Unemployment rate gap and the Hybrid New Keynesian Phillips Curve: an application of empirical mode decomposition

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Abstract

Although theoretically robust, the Hybrid New Keynesian Phillips Curve (HNKPC) exhibits certain limitations in adequately capturing the stylised facts widely acknowledged by economists and central bankers. Numerous authors attribute these shortcomings primarily to the way fluctuations in real economic activity are measured. To address this issue, the present study investigates the empirical validity of the HNKPC in the context of the Brazilian economy, employing an innovative approach: Empirical Mode Decomposition (EMD). This method allows for the calculation of the unemployment gap and the identification of business cycle events, while also assessing the empirical relevance of the HNKPC framework.

The analysis is based on quarterly data from the Brazilian economy. The model developed by Gali and Gertler (1999) is estimated using the Generalised Method of Moments (GMM). The main findings are as follows: (i) EMD effectively captures cyclical fluctuations in the economy through the unemployment gap; (ii) in the short run, the Brazilian monetary authority faces a trade-off between stabilising inflation and stabilising real economic activity; (iii) in the long run, expansionary monetary policy proves ineffective, resulting solely in higher inflation; (iv) historical pricing behaviour by firms exerts a stronger influence on current inflation dynamics than forward-looking expectations.Taken together, these results support the theoretical predictions of the HNKPC and challenge previous empirical studies that had questioned its validity in the Brazilian context.

Keywords: *New Keynesian Phillips Curve, empirical mode decomposition, unemployment rate gap, inflation, generalized method of moments*

***JEL Classification**: C26, E31, E24, E52*

1. Introduction

The Phillips curve, understood broadly as an inverse relationship between inflation and unemployment rate, has been widely criticized (Roberts, 1995; Mavroeidis, 2005; Villieu, 2015; Forder, 2018; Mankiw, 2019; Hagemann, 2020; Rancan, 2022). Each criticism gave rise to a new formulation. As a result, the

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Phillips curve is found today to be central to a many number of macroeconomic analyses, particularly in the area of monetary policy, but in far removed forms from the original formulation.

Since the end of the 1990s, the introduction of the "hybrid New Keynesian Phillips curve" (HNKPC) in the new theories of monetary policy has appeared relevant and promising. On the one hand, recourse to the microeconomic model of the economic agents behavior enriches, by rendering the HNKPC immune to Lucas' criticism, the analytical framework of monetary policy. On the other hand, the HNKPC increasingly retains the need for a redesigned empirical validation compatible with two important stylized facts: the persistence of inflation and disinflation generates an economic recession. In order to provide reliable normative policy implications, a short-term model of inflation dynamics must imperatively reproduce these two consensual facts.

The HNKPC presents current inflation dynamics as a function of past inflation and expected future inflation, and a measure of fluctuations in real economic activity, such as the real marginal cost and the output gap. Generally, researchers use the Hodrick-Prescott filter (1997) or the Baxter-King filter (1999) to calculate the output gap. More recently, Lai (2017) used another approach called: "Empirical Mode Decomposition, EMD". Since its introduction in 1998 by Huang et al., it has been well used in a variety of scientific analyses and studies, including those involving biomedical signal, seismic signals, power signals, atmospheric and climate studies, geophysical studies, and oceanographic studies (such as Huang and Schmitt, 2014; Liu et al., 2016; Kim et al., 2018; Yousefi Rizi, 2019; Zhang and Li, 2020; Long et al., 2021; Aslan, 2022; Dubey et al., 2022; Zare and Nouri, 2023; Nath et al., 2023 and many more). The application of the EMD approach in economic and financial studies is not only sparse, but also limited to asset-price forecasting (e.g., Zhang et al., 2008; Hua and Jiang, 2015).

Fidrmuc and Daniková (2020) identified nearly 200 empirical papers estimating the HNKPC, confirming that it is one of the most debated questions in economics. It should be noted, however, that most of the empirical works on the HNKPC are done for developed economies. It is only recently that a similar work for developing countries has gained momentum. Given their state of economic development, especially in the context of important macroeconomic variables such as inflation and unemployment, we think that it is important to know whether the HNKPC is adequate to improve the understanding of the monetary policy practiced today in certain developing countries.

