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Asymmetry of Relative Prices and Inflation Dynamics in Brazil

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Abstract

This paper analyzes how the asymmetry of relative prices fits as a measure of supply shock in the Hybrid New Keynesian Phillips Curve (HNPKC). For this purpose, monthly data from January 2003 to December 2023 is used, along with the generalized method of moments robust to heteroskedasticity and autocorrelation (GMM-HAC). The results indicate that the asymmetry of relative prices performs well as an indicator of supply shocks, having a positive effect on inflation, and its impact is amplified in a scenario of greater economic instability. Additionally, there is evidence of strong inertial inflation that intensifies in an unstable environment, while forward-looking expectations are statistically significant only in stable conditions. Finally, the output gap is statistically significant regardless of the macroeconomic scenario analyzed.

Keywords: Asymmetry of Relative Prices, HNKPC, GMM-HAC

1. Introduction

According to Friedman (1975), real factors in the economy affect the relative prices of markets, while the level of prices is determined by the money supply. Thus, given a stock of money, changes in relative prices translate into increases in some prices and decreases in others; that is, changes in relative prices would not translate into alterations in the general level of prices.

In contrast to Friedman's view (1975), Ball & Mankiw (1995) propose a menu cost model in which changes in relative prices affect the general level of prices. The authors argue that fluctuations in relative prices can be interpreted as supply shocks in the analysis of inflation dynamics. Using the third moment of the variations in relative prices as a measure of price asymmetry, the authors conclude that measures of asymmetry incorporate a significant fraction of inflation dynamics in the U.S. from the early second half of the 20th century until the end of the 1980s, especially in the 1970s.

More recent works such as Assarsson (2004), Rátfai (2004), and Çatik, Martin, & Onder (2011) seek to study the impact of the asymmetry of changes in relative prices on inflation or the adequacy of this indicator in estimating the Phillips Curve and conclude that this variable has a positive and statistically robust impact on modeling the Phillips Curve.

In Brazil, the discussion about the Phillips Curve began with the seminal work of Cysne (1985). The author concluded that there is no trade-off between inflation and idle capacity in the long run for the period between 1950 and 1983 and that supply shocks, such as the oil shock, should be included as variables that explain the change in the level of inflation in the 1980s.

More recent works such as Mendonça, Sachsida, & Medrano (2012), Sachsida (2013), Arruda, Oliveira, & Castelar (2017, 2018), and Brito, Arruda, Castelar, Trompieri Neto & Santos (2019) point out that, in addition to the traditional trade-off between inflation and unemployment, Brazilian inflation dynamics are related to components of backward-looking and forward-looking expectations, a measure of economic cycles/marginal costs of firms, and a variable for supply shocks. This version is known in the literature as the Hybrid New Keynesian Phillips Curve (HNPKC), proposed by Blanchard & Gali (2007).

Although well-adjusted to capture brazilian inflation dynamics, the results of the HNPKC estimations prove sensitive to the various proxies adopted (Arruda et al., 2017, 2018; Brito et al., 2019), especially regarding the supply shock variable. In this regard, Sachsida (2013) highlights that the exchange rate pass-through, the most used proxy for supply shock in the national literature, shows contradictory signs and statistically insignificant results in some cases across

different exercises.

Therefore, considering the possible inadequacy of the traditionally employed exchange rate pass-through variable as an indicator of supply shock in the HNPKC in Brazil, the present study proposes to fill this gap; that is, based on the theoretical framework presented by Ball & Mankiw (1995) and empirical exercises such as those by Assarsson (2004), Rátfai (2004), and Bernanke & Blanchard (2024), the asymmetry of relative price changes will be utilized as a variable, which may reflect supply shocks in the HNPKC.

It should be noted that, in a recent study, Bernanke & Blanchard (2024) stress that the inflation peak observed in eleven countries in the post-pandemic period was largely due to supply problems for certain products and shocks in relative prices. Thus, the standardized Fisher-Pearson moment coefficient adjusted will be used as a proxy for price asymmetry, and we will test whether this measure is suitable for modeling supply shocks in the HNPKC of Brazil. Furthermore, different macroeconomic scenarios of the Brazilian economy will also be considered.

To this end, HNPKC estimations for the Brazilian economy will employ the generalized method of moments with correction for heteroscedasticity and correlation (GMM-HAC) and monthly data between January 2003 and December 2023. Following the pattern of recent literature applied to Brazil, inflation measured by the IPCA will be used; the IBC-BR gap, as a variable for economic cycles; lagged IPCA inflation to capture inflation inertia; the average expectations from the Central Bank of Brazil's FOCUS report as a measure of forward-looking expectations; and the adjusted standardized Fisher-Pearson moment coefficient as an indicator of supply shock, in the manner suggested by Ball & Mankiw (1995).

