Inflation Persistence and Club Convergence: A Regional Analysis of the Brazilian Case

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Abstract

This paper investigates the dynamics of regional prices in Brazil, focusing on inflation persistence and convergence, for the period January 2003 - November 2024. Time-Varying Parameter models and Club Convergence estimations are applied to analyze the regional inflation rates of the following cities: Belem, Belo Horizonte, Brasilia, Curitiba, Fortaleza, Goiania, Recife, Salvador, Rio de Janeiro, Sao Paulo, and Porto Alegre. Regional inflation is also disaggregated into nine components: food and beverage, housing, household items, clothing, transportation, health and personal care, personal expenses, education, communication. The "food and beverage" component is also broken into "food at home" and "food away from home". The results reveal significant heterogeneity in price dynamics among Brazilian cities, with low inflation persistence in Sao Paulo, Salvador, Belem, and Brasilia, and high persistence in Curitiba. The Covid-19 pandemic increased inflation inertia in Recife, Belo Horizonte, Rio de Janeiro, and Curitiba, but not in Fortaleza. Overall convergence is not observed in the regional headline CPI-IPCA inflation rates, but only clubs characterized by the transitional divergence and turn-around phase. However, when the regional sectoral disaggregated inflation rates are analyzed, global convergence is found in the household items and transportation components, whereas the transitional divergence and turn-around phase is detected in the behavior of the communication, food and beverages, and food at home components. This transitional divergence and turn-around phase, which can be seen as a type of weaker convergence, is also the pattern observed in the convergence clubs formed by the other regional sectoral inflation rates, except in one case. It means that, even though Brazil is a country of continental dimensions, its inflation rate components have some idiosyncrasies that eventually make them converge in some way.

Keywords: CPI Index; Kalman Filter; Phillips and Sul; Inertia; Convergence.
JEL Classification: E31; C32; R11

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1 Introduction

Inflation plays a key role in the economy of any nation, affecting everything from monetary policy formulation to the economic well-being of the population. This is no different in the Brazilian economy, a country of continental dimensions with diverse characteristics, but also similarities in the behavior of prices from north to south and from east to west.

Since the implementation of the Real Plan in 1994, which aimed at stabilizing and controlling prices, after a long period of massive inflation rates, Brazil has made significant progress in this process, which is confirmed by academic research and by the data. However, there is much more to be done, especially understanding the nuances of regional inflation. First, it is important to examine whether the inflation persistence detected in the national inflation is also detected in different cities across the country. Second, it is commonsense to assume that the behavior of inflation rate is relatively homogeneous across different regions of a country, an assumption that may not apply to the Brazilian context. Therefore, it is also important to analyze whether regional inflation rates converge to a long-run trend. Both topics are somehow related. The effectiveness of economic policies to control inflation nationwide, and therefore to mitigate inflation persistence is connected to the behavior of prices regionally. As a result, the influence of regional price inertia and the complexities associated with regional inflation fluctuation highlight the difficulty in achieving effective and uniform inflation convergence across the Brazilian territory.

The analysis of regional inflation disparities by CPI-IPCA groups reveals heterogeneous price dynamics among Brazilian cities, underscoring the need for targeted policies. Sectoral disaggregation enables the identification of convergence or divergence patterns essential to design effective inflation control measures and reduce regional inequalities. These results contribute directly to the Sustainable Development Goals, especially Target 8.5 (Decent Work and Economic Growth) and Target 10.2 (Reduced Inequalities), supporting the promotion of economic stability, inclusive growth, and socio-economic regional inclusion.

This paper investigates the dynamics of regional prices in Brazil, addressing the level of inflation persistence in different Brazilian cities, and the presence of convergence in the regional inflation rates, for the period ranging from January 2003 to November 2024. The econometric methodology used involve Time-Varying Parameter models and Club Convergence estimations to investigate the inflation rates of the following cities: Belem, Belo Horizonte, Brasilia, Curitiba, Fortaleza, Goiania, Recife, Salvador, Rio de Janeiro, Sao Paulo, and Porto Alegre. Regional inflation is also disaggregated into nine components: food and beverage, housing, household items, clothing, transportation, health and personal care, personal expenses, education, and communication. The "food and beverage" component is also broken into "food at home" and "food away from home".