Moreover, despite the strong theoretical foundations of the HNKPC, some researchers have shown that its empirical relevance remains open to further discussion (see, e.g., Galí and Gertler, 1999; Minella et al., 2003; Schwartzman, 2006, 2007; Rudd and Whelan, 2005, 2007; Chowdhury and Sarkar, 2016;

Arruda et al., 2018; Fidrmuc and Danišková, 2019). Contrary to the theoretical prediction, they found that the HNKPC fails to capture the statistically significant impact of fluctuations in real economic activity on inflation dynamics. One of the debates concerns the measurement of fluctuations in real economic activity. In order to overcome this shortcoming, Lai (2017) measured fluctuations in real economic activity of the US economy using the EMD approach. He concluded that this approach offers a new avenue for re-examining the empirical relevance of the HNKPC.

Hence, the objective of this document is to examine the suitability of the HNKPC in analyzing the effects of real economic activity fluctuations and economic agents' expectations on inflation dynamics in a developing country, specifically Brazil. Additionally, it expands on the research conducted by Lai (2017) by investigating the empirical mode decomposition approach's capability to identify business cycle events and validate the theoretical prediction of the HNKPC.

In order to achieve our goals, we will estimate the HNKPC developed by Gali and Gertler (1999). In fact, their model assumes that the proportion of agents using a backward-looking pricing rule varies with the monetary regime. Therefore, it is considered to be the most suitable as it can reproduce different degrees of inflation persistence, which is not the case for other models such as: Fuhrer and Moore (1995), Christiano, Eichenbaum and Evans (2005). As Gali and Gertler's model assumes that a fraction of agents have rational expectations, we will use the Generalized Method of Moments (GMM) as the estimation method.

We will calculate fluctuations in real economic activity using the EMD approach. It has many advantages: (1) It is model-free (empirical-based), since it has assumed linearity and stationarity on time-series data; (2) The EMD contributes a better insight to time series structure. Not only by decomposing a time series into trend and cycle, but also by providing an effective procedure to further decompose the cycle series into orthogonal components of different frequencies; (3) This approach enables synthesizing the decompositions driven by the data since distortions have been established by subjective judgments frequently applied to standard time series analysis, such as the difference-stationary, linear ARIMA and trend-stationary processes. Nevertheless, from the literature, we found that only Lai (2017) exploited the EMD approach to examine the empirical validity of the HNKPC in the US economy.

The rest of this article is structured as follows. Section 2 describes the literature review. Section 3 presents the data and the research methodology adopted. Section 4 presents the empirical results and the discussion. Finally, section 5 is devoted to the conclusion.

2. Literature review

The history of macroeconomics is characterized by a chain of "revolution" and "counter-revolution", presenting as many battles between "classical" and "Keynesian" economists, since the "revolution Keynesianism" of the 1930s through the fight between "Keynesian" and "monetarist" in the 1960s, the "counter-revolution" of rational anticipations in the 1970s, then the new conflict between the supporters of the "cycles real people" and the "new Keynesians" of the 1980s. In this story, the Phillips curve has quickly become an important macroeconomic relationship and also one of the most controversial.

In his seminal paper published in 1985, Phillips showed that there is an inverse and stable relationship between the rate of unemployment and the growth rate of nominal wages. The underlying premise is that: the increase in the demand for labor will reduce unemployment and, as a result, workers will be in a strong position to demand an increase in their nominal wages (the contrapositive is also true). Samuelson and Solow (1960) reinterpreted Phillips' relationship as a trade-off between inflation and unemployment. This meant that economic policy makers should be able to choose between a low rate of unemployment versus a certain rate of inflation and vice versa. Moreover, they considered that the inflation-unemployment trade-off is stable, which implies that expansionary monetary policy could durably reduce the unemployment rate. This idea was strongly criticized by monetarists.

Phelps (1967) and Friedman (1968) criticized the idea of stable arbitrage using the adaptive expectations hypothesis. More specifically, they mentioned that in the short-term workers carry out a scenario of price anticipation error because of their retrospective characters: they form their expectations of what will happen in the future on the basis of what is done in the past. Consequently, any increase in the money supply can lead to an increase in inflation accompanied by an equivalent reduction in unemployment in the short term. Nevertheless, expectations will be corrected in the long term and any monetary injection aimed at lowering the unemployment rate will only cause inflation to accelerate. The stagflation of the 1970s confirmed their interpretations and showed the weaknesses of Keynesianism.