Thus, the main contribution of this work lies in evaluating the adjusted standardized Fisher-Pearson moment coefficient as a measure of supply shock in the HNPKC. Additionally, to incorporate different macroeconomic scenarios, three empirical exercises will be conducted following the discussion in Barbosa Filho (2017): the first encompasses the complete sample; the second analyzes the HNPKC for the period from January 2003 to December 2013; finally, a HNPKC is estimated for the period from January 2014 to December 2023. Besides evaluating the stability of the HNPKC for the Brazilian economy in distinct scenarios, particularly regarding the proxy for supply shock used, one can identify asymmetries in the effects of the explanatory variables on the Brazilian inflation dynamics.

In addition to this section, this study contains four more sections. The second section presents a literature review on the impact of relative price asymmetry on inflation and on the HNPKC in Brazil. Next, the methodological aspects of the research are presented, which involve the description of the data, the presentation of the empirical model, and the econometric strategy. In the fourth section, the results are presented and discussed. Finally, the concluding remarks are made.

2. Literature Review

2.1 Fluctuations of Relative Prices and Inflation

In a pioneering study, Ball & Mankiw (1995) use the theoretical framework of menu[1] cost models to argue that the third moment of price changes and inflation are positively correlated. In this sense, inflation would be affected by the distribution of relative prices. If it were asymmetrical to the right or to the left, prices would be positively and negatively affected, respectively. Thus, the results obtained by the authors explain changes in the short-term Phillips Curve in the early 1970s in the U.S. and how the third moment of variations in relative prices influences the trade-off between inflation and unemployment. Moreover, this measure of asymmetry showed stability in subperiods, leading the authors to advocate for the third moment as a better measure of supply shock than those used at the time.

Adopting a distinct theoretical approach compared to Ball & Mankiw (1995), Balke & Wynne (2000) develop a general equilibrium model with multiple sectors and flexible prices, observing that productivity[2] shocks in a specific sector will imply a relative decline in the price of that sector. Therefore, if enough industries are affected by sector-specific productivity shocks of the same sign, and some sectors are more affected than others, a model of flexible prices also allows for a positive correlation between inflation and the third moment of relative price changes.

Using an empirical analysis, Dopke & Pierdzioch (2003) opt to study the relationship between aggregate inflation and the third moment of the distribution of relative price changes for Germany between 1969 and 2000. The authors use different specifications to model inflation and find that the third moment of the distribution of relative price changes has a significant positive effect. In this regard, the second moment of the distribution of relative prices also shows a positive effect. Additionally, the authors conclude that changes in the Phillips Curve can be modeled using a measure of asymmetry of relative price changes as supply shocks.

Aucremanne, Brys, Hubert, Rousseeuw, Struyf (2002) examine the consumer price distribution in Belgium and its interaction with aggregate inflation between June 1976 and September 2000. In this sense, given that this distribution naturally has large tails, both classical and robust measures of location, scale, and asymmetry were used. Thus, the

authors found a short-term positive effect of the asymmetry of relative prices on aggregate inflation, regardless of the inflation level. Furthermore, they observed that the dispersion of relative prices also has a positive short-term effect, but this effect depends on the prevailing monetary regime. Finally, a rightward asymmetry in the distribution of relative prices was found to cointegrate positively with aggregate inflation, suggesting that such asymmetry would be endogenous to the inflationary process and would disappear with zero inflation.

Seeking a better identification of the Swedish Phillips Curve, Assarsson (2004) criticizes the previous exclusion of both the variance of relative prices and a measure of price asymmetry as explanatory variables of inflation. In this sense, the author uses data from the Swedish economy between 1980 and 2003 to make various estimates of different Phillips Curves and obtain the specification that best estimates inflation. The results indicate that including both variance and asymmetry of the distribution of relative prices improves the fit of the Swedish Phillips Curve, and these variables stand out in terms of magnitude of impact.

Studying the dynamic interaction between inflation and asymmetry of relative prices, Rátfai (2004) applies structural bivariate VAR models of inflation and relative price asymmetry to evaluate the impact of idiosyncratic shocks on the dynamics of aggregate price changes in the short term. To do this, the author uses monthly price data from Hungary between January 1992 and July 1996. The results indicate that idiosyncratic shocks explain between 25% to 30% of the forecast error variance of inflation over a twelve-month horizon. Furthermore, the correlation between relative price asymmetry and inflation is positive, and idiosyncratic shocks lead to a substantial accumulation of inflation two to five months after the initial disturbance.

After identifying uncertainty regarding the best specification of the Phillips Curve for Turkey, Çatik et al. (2011) add measures of variance and asymmetry of relative prices to define a model that better explains inflation. The authors use monthly data from 1996 to 2007 and an ARDL model to establish the long-term relationship between the variables. Initially, a traditional Phillips Curve model is estimated, and no long-term relationship between inflation and output is found. However, when variance and asymmetry of relative price changes are included in this model, a long-term relationship is established, and the effect of asymmetry is greater than that of variance in inflation, a result that supports the hypothesis formulated by Ball & Mankiw (1995).

Silva (2015) analyzed the causal relationship between inflation and the variability of relative prices in Brazil during the period from January 1995 to June 2011. Thus, the author employed time series methods to study this relationship and focused his analysis on the Consumer Price Index (IPCA), in its core, and considered the period in which the inflation targeting regime was implemented. The results indicate that the correlation between inflation and the dispersion of its prices is positive and significant and that during the inflation targeting regime, the impact of price dispersion was reduced.

