity prices and industrial output result in forecast error percentages in consumer price variations (after 12 months) similar to those obtained for the symmetric model. In the asymmetric model, the exchange rate series was decomposed into positive (currency devaluations) and negative (currency appreciations) variations. Together, they represent 27.6% of consumer price variance after 12 periods, a result also similar to the symmetric model. However, when analyzed separately, currency devaluations shocks have a greater share in price variance (24%) than currency appreciations (3,6%). This result gives further evidence for asymmetric exchange rate pass-through.

Table 1: **Variance Decomposition – Symmetric and Asymmetric Models**

Symmetric Model					
Period	**s.e.**	**ER**	**COMM**	**Y**	**CPI**
1	0.27	0.00	0.00	0.00	100.00
2	0.33	4.58	0.90	0.45	94.08
3	0.35	10.35	1.82	0.59	87.25
4	0.36	15.83	2.04	0.54	81.58
5	0.39	21.79	1.90	0.83	75.47
6	0.40	25.03	1.98	1.04	71.95
12	0.40	26.53	2.13	1.10	70.24
Asymmetric Model					
Period	**s.e.**	**ER +**	**ER -**	**COMM**	**Y**	**CPI**
1	0.27	0.00	0.00	0.00	0.00	100.00
2	0.32	3.80	0.46	0.76	0.63	94.36
3	0.34	6.50	2.71	1.73	1.10	87.96
4	0.36	10.20	3.98	2.17	1.05	82.61
5	0.38	17.75	3.68	1.93	1.50	75.14
6	0.39	22.25	3.45	1.94	1.67	70.69
12	0.40	24.00	3.57	2.17	1.81	68.45

Source: Author's estimation. Note: ER (-) means a decrease in exchange rate (BRL/USD) and it is equivalent to an appreciation of Brazilian currency.

As the exchange rate pass-through can be defined as the percentage response of prices to a one percent shock in the exchange rate (McCarthy, 2007; Campa and Goldberg, 2005), it can be also calculated from the impulse response functions estimated from SVAR models.
Table 2 shows the symmetric and asymmetric estimated exchange rate pass-through for Brazil from 1999 to 2016. As expected, results show that pass-through after a currency devaluation is higher (16%) than after an appreciation (5.8%).

Table 2. **Exchange Rate Pass-Through**

Period	Symmetric	Asymmetric	
		(+)	(-)
1	0.00	0.00	0.00
2	1.46	1.82	0.93
3	3.10	3.43	2.84
4	4.72	5.36	4.22
5	6.36	7.75	4.69
6	7.77	10.02	4.81
7	8.82	11.82	5.17
8	9.59	12.90	5.70
9	10.37	14.19	5.91
10	11.00	15.61	5.83
11	11.23	16.40	5.80
12	11.21	16.71	5.80

Source: Author's estimation. Note: (-) means a decrease in exchange rate (BRL/USD) and it is equivalent to an appreciation of Brazilian currency.

In summary, the results of the three analysis (Wald tests, variance decomposition and exchange rate estimation) offer compelling evidence of asymmetric exchange rate pass-through with pass-through after a devaluation being higher than after an appreciation.

5. Concluding Remarks: Inflation Dynamics and Policy Implications

The present chapter analyzes exchange rate pass-through to consumer prices in Brazil. The main objective is to search for evidence of asymmetric pass-through to consumer prices, i.e., that devaluations of the domestic currency affect domestic prices differently from appreciations. The analysis covers the period from August 1999 to June 2016, beginning after the adoption of the IT regime and *de facto* dirty floating exchange rate.

In this chapter, asymmetric exchange rate pass-through is investigated through the estimation of SVAR models with exchange rate decomposed, period by period, into currency devaluations and appreciations.

Wald coefficient restrictions tests and variance decomposition analysis are performed and symmetric and asymmetric pass-through are estimated through impulse response functions. Taken together, the results offer compelling evidence of asymmetric exchange rate pass-through in Brazil. Estimated pass-through after a currency devaluation is 16% while after an appreciation 5.8%.