Monetarist critics set the stage for the revolution of the new classics, notably Lucas (1972, 1973, 1976) who questioned the validity of Phillips' relationship even in the short term. Lucas (1972) criticized standard Keynesian models for two reasons; Firstly, because of its empirical failure to explain the stagflation of the 1970s and secondly for its lack of microeconomic foundations. To overcome these shortcomings, the New Keynesian literaturehas been primarily concerned with finding rigorous and convincing models of nominal price rigidity based on the optimizing behavior of economic agents. In

this regard, two broad categories of models can be distinguished: models that adopt a "time-dependent" price adjustment rule, in which prices adjust "from time to time" [such as the Taylor model (1980) and the Calvo (1983) model] and those that adopt a "state-dependent" rule in which prices adjust according to the state of the economy.

The different models of nominal price rigidity lead to a new specification of the Phillips curve known as the "New Keynesian Phillips curve (NKPC)", according to the name introduced by Clarida, Gali and Gertler (1999). It predicts a positive relationship between the inflation rate (π_t) the expected future inflation rate ($E_t\pi_{t+1}$) and the companies' real marginal costs (cm_t) which can be translated by the following general expression:

$$\pi_t = \beta E_t\{\pi_{t+1}\} + \lambda cm_t + \varepsilon_t \quad (1)$$

Where E_t is the anticipation operator and β is the discount factor. The coefficient λ designates the slope of the NKPC. It is a function of the structural parameters, namely: $\lambda = \frac{(1-\theta)(1-\theta\beta)}{\theta}$.

This formula indicates that at each period, a firm can adjust its price only with a certain probability $1 - \theta$ and must keep its price unchanged with probability θ, regardless of the previous adjustment date. Calvo (1980) considered this probability the fraction of firms that adjust their price. ε_t is the random error term.

The NKPC managed to evade Lucas' criticism. The interpretation is nevertheless very different from the traditional Phillips curve. Indeed, it represents inflation as a phenomenon essentially turned towards the future ("forward-looking"), resulting from the dynamic optimization behavior of companies. The intuition of this forward-looking behavior is as follows: companies redefine their prices today knowing that these are likely not to be able to be adjusted for a certain period of time. They will, therefore, incorporate their expectations of future production costs to set their current prices. This property has two implications: on the one hand, the non-persistence of inflation and on the other hand, disinflation that can be caused by economic decision-makers without incurring any costs in terms of unemployment or production.

The implications of the NKPC are in stark contrast to two stylized facts of consensus among economists and central bankers. The first is that disinflation policies always cause economic recessions (see, for example, Ball 1994; Romer and Romer 1989). The second resides in the fact that the response of inflation, following a monetary shock, will only be gradual and highly persistent (see, for example, Fuhrer and Moore, 1995; Fuhrer, 1995; Christiano, Eichenbaum and Evans, 1999; Mankiw, 2001). In order to provide reliable normative implications, a

short-term model of inflation dynamics must imperatively reproduce these two consensual elements. Indeed, one can doubt the validity of the structural implications provided by a model that reproduces without success the responses of the economy to very simple shocks.

In an attempt to make the NKPC compatible with stylized facts, some authors, following Fuhrer and Moore (1995), have proposed to include an inflation lag to increase its degree of persistence. One of the most interesting contributions in this regard is that of Gali and Gertler (1999) who extended Calvo's (1980) model by assuming that a fraction ω of firms that can change their price uses a pricing rule backward-looking and a fraction $(1 - \omega)$ uses a forward-looking one. This led to a hybrid version of the NKPC which predicts a positive relationship between current inflation, (π_t) expected future inflation ($E_t\{\pi_{t+1}\}$) past inflation (π_{t-1}) and the evolution of the real marginal cost (cm_t) supported by companies. The equation of the hybrid version of the NKPC of Gali and Gertler (1999) is the following:

$$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \lambda cm_t \quad (2)$$

Where γ_f and γ_b are weights assigned respectively to expected future inflation and lagged inflation.