Finally, Pereira & Souza (2018) study the relationship between inflation and price volatility for the Brazilian economy after the implementation of the Real Plan. To this end, they calculate the price volatility of eleven state capitals by dividing the post-Real Plan period into three, each with a distinct macroeconomic scenario. From there, they estimated econometric models of standard errors corrected panels and autoregressive vector panels for both the period immediately following the Real Plan until 2016 and for three distinct subperiods. The results of both models indicate a positive relationship between inflation and price volatility, and that this relationship is not constant over time.

2.2 Phillips Curve in Brazil

The inverse relationship between wage inflation and unemployment was developed in the seminal work of Phillips (1958) and became known as the Phillips Curve. This relationship has been studied to this day by the central banks of most countries, especially those that adopt an inflation targeting regime (Hargreaves, Kite & Hodgetts, 2006).

In the Brazilian case, Cysne (1985) developed an innovative work by formulating a Phillips Curve for the period from 1950 to 1983, concluding that there is no trade-off between inflation and idle capacity in the long run. Furthermore, he points out that changes in wage policy between 1979 and 1983 and various supply shocks, such as the oil shock of 1979, should be incorporated as variables that explain the change in the inflation level observed from 1980 onward.

A different approach to the Phillips Curve was employed by Lima (2003), using data from the National Consumer Price Index (INPC) and the average unemployment rate from the early 1980s to the 2000s to estimate the unemployment rate that keeps inflation stable (NAIRU) and the stability of the coefficients of the Brazilian Phillips Curve. In this sense, the author adopts two state-space models: one with a NAIRU that changes according to the specification of a hidden Markov chain and another with a NAIRU that changes over time. The results indicate that there is a significant and negative relationship in response to inflation when cyclical unemployment increases, and that the slope of the Brazilian Phillips Curve remains stable over time, but the Brazilian NAIRU has changed over time.

Schwartzman (2006) uses disaggregated prices to estimate the Brazilian Phillips Curve using the three-stage least squares method. As a result, different versions are estimated to observe the effect of various options used in the

literature, such as the imposition of long-term verticality of the Phillips Curve and the test of the political instability effect in the second half of 2002 on inflation dynamics. The results indicate that the utilization of industrial capacity is a good proxy for the output gap, that there is no observable direct effect of exchange rate depreciations on the prices of non-tradable goods, that the hypothesis of verticality of the Brazilian Phillips Curve cannot be rejected, and that the effect of political uncertainty in the second half of 2002 intensified through the effect of pass-through in tradable goods.

Pioneering the use of the Hybrid New Keynesian Phillips Curve (HNPKC) in Brazil, Areosa & Medeiros (2007) introduce a discussion about the impacts of economic opening on inflation dynamics. To this end, the authors use monthly data from January 1995 to September 2003. They conclude that, in a closed economy version, the economy has strong nominal rigidity and a high degree of indexing, whereas in an open economy model, in addition to these effects, exchange rate appreciation combined with foreign inflation affects consumer inflation, an effect that is intensified the more open the economy is. Furthermore, as an indirect effect, the open economy model strengthens the forward-looking expectations component at the expense of its backward-looking expectations component.

To address possible estimation issues when using instrumental variables, due to potential autocorrelation and heteroscedasticity of errors, Mendonça et al. (2012) use the GMM-HAC method, which accounts for these issues when estimating a HNPKC with monthly data between January 1995 and March 2012. In this regard, the authors utilize various proxies to represent the variables of interest. The results indicate that future inflation expectations and past inflation have a significant impact on the Brazilian inflation process. Moreover, when studying different periods, it is observed that when considering data after 2002, the role of future inflation expectations is greater. However, when considering data in its entirety since 1995, the effect of future inflation expectations is equal to or less than that of inflation inertia.

Arruda et al. (2017) analyze how Brazilian inflation reacts to different forward-looking expectations scenarios in the HNPKC using monthly information from January 2002 to August 2015 and the GMM-HAC estimation method. The authors conclude that Brazilian inflation has a robust inertial component, which in a scenario of lower predictability from agents, becomes more sensitive to cyclical fluctuations in economic activity, and that there is a positive pass-through effect on inflation.

Several studies indicate that the HNPKC is an adequate representation of Brazilian inflation dynamics, such as Mendonça et al. (2012) and Arruda et al. (2017). However, as Sachsida (2013) warns, the results are quite sensitive to the proxies used, and there is room for discussion about alternatives to the traditionally employed indicators.

Ferreira, Gois & Arruda (2018) study the asymmetric effects of the credibility of the monetary policy authority in the HNPKC during the period after the adoption of the Inflation Targeting Regime. To create credibility indices, the authors use the indices of Cecchetti and Krause (2002) and Mendonça & Souza (2007). The results indicate that in a high credibility regime, the forward-looking component is statistically significant, inflation inertia is lower than in a low credibility regime, and the unemployment gap is statistically null. In contrast, in a low credibility regime, future inflation expectations are not significant, inflation inertia is higher than in a high credibility regime, and a trade-off between inflation and unemployment is established. Therefore, higher credibility of monetary policy reduces the costs of a disinflationary monetary policy.