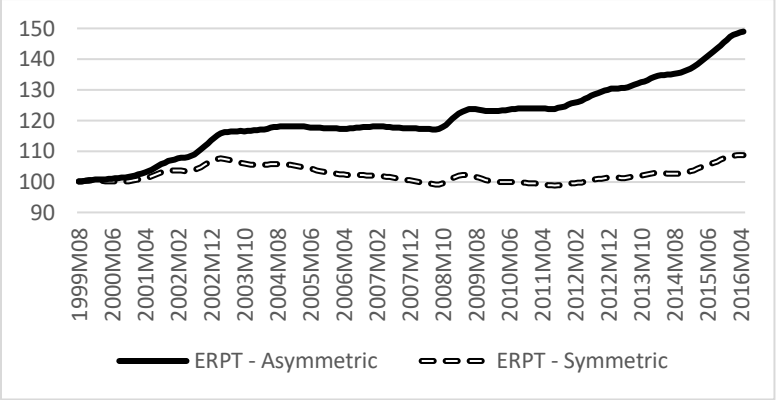
It is important to highlight a relevant implication of our results for inflation dynamics. The asymmetric exchange rate pass-through implies that the inflationary effect of (systematic) currency devaluation is not fully offset by the deflationary effect of (systematic) appreciation of the same magnitude.

For instance, consider a currency devaluation followed by an appreciation of the same magnitude so that the exchange rate returns to its initial level. Given a symmetric exchange rate pass-through, the final effect on inflation would be zero. After the currency appreciation,

the price level would eventually return to the level observed before the initial devaluation. In other words, the inflationary impact on prices of the devaluation would be completely offset by the deflationary effect of the currency appreciation. In the presence of asymmetry, the net result will be an increase in price level.

To illustrate this result, we simulated the impact of exchange rate variations on IPCA from 1999 through 2016, based on our estimations (Table 4). The bold line in Graph 4 shows the trajectory of the IPCA under asymmetric pass-through, while the dotted line shows the simulated index under the hypothesis of a symmetric pass-through. The asymmetric pass-through simulation results in a strong upward trend: Accumulated inflation is around 50%. For the symmetric pass-through (dotted line), the simulated IPCA fluctuates around its initial level: Eventually, accumulated inflation would converge to zero.[20]

Graph 4. **Simulation: Exchange Rate Pass-Through (Asymmetric and Symmetric) (1999.08 = 100)**



Source: Author's elaboration.

In a few words, if pass-through were symmetric, exchange rate fluctuations would have a neutral inflationary impact. The asymmetric exchange rate pass-through implies that the inflationary effect of a (systematic) currency devaluation is not fully offset by the deflationary effect of a (systematic) appreciation of the same magnitude. In a few words, exchange rate fluctuations may result in an (upward) inflationary bias.

This empirical result helps to explain a stylized fact of Brazilian economy, the downward rigidity of the IPCA. This result also cast doubts on the current inflation control strategy, based on IT and *de facto* dirty floating exchange rate (with capital mobility).

Our results provide a strong case against excess exchange rate volatility and capital mobility. Accordingly, a stable exchange rate may favor price stability. Indeed, many authors favor a stable exchange rate. For instance, Keynes (1943; 1980, p. 8), Davidson (2003), Kregel (2015), Carvalho (2000-2001), and Paula et. al (2017), amongst others Post Keynesians authors, advocate exchange rate interventions and capital controls to stabilize the exchange rate. For Krugman and Obstfeld (1997), an unstable exchange rate raises uncertainty

[20] The simulated indexes are a partial analysis that only considers the impact of exchange rate variations on the IPCA for comparative purposes, not considering other factors also important for the dynamics of the Brazilian inflation rate. The upward trend shown by the simulated asymmetric index resembles much more the observed trajectory of actual IPCA.

regarding export/import revenues. Accordingly, excessive exchange rate volatility would jeopardize trade. Although we do not aim at addressing this debate explicitly, the existence of an asymmetric pass-through may be another item in the list in favor of stable exchange rates.