In the equation of the hybrid New Keynesian Phillips curve (HNKPC), all the coefficients are explicit functions of three structural parameters: θ which measures the fraction of firms that do not adjust their prices, ω which determines the degree of lag in pricing and β which is the discount factor. These coefficients were defined by the following expressions:

$$\begin{bmatrix} \gamma_f = \beta\theta\phi^{-1} \\ \gamma_b = \omega\phi^{-1} \\ \lambda = (1-\omega)(1-\theta)(1-\beta\theta)\phi^{-1} \\ avec\ \phi = \theta + \omega[1-\theta(1-\beta)] \end{bmatrix} \quad (3)$$

Rotemberg and Woodford (1997) showed that under certain assumptions, the output gap is linearly related to the real marginal cost, which justifies the introduction of the output gap in the Phillips curve equation. Again, Fuhrer and Moore (1995), Fuhrer (1997), Neiss and Nelson (2005) also used the output gap as a proxy for real marginal cost. In this context, Gali and Gertler (1999) established an approximate log-linear relationship between these two indicators as follows:

$$cm_t = K\hat{y}_t \quad (4)$$

Where $\hat{y}_t$ denotes the output gap, i.e. the gap between real production and its equilibrium level. Using equations (2) and (4), we obtain the following HNKPC equation:

$$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \lambda' \hat{y}_t + \varepsilon_t \quad (5)$$

Where $\lambda' = K\lambda$ designates the sensitivity of inflation to fluctuations in real output around its equilibrium value which represents the optimal value. The variables and coefficients are defined above. According to this equation, a positive output gap means that real GDP is above its potential level. This excess demand generates inflationary pressures. On the other hand, a negative output gap implies an economic recession. In this context, the central bank must use its key rate, in the short term, to stabilize the output gap (as well as inflation).

In their famous papers, Gali and Gertler (1999) estimated the HNKPC for the United States by the Generalized Method of Moments (GMM). They used two measures of fluctuations in economic activity: the labor income share and the output gap. They found that the retrospective component coefficient (π_{t-1}) is non-zero and statistically significant, implying that the purely prospective model (i.e. NKPC) is rejected by the data. However, their results indicate that the coefficient of expected future inflation was quantitatively larger than that of lagged inflation. This means that the forward-looking behavior of firms in pricing has a dominant effect over the backward-looking one on inflation dynamics. Moreover, their estimation results indicated that the labor income share coefficient is positive and statistically significant. This finding is consistent with the theoretical predictions of the HNKPC. However, the output gap coefficient turns out to be incorrectly signed (negative) and statistically insignificant.

In support of the findings of Gali and Gertler (1999), many studies have estimated NKPC and its hybrid version (HNKPC) for developed economies (see, e.g., Bloch, 2012; Lubik and Teo, 2012; Lanne and Luoto, 2013; Lagoa, 2017; Coibion et al., 2018; Dur and García, 2020; Juselius and Takáts, 2021; Zobl and Ertl, 2021; Aguiar-Conraria et al., 2023 and many more). The availability and quality of data explain why studies on the HNKPC for developing economies are rare (Vašíček 2011). In order to fill this gap in the literature, some economic researchers have tried to examine the validity of the HNKPC in developing economies (see, e.g., Agénor and Bayraktar, 2010; Ben Ali, 2013; Zhang, 2013; Başer Andiç et al., 2015; Chowdhury and Sarkar, 2016; Sakurai, 2016; Kobbi and Gabsi, 2017; Salunkhe and Patnaik, 2019; Ayisi and Afful-Mensah, 2023).

Moreover, despite the strong theoretical foundations of the HNKPC, some researchers have shown that its empirical relevance remains open to further investigation (see, e.g., Gali and Gertler, 1999; Minella et al., 2003; Schwartzman,

2006; Rudd and Whelan, 2005, 2007; Chowdhury and Sarkar, 2016; Arruda et al., 2018; Fidrmuc and Danisková, 2020). Contrary to the theoretical prediction, they found that the HNKPC fails to capture the statistically significant impact of fluctuations in real economic activity on inflation dynamics. One of the debates concerns the measurement of fluctuations in real economic activity.

Chowdhury and Sarkar (2016) conducted a study on the HNKPC in four major emerging economies: Brazil, Russia, India, and South Africa. They employed a Modified Hamilton Markov Switching Model to estimate the production gap. The results of their estimation revealed that the coefficient associated with the output gap was insignificant for Brazil, India, and Russia. In another study, Arruda et al. (2018) estimated both the NKPC and HNKPC for the Brazilian economy. They utilized three indicators of nocturnal fluctuations in real economic activity, namely the real marginal cost of businesses, the output gap, and the unemployment gap. To estimate the output and unemployment gaps, they employed the well-known Hodrick-Prescott filter (1983). Similarly, their findings demonstrated the inadequacy of the output gap as a measure to capture the transmission of real economic activity fluctuations to inflation. Conversely, Jašová et al. (2020) demonstrated the undeniable role of the output gap in inflation dynamics for twenty-six advanced economies and twenty-two emerging economies, both globally and domestically. They also noted the increasing similarity between emerging and advanced economies in terms of output gaps as a determinant of inflation.