Mansilla, Arruda & Ferreira (2020) analyze asymmetries in the inflation dynamics of Brazil under different trade openness regimes. To this end, a non-linear HNPKC is estimated with the degree of trade openness as the threshold variable, using monthly data from January 2002 to December 2017 and econometric models with threshold effects in the presence of endogenous regressors. The results indicate that in a regime of greater openness, there is an absence of a trade-off between inflation and unemployment and of inflation inertia. In a regime of lower openness, the HNPKC is significant in its original form.

Finally, Brito et al. (2019) investigate whether core inflation measures can be good indicators of inflation expectations and if the estimated parameters are consistent with the literature. To this end, the authors use monthly data from January 2002 to August 2015 and the GMM-HAC method for estimation. The evidence indicates that Brazilian inflation has a strong inertial component, that there is a trade-off between inflation and unemployment, and that there is a pass-through effect of the exchange rate. Additionally, it was observed that core inflation measures proved to be good proxies for inflation expectations.

In summary, recent literature applied to Brazil indicates that the HNPKC has proven to be an important mechanism for modeling Brazilian inflation dynamics. However, regarding the proxy typically employed for supply shocks, the exchange rate pass-through, Sachsida (2013) suggests caution, as empirical evidence presents inconsistent and insignificant signs, and moreover, the pass-through does not have an adequate association with economic theory in the structure of the HNPKC.

Therefore, the present study aims to contribute to this regard by employing the adjusted standardized Fisher-Pearson

moment coefficient as an alternative for modeling supply shocks in the HNPKC. Additionally, exercises will be conducted in sub-samples to examine the robustness of this indicator and any asymmetries in Brazilian inflation dynamics under distinct macroeconomic conditions.

3. Methodological Aspects

3.1 Database

To investigate whether the adjusted standardized Fisher-Pearson moment coefficient is a good proxy for price asymmetry and fits well as a measure of supply shocks in the HNPKC, monthly information from January 2003 to December 2023 will be used. Chart 1 provides a descriptive summary of the variables used and their respective sources.

Chart 1. Summary of the Variables Used

INDICATOR	VARIABLE	PROXY	MEASURE ORIGINAL VARIABLES	DATA SOURCE
Economic Cycle	Output Gap	Outgap of IBC-BR	Index	CBB
Inflation	Inflation	IPCA	Inflation Rate	IBGE/SNIPC
Expectation	Backward-looking expectation	Lagged IPCA	Inflation Rate	IBGE/SNIPC
	Forward-looking expectations	Average Inflation Expectation for the IPCA	Expectation for the Inflation Rate	FOCUS report/CBB
Assimetry of relative prices	Assimetry of relative prices	Adjusted Standardized Fisher-Pearson moment coefficient	Inflation Rate	IBGE/SNIPC

Source: Own elaboration

The inflation variable used is measured based on the Broad Consumer Price Index (IPCA) accumulated over twelve months. This index was obtained from the National Consumer Price System (SNIPC) of the Brazilian Institute of Geography and Statistics (IBGE).

The economic cycle measure employed was the output gap of the Central Bank's Economic Activity Index (IBC-BR). This variable is an economic activity indicator developed by the Central Bank of Brazil (CBB), with its value being subtracted from the trend extracted using the Hodrick-Prescott (HP) filter.

The measure of forward-looking inflation expectations used was the Average Inflation Expectation for the IPCA – the accumulated rate for the next 12 months – generated from the FOCUS report and made available by the Central Bank. The backward-looking expectations indicator, or inflation inertia, used is the lagged IPCA itself.

For the construction of the asymmetry variable, it was considered that the IPCA has different levels of aggregation, such as: group (most aggregated level), subgroup, item, and subitem (most disaggregated level). Thus, 49 subitems were used, distributed across the following groups: Food and Beverages, Housing, Household Items, Clothing, Transportation, Health and Personal Care, Personal Expenses, Education, and Communication. Chart 2, in the appendix, summarizes the inflation subgroups used within each group.

After defining the IPCA subgroups to be employed, the adjusted standardized Fisher-Pearson moment coefficient was used as a measure of asymmetry, which can be expressed by the following formula:

$$A = \frac{n}{(n-1)(n-2)} \sum_{i=1}^{n} \left(\frac{x_i - \bar{x}}{s} \right)^3 \quad (1)$$

where: x_i represents subitem i of the IPCA inflation, detailed in the appendix, $\bar{x}$ is the sample mean of the subitems and *s* is the sample standard deviation of the subitems.

It is worth noting that Joannes & Gill (1998) compare different measures of asymmetry in samples of various sizes from normal and skewed populations, highlighting that the adjusted Fisher-Pearson coefficient performs well with low mean squared error in samples from skewed populations. Furthermore, Doane & Seward (2011) report that this measure, in addition to being widely used in literature, is convenient because it is available in various statistical software packages.