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APPENDIX

1. SVAR model

Consider a K-dimensional time series $Y_t = (y_1, y_2, y_3, y_4)'$ where Y_t is a SVAR of finite order p of the structural form

$$AY_t = v_0 + B_1 Y_{t-1} + \cdots + B_p Y_{t-p} + Bu_t \quad (1)$$

Where A is a KxK matrix that defines the causal interrelationships among the contemporaneous variables and u_t denotes a mean zero uncorrelated error term (also referred to as structural innovation or structural shock) with a variance-covariance matrix $E(u_t, u_t') = \Sigma_u$. Because structural shocks are by definition uncorrelated, Σ_u is a diagonal matrix (KILLIAN, 2011).

Equation (1) cannot be estimated by ordinary least squares (OLS) since the variables have contemporaneous effects on each other. OLS estimates would suffer from simultaneous equation bias since the regressors and error terms would be correlated (ENDERS, 2014).

In order to allow estimation it is necessary to derive its reduced form representation. Premultiplication on both sides of equation (1) by A^{-1} allows the reduced form (2) to be obtained.

$$Y_t = c_0 + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \cdots + \Phi_p Y_{t-p} + e_t \quad (2)$$

Where $c_0 = A^{-1}v_0$; $\Phi_i = A^{-1}B_i$; $Ae_t = Bu_t$.

Standard OLS method obtain consistent estimates of the reduced form (2) parameters Φ_i, the reduced form errors e_t and their covariance matrix $E(e_t e_t')$=Σ_e (LÜTKEPOHL, 2005)

However, the reduced form errors are correlated. Only in the special case where there are no contemporaneous effects among variables (i.e. matrix A elements, a_{ij} $(i \neq j)$, equals zero) the shocks will be uncorrelated.

It is possible, however, to recover the structural VAR coefficients and analyze how Y_t respond to structural shocks in u_t, from the estimates of the model in reduced form since, by construction, $Ae_t = Bu_t$. Hence, the variance of e_t is

$$\Sigma_e = A^{-1}B\Sigma_u B' A^{-1\prime} \quad (3)$$

Σ_e can be consistently estimate from the reduced form by OLS and the system can be solved for the unknown parameters provided that the number of unknown parameters do not exceed the number of equations. This involves imposing restrictions on matrix *A*. Usually, the most common approach is to impose $a_{ij} = 0$ restrictions. (KILIAN, 2011)[21]

The assumption $a_{ij} = 0$ means that *yj* does not have a contemporaneous effect on *yi*. The imposition of different restrictions will result in different impulse response functions

[21] It is necessary to impose $K(K+1)/2$ restrictions on both matrices *A* and *B* to satisfy order condition. The order condition is necessary for identification but may not suffice if rank condition fail. Rubio-Ramirez *et al.* (2010) discuss rank conditions for identification in SVAR models.

depending on the correlation between errors in the reduced form. Only if all reduced form errors are uncorrelated impulse-response functions will be the same regardless of the restrictions imposed.

1.1. Asymmetry

One possible approach to investigate the existence of asymmetric effects of x_t on y_t is to decompose the variable x_t into two new series: x_t^+ of its positive variations and x_t^- , of the negative variations
Based on Schorderet (2004) and Granger and Yoon (2002) method, a time series can be decomposed as follows:

$$x_t = x_0 + x_t^+ + x_t^- \tag{4}$$

Where

$$x_t^+ = \sum_{i=1}^{t} \theta_i(\Delta x_i) \quad ; \quad \begin{cases} \theta_i = 1 \; se \; \Delta x_i > 0, \\ 0, \; otherwise. \end{cases} \tag{5}$$

$$x_t^- = \sum_{i=1}^{t} \theta_i^*(\Delta x_i) \quad ; \quad \begin{cases} \theta_i^* = 1 \; se \; \Delta x_i < 0, \\ 0, \; otherwise. \end{cases} \tag{6}$$

Such as that, x_t value, for all *t*, is equal to its initial value (x_0) plus the sum of all its positive and negative variations up to t.
In this way, we have first difference of x_t^+ and x_t^- series:

$$dx_t^+ = \theta_i(\Delta x_i) \quad ; \quad \begin{cases} \theta_i = 1 \; se \; \Delta x_i > 0, \\ 0, \; otherwise. \end{cases} \tag{7}$$

$$dx_t^- = \theta_i^*(\Delta x_i) \quad ; \quad \begin{cases} \theta_i^* = 1 \; se \; \Delta x_i < 0, \\ 0, \; otherwise. \end{cases} \tag{8}$$