In the context of examining the validity of the HNKPC in the US economy, Lai (2017) pointed out that one can use a new technique called “empirical mode decomposition, EMD” to estimate the output gap. He showed that this technique offers a new way to re-examine the empirical relevance of HNKPC

3. Data and Methodologies

3.1. Data

Most economists use the real marginal cost and/or the output gap as an indicator of fluctuations in real economic activity. However, other economists have pointed out that one can also use the unemployment rate gap based on Okun's law (such as Lai 2017; Kobbi and Gabsi 2017; Arruda et al. 2018 and many more). In 1962, Okun established a negative relationship between unemployment and production. This relationship has been explained by the fact that any increase in production generates an increase in the demand for labor and therefore a decrease in the unemployment rate.

Several economists, such as Vašíček (2011) and Ben Ali (2013), have pointed out that supply shocks directly impact inflation and such effects should be included in the HNKPC. In particular, the inclusion of exchange rates in the

HNKPC of Gali and Gertler (1999) appeared to be a relevant measure of supply shock.

Thus, we will use quarterly unemployment rate, inflation rate and real effective exchange rate data. Inflation rate, measured by the consumer price index, is taken from the Organisation for Economic Co-operation and Development (OECD, 2019). Unemployment rate and real effective exchange rate are extracted from the IMF's monthly International Financial Statistics (IFS, 2019). The analysis period extends from the fourth quarter of 2001 to the fourth quarter of 2018. To estimate the unemployment rate gap, we will use the Empirical Mode Decomposition Technique.

Empirical Mode Decomposition Technique

The empirical mode decomposition (EMD) is a decomposition technique by which the data series could be decomposed into a rapidly oscillating part d_1 and a slower oscillating part r_1, this later being decomposable in turn on the same principle. Indeed, consider a series $Z(t) = d_1 + r_1$. The EMD will also decompose the slower oscillating part r_1 into a finite sum of oscillating modes d_s named "intrinsic mode function (IMFs)", which gives the following writing:

$$Z(t) = \sum_{s=1}^{N} d_s + r_s$$
$$= \sum_{s=1}^{N} IMFs + r_s \qquad (6)$$

The IMFs should satisfy the following two conditions: (i) must have a zero mean and (ii) the number of its extremes (minima and maxima) and the number of zero crossings cannot differ by more than one unit. By fulfilling the above conditions, it is implied that all IMFs have positive maxima and negative minima. Moreover, the final residue r_N does not present any more oscillation. This residual represents the general trend of the data series used. This leads to a final decomposition of the form:

$$Z(t) = r_N + \sum_{s=1}^{N} IMFs \qquad (7)$$

3.3. Estimation technique and diagnostic tests

By replacing the output gap by the unemployment rate and by introducing the variation in the real effective exchange rate as an approximation of the

supply shock, the expression of the HNKPC of Gali and Gertler (1999) becomes as follows:

$$\pi_t = \gamma_f E_t\{\pi_{t+1}\} + \gamma_b \pi_{t-1} + \lambda' u_t + \delta \Delta v_t + \varepsilon_t \quad (8)$$

According to this equation, current inflation (π_t) depends on past inflation (π_{t-1}) expected future inflation $E_t\{\pi_{t+1}\}$, unemployment rate gap u_t and the supply shock Δv_t measured by the change in the real effective exchange rate. Signs are expected for all variables, but for the unemployment rate, it should not be positive.

We will estimate the above equation using the Generalized Method of Moments (GMM). Since the theoretical model assumes that agents are rational, a natural way to form current expectations of future inflation is based on lagged variables included as instruments in the regression. The validity of the instruments must be checked by the over-identification J test of Hansen (1982).

A number of studies, such as: Roberts (1995), Dufour et al. (2006), Paloviita (2006), Zhang et al. (2009), Adam and Padula (2011), used survey data on inflation expectations to examine the validity of the NKPC or its hybrid version. Although the survey data reflected agents' behavior in inflation expectation and showed the empirical validity of the HNKPC, they are heavily criticized. One of the important criticisms is related to its validity. Indeed, survey responses may be of limited interest and sometimes an irresponsible response from officers. In this context, the empirical success of the HNKPC with survey data remains questionable (Kapounek and Lacina, 2011; Lunn and Duffy, 2015; Abbas et al., 2016; Güler and Polat, 2018).