3.2 Hybrid New Keynesian Phillips Curve

Based on micro-founded models of rational expectations, the Keynesian version of the Phillips Curve considers that prices do not change instantly and that there is a direct relationship between inflation and the economic cycle. Furthermore, the New Keynesian Phillips Curve (NKPC) establishes that rising inflation can reduce unemployment in the short term, but it is not capable of reducing it definitively.

However, the original version of the NKPC has a significant deficiency in not considering the inertial, or backward-looking, component of inflation. Therefore, Gali & Gertler (1999) formulated a new version that added this component, which can be developed from the following equation:

$$p_t^* = (1\text{-}\mu)\ p_t^f + \mu\ p_t^b \quad (2)$$

Where, p_t^* is the price level derived from firms' profit maximization, p_t^f is the price set by firms using forward-looking expectations, and p_t^b is the price practiced by the set of firms using backward-looking expectations.

Considering that the two groups set prices differently, the first group of firms sets prices as established by Calvo (1983). Thus, p_t^f will be:

$$p_t^f = (1 - \alpha\theta)\sum_{k=0}^{\infty} (\alpha\theta)^k\ E_t\{cm_{t+k}^n\} \quad (3)$$

The equation (3) is derived from a process of maximizing the present value of firms' expected profits and defines the optimal price chosen by firms as a function of θ[3], the real marginal cost, and a discount factor α (Calvo, 1983). Thus, this equation indicates that firms set their prices equal to the marginal cost in each period t in the absence of frictions or adjustment costs. However, since firms do not change their prices in every period, they must be fixed based on the expectation of the behavior of the expected marginal cost to maximize the present value of expected profits.

The second group of firms forms their expectations in a backward-looking manner, considering the price level of the last period plus its respective inflation.

This formulation can be expressed as follows:

$$p_t^b = p_{t-1}^* + \pi_{t-1} \quad (4)$$

Thus, the representation of the NKPC can be shown as follows:

$$\pi_t = \delta cm_t + \gamma_f\ E_t\{\pi_{t+1}\} + \gamma_b\ \pi_{t-1} \quad (5)$$

Where γ_f is the coefficient of the forward-looking component, γ_b represents the backward-looking term of inflation, and δ incorporates the contribution of firms' marginal costs/economic cycles. It is worth noting that γ_b indicates the degree of inflation persistence, and if $\gamma_f = 0$ the Phillips Curve reverts to its original version.

More recently, Blanchard & Gali (2007) advocated for the inclusion of supply shock impacts on inflation dynamics, which led to the formation of the so-called Hybrid New Keynesian Phillips Curve (HNPKC), which can be represented as follows:

$$\pi_t = \delta cm_t + \gamma_f\ E_t\{\pi_{t+1}\} + \gamma_b\ \pi_{t-1} + \theta\ v_t \quad (6)$$

where θ measures the impact of supply shocks on inflation. Typically, the variable v_t most used in the Brazilian literature is a measure of exchange rate pass-through. However, the observed evidence indicates that this indicator is problematic as it varies according to the number of allowed lags, presents contrary signals, is statistically insignificant, and, most importantly, does not indicate an adequate theoretical association with supply shocks.

In this sense, the present study incorporates the adjusted standardized Fisher-Pearson moment coefficient as a measure of supply shocks, given the theoretical prediction raised by Ball & Mankiw (1995), which demonstrated that these asymmetry indicators are positively related to inflation, cause changes in the trade-off between inflation and unemployment, and justify their use within a menu cost model framework. Furthermore, in a recent study, Bernanke & Blanchard (2024) also indicates that relative prices are important indicators of the supply conditions in the economy.

3.3 Econometric Strategy

Considering that estimating rational expectations models using the Ordinary Least Squares (OLS) method produces inconsistent estimates, since the error term is correlated with some of the endogenous regressors, the most used methods in this type of model are: Generalized Method of Moments (GMM) and Instrumental Variables (IV) method. For example, Blanchard & Gali (2007) use the IV method to estimate the Hybrid New Keynesian Phillips Curve, but as pointed out by Baum, Schaffer & Stillman (2007), in the presence of heteroscedasticity, the GMM method is more appropriate[4].

Thus, to select the best model for estimating, the heteroscedasticity test by Pagan & Hall (1983) is applied in the instrumental variables (IV) estimation. Next, the autocorrelation test by Cumby & Huizinga (1992) is conducted[5]. If the Pagan & Hall (1983) test rejects the null hypothesis of homoscedasticity, the GMM method is used with a correction for this problem. Furthermore, if the Cumby & Huizinga (1992) test indicates serial autocorrelation, the so-called GMM-HAC is utilized, which is a GMM estimator that is consistent in the presence of autocorrelation and heteroscedasticity.