The decomposition in form (5) and (6) is known in literature as decomposition by cumulative variations whereas the form in (7) and (8) is known as period-to-period variations.
Series decomposed by cumulative variations have unit root and cointegrate and are used in the estimation of error correction models (ECM) and its multivariate form vector error correction (VEC).
For purpose of this chapter, that estimates a model with the stationary variables in first difference, the most adequate decomposition, that was used, is the period-to-period decomposition.

1.2.Exchange Rate Pass-Through

The exchange rate pass-through can be calculated from impulse response functions estimated by the SVAR model. This method was used by McCarthy (2007) to calculate the exchange rate pass-through for several industrialized countries and by Belaisch (2003) and Araújo and Modenesi (2010) for Brazil.

$$R_{t,t+j} = \left(\frac{\Sigma \Delta CPI_{t,t+j}}{\Sigma \Delta \mathrm{ER}_{t,t+j}}\right).100 \quad (9)$$

Where ΔCPI is consumer price index variations and ΔER exchange rate variations.

1.3.Wald Coefficient Restriction Test

Wald coefficient restriction tests were performed in asymmetric models to test the hypothesis that the coefficients relative to exchange rate positive variations are statistically different from the negative variations.
The test was performed under two different null hypothesis specifications:
H_0 (A): null hypothesis that the sum of the coefficients of x^+ lags is equal to the sum of the coefficients of x^- lags.
H_0 (B): null hypothesis that the lag coefficient *i* of y^+ is equal to the lag coefficient *i* of y^- for all lags.
To illustrate, generically, a two lags model, SVAR (2), and three variables, $Y_t = (y_1^+, y_1^-, y_2)'$, where y_1^+ and y_1^- are period-to-period decompositions of y_1
In reduced form:

$$Y_t = c_0 + \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + e_t \quad (10)$$

Can be written in the form

$$\begin{cases} {y_1}_t^+ = c_1 {y_1}_{t-1}^+ + c_2 {y_1}_{t-2}^+ + c_3 {y_1}_{t-1}^- + c_4 {y_1}_{t-2}^- + c_5 {y_2}_{t-1} + c_6 \Delta {y_2}_{t-2} + c_7 \\ {y_1}_t^- = c_8 {y_1}_{t-1}^+ + c_9 {y_1}_{t-2}^+ + c_{10} {y_1}_{t-1}^- + c_{11} {y_1}_{t-2}^- + c_{12} {y_2}_{t-1} + c_{13} \Delta {y_2}_{t-2} + c_{14} \\ {y_2}_t = c_{15} {y_1}_{t-1}^+ + c_{16} {y_1}_{t-2}^+ + c_{17} {y_1}_{t-1}^- + c_{18} {y_1}_{t-2}^- + c_{19} {y_2}_{t-1} + c_{20} \Delta {y_2}_{t-2} + c_{21} \end{cases}$$

The Wald test was then calculated under H_0 with two different specifications
H_0 (A):

$$H_0: c_1 + c_2 = c_3 + c_4 \; and \; c_8 + c_9 = c_{10} + c_{11} \; and \; c_{15} + c_{16} = c_{17} + c_{18}$$

H_0 (B):

$$H_0: c_1 = c_3 \; and \; c_2 = c_4 \; e \; c_8 = c_{10} \; and \; c_9 = c_{11} \; and \; c_{15} = c_{17} \; e \; c_{16} = c_{18}$$

Under H_0, the Wald statistic is asymptotically distributed as a $\chi^2(q)$, where q is the number of linear restrictions.
Wald test statistics reject the null hypothesis that coefficients are equal at conventional significance levels. Under the null hypothesis A, the test statistic was 8.38 (0.08 p-value). Under the null hypothesis B, test statistic was 16.57 (0.03 p-value). Therefore, results indicate the existence of asymmetry, that is, that exchange rate devaluations have different effects on inflation than exchange rate appreciations.