The presence of autocorrelation and heteroscedasticity of the error term implies poor model specification and parameter instability. It, thus, suggests that the estimates are biased. For these reasons, the Breusch-Godfrey error autocorrelation LM test and the Breusch-Pagan-Godfrey (PBG) heteroscedasticity test will be performed.

4. Results and discussion

4.1. Graphical analysis

By applying the EMD technique, we have determined the general tendency (or the trend component) of the series of unemployment rates. Thus, to calculate the unemployment rate gap, we eliminated the trend component estimated by the EMD technique from the original series of unemployment rates. The graph below represents the difference in the unemployment rate obtained.

Reading the chart above shows that between 2004 and 2007 the unemployment rate gap was negative, which implies that the unemployment

rate was lower than its level of balance. This is explained by the fact that during this period, the Brazilian economy recorded a contained drop in the unemployment rate, although it reached 9.29% in 2007 . The significant drop in the unemployment rate is in turn explained by the contained increase in the real GDP growth rate, reaching 6.07% in 2007. This increase was stimulated by the economic interventions of the State and the reduction of income inequalities. Specifically, during this period, public spending was increased and Lula's government devoted more resources to income transfers to poor families and implemented a minimum income program; "Bolsa Familia". In addition, the minimum wage has seen a faster increase following an agreement between the country's unions and the government. The remarkable drop in the unemployment rate is also explained by the fact that a large part of the Brazilian population has benefited from better education and increased access to educational programs. Young people between the ages of 15 to 17 and 18 to 24 are considered to be in training.

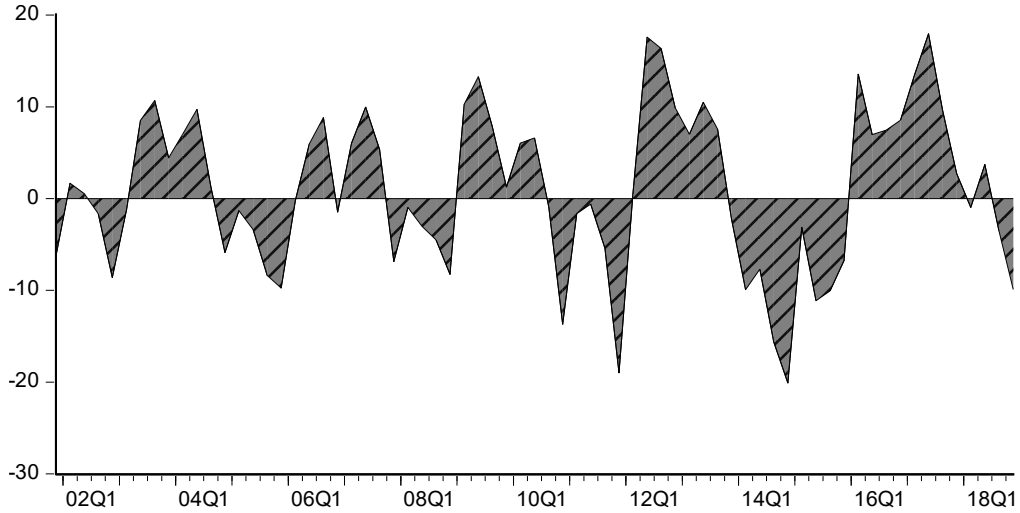
In 2008 and 2009, the gap in the unemployment rate becomes positive, which means that the unemployment rate has risen sharply compared to its equilibrium level. This increase is explained by the financial crisis of 2008 that generated a recession in the Brazilian economy. The real GDP growth rate was -0.13% in 2009. To reduce the extent of the effects of the crisis, economic decision-makers adopted counter-cyclical economic policies. After a year, their effect was absorbed without major disruption to the Brazilian banking system and the economy resumed its growth in 2010. More precisely, the real GDP growth rate becomes positive, i.e .7.54%. The actions and programs implemented before and respected until the end of the crisis also contributed to the strengthening of Brazilian economic growth. In fact, income transfers between 2003 and 2008, the decision not to lower the social protection established for 2009 and to maintain the increase in the minimum wage planned for 2009 and 2010 ensured a slight contraction in private demand during the period of crisis and its rapid recovery thereafter. As a result, from the graph, we see that at the end of 2010 the gap in the unemployment rate fell until it became negative at the start of 2012.