In all the scenarios examined in this study, the presence of heteroscedasticity was detected, and consequently, the generalized method of moments was chosen for all the estimated models. Hansen (1982) shows that if the instruments

are valid, that is, the instruments are orthogonal to the regression disturbance and simultaneously correlated with the endogenous regressors, the GMM estimators are consistent and asymptotically normal. Therefore, the Hansen (1982) overidentification test is used [6]. If the null hypothesis is not rejected, it can be stated that the instruments are appropriate and that the model is correctly estimated. Thus, up to six lags of the IBC-BR output gap, the adjusted standardized Fisher-Pearson moment coefficient, and the IPCA were used.

Therefore, the model to be estimated in this empirical exercise and its orthogonality condition in the GMM estimation are shown in the following equations (7) and (8), respectively:

$$\pi_t = \beta + \lambda cm_t + \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \theta v_t + e_t \quad (7)$$

$$E_t[e_t z_t] = E_t\{(\pi_t - \beta - \lambda cm_t - \gamma_f \pi_{t+1} - \gamma_b \pi_{t-1} - \theta v_t) z_t\} = 0 \quad (8)$$

Finally, the econometric strategy adopted for the estimation of the models used in this study involves initially verifying the presence of heteroscedasticity and serial autocorrelation in the IV estimation using the tests by Pagan & Hall (1983) and Cumby & Huizinga (1992), respectively. If the null hypothesis of homoscedasticity is rejected, GMM with correction for this problem is employed. If autocorrelation is also detected, corrections for both problems are adopted, meaning GMM-HAC is used. Lastly, the Hansen (1982) test is utilized to confirm the validity of the instruments.

4. Analysis and Discussion of the Results

To estimate the proposed HNPKC in this study, an initial analysis of the stationarity of the employed series was conducted using unit root tests. Therefore, three tests were used: the Augmented Dickey-Fuller (ADF) and Phillips–Perron tests, which have the null hypothesis of the presence of a unit root; and the KPSS test, proposed by Kwiatkowski, Phillips, Schmidt & Shin (1992), whose null hypothesis is that the series is stationary. Table 1 summarizes the results of these tests. Unit root tests were applied to each variable separately, as Enders (2015) warns, the assumptions of the classical regression model necessitate that all variables be stationary and that the errors have a zero mean and a finite variance. In the presence of non-stationary variables, there may be what Granger & Newbold (1974) terms a spurious regression.

Table 1. Results of the Unit Root Tests

Variable	ADF	KPSS	Phillips–Perron
Inflation IPCA	-4.43* [-2.87]	0.18 [0.46]	-3.28* [-2.87]
Inflation Expectations	-5.84* [-2.87]	0.33 [0.46]	-5.52* [-2.87]
Output Gap	-6.17* [-2.87]	0.02 [0.46]	-10.15* [-2.87]
Assimetry of Relative Prices	-9.93* [-2.87]	0.03 [0.46]	-8.62* [-2.87]

Source: Own elaboration. The critical value of the test at significance level 5% expressed in brackets.

The results indicate that all the employed series are stationary at the 5% level. Subsequently, to select the best method for estimating the HNPKC, the Pagan & Hall (1983) test was utilized in the estimation by instrumental variables. The results indicate the presence of heteroscedasticity in the HNPKC; therefore, all models were estimated using GMM with correction for this issue. Moreover, the Cumby & Huizinga (1992) test indicated the presence of autocorrelation. Thus, all models were estimated using GMM-HAC, that is, the generalized method of moments robust to heteroscedasticity and autocorrelation. Finally, the analysis of Hansen's (1982) instrument validity test indicates that we cannot reject the null hypothesis that the instruments are valid. The results of the GMM-HAC estimation of the HNPKC are summarized in Table 2.

Table 2. Results of the GMM-HAC Estimation of the HNPKC (Full Sample)

Variable	Coefficient	Standard Error
$E_t\{\pi_{t+1}\}$	0.18*	0.06
π_{t-1}	0.90*	0.02
x_t	0.015*	0.006
v_t	0.025*	0.006
β	-0.40**	0.21
Tests	Test Statistic	Critical Value
Pagan & Hall	44.75*	40.10

Cumby & Huizinga	81.93*	3.84
Hansen J	14.10	35.2

Source: Prepared by the authors based on the equation $\pi_t = \beta + \lambda cm_t + \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \theta v_t + e_t$. Note: * Significant at 5%. ** Significant at 10%. The autocorrelation tests of Cumby and Huizinga and the heteroscedasticity tests of Pagan and Hall were applied in the estimation with instrumental variables.

In general terms, it is observed that all the coefficients were statistically significant at the 5% level. It is worth highlighting that the coefficient associated with inflation inertia, or backward-looking expectations, was found to be greater than that of forward-looking expectations, indicating that Brazilian inflation still has an important inertial component that can be explained by a high level of indexing in the Brazilian economy. Authors such as Arruda et al. (2017, 2018) and Brito et al. (2019) find results in the same direction. On the other hand, Gali and Gertler (1999) find evidence of a HNKPC with a forward-looking component having a greater impact on the U.S. economy.

Analyzing the impact of economic cycles, it is observed that the IBC-BR gap had a positive and statistically significant impact of 0.015, meaning that with an increase of 1 percentage point in economic activity, inflation will increase by 0.015 percentage points. This result strengthens the hypothesis of the trade-off between inflation-unemployment or inflation-economic activity observed by some authors (Mendonça et al. 2012; Sachsida, 2013).

Considering the indicator proposed in the present study for the impact of supply shocks, it is observed that the adjusted standardized moment coefficient of Fisher-Pearson reported a positive and statistically robust impact, meaning that, as discussed by Ball & Mankiw (1995), an asymmetric change in relative prices has inflationary effects. In terms of magnitude, increasing the asymmetry of relative prices by 1 percentage point (p.p.) will raise inflation by 0.025 p.p.

Additionally, bringing the discussion of the impacts of relative price shocks to the present day, Bernanke & Blanchard (2024) developed a theoretical model to analyze inflation dynamics in the post-pandemic period and conclude that, in a set of eleven countries, relative price shocks have impacted inflation positively and significantly, corroborating the results observed in this work.

Considering that the Brazilian economy and other emerging markets are subject to internal and external shocks, as well as changes in the macroeconomic environment, robustness exercises were conducted on subsamples. Following the framework outlined by Barbosa Filho (2017), which describes the severe recession faced by the Brazilian economy, primarily starting in 2014, the periods from January 2003 to December 2013 and from January 2014 to December 2023 were chosen.

In both HNPKC models applied to the subsamples, the tests by Pagan & Hall (1983) and Cumby & Huizinga (1992) also indicated the presence of heteroscedasticity and autocorrelation, respectively. Thus, GMM-HAC was employed in the estimation process for both models. The Hansen (1982) test also confirmed the validity of the instruments used in the estimations. The results of the HNPKC for the periods 2003-2013 and 2014-2023 are summarized in Tables 3 and 4, respectively.

Table 3. Results of the GMM-HAC Estimation of the HNPKC (2003-2013)

Variable	Coefficient	Standard Error
$E_t\{\pi_{t+1}\}$	0.27*	0.04
π_{t-1}	0.84*	0.01
x_t	0.013*	0.005
v_t	0.017*	0.005
β	-0.52*	0.16
Tests	Test Statistic	Critical Value
Pagan & Hall	69.38*	35.2
Cumby & Huizinga	41.60*	3.84
Hansen J	8.6	30.1

Source: Prepared by the authors based on the equation $\pi_t = \beta + \lambda cm_t + \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \theta v_t + e_t$. Note: * Significant at 5%. The autocorrelation tests of Cumby and Huizinga and the heteroscedasticity tests of Pagan and Hall were applied in the estimation with instrumental variables

In the model estimated for the period 2003-2013, the results were like those of the regression for the full sample; that is, all coefficients were statistically significant at the 5% level. It is worth noting that during this pre-crisis period, although the coefficient for inertial inflation remained higher than that of forward-looking expectations, it displayed a greater impact while the latter showed a smaller effect compared to the model with the full sample.

Aligned with the observations by Arruda et al. (2017), this evidence seems to indicate that, in periods of greater economic stability, forward-looking expectations become more anchored and therefore report lower costs for

disinflationary interventions, even though the inertial component still poses a challenge for the Brazilian economy.

Analyzing the impact of economic cycles, it is observed that the IBC-BR gap presented a positive impact of 0.013; that is, with an increase of 1 percentage point (p.p.) in economic activity, inflation will rise by 0.013 p.p. This value is like that of the full sample.

Considering the effect of supply shocks via the asymmetry of relative prices, there is a positive impact of a lower magnitude compared to that observed in the full sample, at 0.017 p.p. As discussed by Ball & Mankiw (1995), the inflationary effects of the asymmetry of relative prices tend to be amplified or attenuated depending on price volatility, evidence corroborated by Bernanke & Blanchard (2024).

When considering the sample that incorporates periods of significant crises, 2014-2023, the results report important changes. In general terms, all estimated coefficients were statistically significant at the 5% level, except for the forward-looking component of expectations. This result indicates that a troubled macroeconomic scenario, as indicated by Barbosa Filho (2017), tends to create enough uncertainty to unanchored future inflation expectations. Moreover, the results suggest an increase in the effect of inertial inflation, making the disinflationary policy even more challenging.

The results associated with economic cycles were similar, with a magnitude slightly higher than that observed in the more stable environment, at 0.02 p.p. However, the impact of the asymmetry of relative prices in this subsample was approximately 2.3 times greater than that observed in the sample with greater economic stability.

In summary, the evidence confirms that the adjusted standardized moment coefficient of Fisher-Pearson is an important alternative for modeling the impacts of supply shocks on the HNPKC of the Brazilian economy. Furthermore, the results indicate that, in a recessionary environment and/or one of greater economic instability, there is a risk of unanchoring forward-looking expectations, making its component statistically equal to zero, and the inertial component of inflation tends to be amplified.