At the end of 2012, the economic team Dilma Rousseff has exploited several instruments, such as credit expansion and tax exemption for most sectors of the economy, to stimulate both demand and supply. GDP growth started to pick up in 2013, reaching an annualized rate of 3%. However, the inflation rate increased from 5.4% in 2012 to 6.2% in 2013. The monetary authorities reacted by implementing a series of increases in the key rate. This restrictive monetary policy largely explains why the gap in the unemployment rate is positive during this period.

The Brazilian economy stagnated between 2014 and 2016 due to poor governance at Petrobras, the sharp decline in domestic demand and the depreciation of the exchange rate since 2011. In 2017, it recovered and real GDP

grew by 1.01%. Several factors may explain this growth; First, the adoption of several structural reforms since the end of 2016, notably the reduction of obstacles, the reduction of corruption and the improvement of the efficiency of the public sector. Then, the rapid improvement in fiscal performance. Third, inflation closer moving to its target, leading to a recovery in investment and consumption. Finally, the increase in exports, which exceeds that of imports, thanks to favorable external conditions and a depreciation of the real effective exchange rate. The Brazilian economy confirmed its return to growth, recording a growth rate of 1.4% in 2018. As a result, the graph above represents a negative unemployment rate gap between 2017 and 2018. This graphical analysis confirms that the empirical mode decomposition technique is adequate to detect all events of the economic cycle.

Graph no.1 The unemployment rate gap estimated by the EMD technique, 2001:Q4-2018:Q4



Source: *Prepared by the authors.*

4.2. Unit root tests

A time series who's mean and/or variance varies over time is said to be non-stationary. It can lead to "spurious" regressions if left untreated. Several tests help to verify the stationary character (existence of a unit root) or not of a series such as: augmented Dickey-Fuller/ADF test, Phillippe-Perron /PP test, KPSS test, etc. These tests are easy to apply and commonly used. In this study, we used the ADF and KPSS tests. The results are grouped in the table below. They provide information that all the variables (inflation, unemployment rate gap and variation in the real effective exchange rate) are stationary at the level, I (0).

Table no.1 Unit root tests

		ADF-Test		KPSS-Test
	t-Statistic	Prob.	t-Statistic	Prob.
π_t	-4.53*	-3.53	0.12*	0.21
u_t	-5.6*	-2.6	0.03*	0.73
Δv_t	-5.98*	-2.59	0.05*	0.21

Note: *,** and *** denote stationarity at the 10%, 5%, and 1% levels, respectively.

Source: *Prepared by the authors.*

4.3. Results of the diagnostic tests

The table below shows that the value of the J statistic is significant at the 1% level, which implies acceptance of the null hypothesis related to the instruments validity. We applied other tests, namely the Breusch-Godfrey error autocorrelation LM test and the Breusch-Pagan-Godfrey (PBG) heteroscedasticity test. According to these two tests, the estimation residuals turned out to be non-heteroscedastic and uncorrelated, thus showing that the estimation is consistent and reliable.

Table no.2 Diagnostic tests

Tests	Values (probability)
Over-identifying restrictions test (J-statistic)	0.35 (0.94)
Breusch-Godfrey Serial Correlation LM Test	0.58 (0.44)
Heteroskedasticity Test: Breusch-Pagan-Godfrey	1.07 (0.30)

Source: *Prepared by the authors.*

4.4. GMM estimation of the HNKPC

As can be read in Table 3 below, the Brazilian economy past inflation and expected future inflation have a statistically significant impact, at the 1% level, on the dynamics of current inflation. The sum of the estimated values of these two variables is close to one, i.e. $y_b + y_f \approx 1$. Based on the theoretical model of Gali and Gertler (1999) and that of Blanchard and Gali (2009), this result indicates that any application of a long-term expansionary monetary policy to reduce the unemployment rate only causes acceleration in inflation. Graphically, the HNKPC of the Brazilian economy is vertical in the long run.

The lagged inflation rate coefficient is different at zero, $y_b \approx 0.51$, implies the presence of a fraction of firms that adjust their price using a look-back rule. This suggests that Brazilian inflation is not a purely forward-looking phenomenon.

Consequently, the Brazilian monetary authorities cannot cause disinflation without incurring costs in terms of unemployment.