Table 4. Results of the GMM-HAC Estimation of the HNPKC (2014-2023)

Variable	Coefficient	Standard Error
$E_t\{\pi_{t+1}\}$	0.01	0.11
π_{t-1}	0.96*	0.04
x_t	0.02*	0.01
v_t	0.04*	0.01
β	-0.03	0.33
Tests	Test Statistic	Critical Value
Pagan & Hall	35.20*	32.7
Cumby & Huizinga	32.36*	3.84
Hansen J	8.5	27.6

Source: Prepared by the authors based on the equation $\pi_t = \beta + \lambda cm_t + \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \theta v_t + e_t$. Note: * Significant at 5%. The autocorrelation tests of Cumby and Huizinga and the heteroscedasticity tests of Pagan and Hall were applied in the estimation with instrumental variables

5. Concluding Remarks

This paper analyzed the adequacy of the asymmetry of changes in relative prices as an indicator of supply shocks in the HNPKC of Brazil and how this relationship behaves in different macroeconomic scenarios. To this end, monthly information from January 2003 to December 2023 was used along with the GMM-HAC estimation method.

In general terms, the results support the hypothesis employed in this work; that is, the asymmetry of changes in relative prices emerges as a good proxy for incorporating supply shocks into the HNPKC, as it not only presents the expected sign according to theory but also proves to be statistically robust across the different examined scenarios. Additionally, the evidence suggests that, in scenarios of greater macroeconomic instability, its effects tend to be amplified compared to those in more stable conditions.

It is worth noting that Bernanke & Blanchard (2024) argued that the high inflation observed in the post-pandemic period was largely due to shocks in relative prices, which underscores the importance of the discussion presented in this paper.

Regarding both inflation inertia and forward-looking expectations, both have positive coefficients in the estimation considering the full sample, with the former having a greater coefficient than the latter. This result indicates the maintenance of high levels of indexing in the Brazilian economy. Furthermore, when considering subsamples, the

coefficient of inertial inflation increases during periods of macroeconomic instability, while forward-looking expectations cease to be statistically significant. These results may indicate an unanchoring of forward-looking expectations, which significantly affects the cost of disinflationary policies.

As for economic cycles, a positive effect of the IBC-BR gap was observed in the full sample and during periods of lower and higher macroeconomic instability, reinforcing the existence of the trade-off between inflation and unemployment. Additionally, this effect is slightly greater in periods of greater macroeconomic uncertainty.

In summary, the results point to the asymmetry of relative prices as a good indicator of supply shocks in the HNPKC, with its effect being amplified in scenarios of macroeconomic turbulence, and such unpredictability also strengthens the backward-looking component at the expense of the forward-looking component in the inflationary dynamics, considerably increasing the cost of disinflationary policies.

Finally, a monetary policy is recommended that mitigates the effects of internal or external shocks, reduces the sensitivity of economic activity to disinflationary measures, and anchors the expectations of economic agents. This study may be extended through the use of robust nonlinear models in the presence of endogenous regressors.

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Authors' contributions

Professor Elano Arruda was responsible for the study design and manuscript revision. Dr. Fernando Mansilla oversaw data collection and prepared the initial draft of the manuscript, which was subsequently revised by Professor Elano Arruda. All authors reviewed and approved the final version of the manuscript.

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Notes

Note 1. In menu cost models, firms face a cost when adjusting their prices; therefore, prices are only changed when an external shock to the price is large enough to offset the menu cost.

Note 2. Productivity shocks are calculated using two methods: Solow residuals and the adjusted Basu-Kimball version of the Solow residuals.

Note 3. This term defines the fraction of firms that do not adjust their prices through profit optimization in t.

Note 4. In the presence of heteroscedasticity, the consistency of the coefficients estimated by IV is maintained; however, in the basic estimation of instrumental variables, the standard errors are inconsistent, and consequently, the inference is affected.

Note 5. The null hypothesis of this test is the absence of autocorrelation.

Note 6. The null hypothesis is that the instruments are valid.

Appendix

Chart 2: Description of subitems of inflation

VARIABLE	PROXY	SUBITEMS		SOURCE
Inflation	Monthly Variation of the IPCA Subitems	IPCA groups	IPCA subitems	IBGE
		Food and Beverages	Cereals, legumes and oilseeds, flours, starches and pasta, tubers, roots and vegetables, sugars and derivatives, greens and vegetables, fruits, meats, fish, processed meats and fish, poultry and eggs, milk and dairy products, baked goods, oils and fats, beverages and infusions, canned goods and preserves, salt and seasonings	
		Household Items	Rent and fees, repairs, cleaning products, (domestic) fuels, and residential electricity	
		Clothing	Furniture, utensils and decorations, bedding, tableware and bath, household appliances and equipment, TV, audio and computers, and repairs and maintenance	
		Transport	Public transport, private vehicle, and fuels (vehicles)	
		Health and Personal Care	Pharmaceutical products, glasses and lenses, medical and dental services, laboratory and hospital services, health insurance, and personal hygiene	
		Personal Expenses	Personal services, Recreation, and Tobacco	
		Education	Courses, Reading, and Stationery	
		Comunication	Comunication	

Source: Own elaboration