The coefficient of expected future inflation, $y_f \approx 0.48$, is relatively lower than that of past inflation, $y_b \approx 0.51$. This means that the retrospective behavior of firms in pricing has a relatively predominant effect compared to the prospective one on the dynamics of Brazilian inflation. The predominance of retrospective behavior in price setting reflects a high degree of persistence of Brazilian inflation following a monetary shock. This degree is largely explained by the history of hyperinflations and the recent increase in the indexation of the Brazilian economy.

The estimated coefficient of the unemployment rate gap has a negative sign. It is also statistically significant at the 5% level. Indeed, the 1% increase in the unemployment rate differential calculated by the EMD technique will be accompanied by a 0.01% drop in the inflation rate. Thus, in the event of an exogenous shock, the Brazilian monetary authority will be faced with a trade-off between stabilization of inflation and stabilization of the unemployment rate differential. This result overcomes a number of empirical works that have found that the HNKPC is inadequate to correctly capture the impact of fluctuations in real economic activity on the dynamics of inflation in the Brazilian economy (see, e.g., Schwartzman, 2006; Minella et al., 2003; Chowdhury and Sarkar, 2016; Arruda et al., 2018).

The change in the real effective exchange rate has a statistically significant impact at the 1% threshold on Brazilian inflation. More specifically, an appreciation of the real effective exchange rate of 1% translates into a reduction in inflation of 0.01% in the first quarter. This reflects the effectiveness of the real effective exchange rate as an instrument for stabilizing Brazilian inflation. Moreover, this result is in line with works that demonstrated the relevance of the exchange rate as a measure of the supply shock, such as Vašíček (2011) and Ben Ali (2013).

The appreciation of the real effective exchange rate inevitably has effects on the level of inflation. On the one hand, it leads to a fall in the prices of imported products. This decline reduces production costs and, consequently, a drop in inflationary pressures. On the other hand, the decline in import prices leads to an increase in imports of foreign products. This causes domestic companies to lower their prices in order to attract and retain potential customers. Similarly, the appreciation of the real effective exchange rate leads to an increase in the price of exports, which reduces export price competitiveness. This, in turn, puts downward pressure on domestic prices.

Table no.3 Estimation Results of the HNKPC

Variable	Coefficient	Std. Error	t-Statistic	Prob.
π_{t-1}	0.510145	0.035245	14.47420	0.0000
π_{t+1}	0.484072	0.031210	15.51029	0.0000
u_t	-0.010947	0.004861	-2.252098	0.0283
Δy_t	-0.013804	0.004368	-3.160594	0.0025

Source: *Prepared by the authors.*

5. Conclusion

The analysis carried out in this study confirms the empirical validity of the hybrid New Keynesian Phillips Curve (HNKPC) in the context of the Brazilian economy. By employing Empirical Mode Decomposition (EMD) to estimate the unemployment rate gap, we were able to detect cyclical events and demonstrate that real-activity fluctuations exert a significant influence on inflation dynamics. The results indicate that the Phillips curve is vertical in the long run, emphasising that an expansionary monetary policy cannot sustainably reduce unemployment without engendering inflationary pressures. In the short term, Brazil's monetary authority faces a trade-off between stabilising inflation and closing the unemployment gap, thereby corroborating the theoretical predictions of the model.

Moreover, the study highlights the preponderant impact of firms' historical pricing behaviour on current inflation dynamics, relative to forward-looking expectations. It also underscores the relevance of the real effective exchange rate as a valuable indicator for assessing the effects of supply shocks on price movements.

Importantly, this result overcomes a number of empirical studies that have previously rejected the validity of the HNKPC in the Brazilian context (see, e.g., Schwartzman, 2006; Minella et al., 2003; Chowdhury and Sarkar, 2016; Arruda et al., 2018). In this regard, the EMD technique proves to be a relevant and powerful tool for detecting cyclical events and supporting the theoretical predictions of the HNKPC.

Nevertheless, this study has certain limitations. It focuses exclusively on a single emerging economy—Brazil. To enhance the generalisability and robustness of our findings, extending the analysis to other emerging or advanced economies would be beneficial. Furthermore, our investigation relied solely on the unemployment rate gap as a measure of real-activity fluctuations. A fruitful avenue for future research would be to incorporate the output gap, likewise estimated via EMD, in order to compare the sensitivity of the Phillips curve to different measures of economic activity.

These perspectives for future research offer promising directions for deepening our understanding of the role of real variables in inflation dynamics and contributing to current debates in monetary policy.

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