The findings of this study reveal significant heterogeneity in inflation persistence across cities in Brazil. This first conclusion is supported by a Time-Varying Parameters model via Kalman Filter, which indicates that the fluctuation of the national headline CPI-IPCA persistence is equal to or greater than of the regions, highlighting a possible 'aggregation bias' in regional inflation persistence in Brazil. There is also significant heterogeneity in inflation persistence among Brazilian cities, with low inflation persistence in Sao Paulo, Salvador, Belem, and Brasilia, and high persistence in Curitiba. The

Covid-19 pandemic period seems to be responsible for an increase in inflation persistence in Recife, Belo Horizonte, Rio de Janeiro, and Curitiba.

The second conclusion addresses the club convergence case for the country's regional inflation and shows that even though there is no general convergence among the 11 regional inflation rates, there is global convergence is found in the household items and transportation components, whereas the transitional divergence and turn-around phase is detected in the behavior of the communication, food and beverages, and food at home components. This transitional divergence and turn-around phase, which can be seen as a type of weaker convergence, is also the pattern observed in the convergence clubs formed by the other regional sectoral inflation rates, except in one case.

The structure of this paper is organized as follows: Section 2 provides the literature review. Section 3 brings the Data. Section 4 describes the econometric methodologies employed, including details about the estimated equations; Sections 5 presents the results. Section 6 concludes.

2 Literature

2.1 Inflation Persistence

Inflation persistence has been extensively debated in theoretical and empirical terms, employing several econometric methods. Initially, the debate around the concept of a Phillips Curve was built as a framework to examine the trade-off between inflation and unemployment. Academic research developed with the contribution of several authors, such as Friedman (1961), and his backward-looking model, followed by Calvo (1983), and his forward-looking model showing one of the first equations related to the concept of a New Keynesian Phillips Curve. Over time, substantial changes in inflation dynamics prompted advances and more research on the New Keynesian Phillips Curve, by incorporating backward-looking and forward-looking information on micro-founded models with price/real wage rigidities. Articles such as Gali & Gertler (1999), Clarida *et al.* (1999), and Blanchard & Gali (2007) followed this line of research. Also, Mankiw & Reis (2002) helped improve the perception of information rigidity to explain inflation persistence, and Woodford & Walsh (2005) modified the model to include partial price adjustments based on lagged inflation.

Fuhrer (2010) conceptualized inflation persistence as an analogy to inertia in physics, defining it as the tendency of an economic indicator, such as the inflation rate, to sustain its current trajectory unless influenced by external factors. Even in the Brazilian literature, Bresser-Pereira & Nakano (1986, 1987) argued the country's economic profile of the 1980s and 1990s led to some specific factors related to inertial inflation in Brazil in times of hyperinflation. In fact, the definition of inflation persistence (inertia) followed by this article is close to the so-called "Intrinsic Persistence", connected to the dependence of current inflation on its lagged behavior. But Angeloni *et al.* (2006) adds three other characterizations of persistence worth mentioning: i) inflation expectations persistence; ii) error term persistence, and iii) extrinsic persistence, which has to do with persistent fluctuations in the output gap.

Although inflation persistence studies typically focus on aggregate inflation, econometric models can be employed to analyze the behavior of disaggregated regional inflation. For instance, Benigno & Lopez-Salido (2006) found significant differences in persistence across the countries of the European

Monetary Union. Coleman (2010) found evidence of asymmetry in inflation persistence across member states of the African Financial Community. Romero-Ávila & Usabiaga (2011) identified robust evidence of high inflation persistence in Spain, with significant heterogeneity across Spanish regions. Gerlach & Tillmann (2012) showed a decrease in regional price persistence in the Asia–Pacific region and Vaona & Ascari (2012) found a similar reduction in developed Italian regions. Additionally, Tillmann (2013) and Gajewski (2018) reported patterns of regional price persistence in South Korea and Poland, respectively. Di Bartolomeo *et al.* (2020) found intrinsic price and wage inflation inertia for a sample of seven advanced economies, including the USA, France, Germany, Italy, the UK, Australia and Canada.

As for the Brazilian regional case, Caetano *et al.* (2009) found considerable disparities between regional inflation persistence in different Brazilian cities, but an overall high level of inertia. The authors argued that, despite the heterogeneity, inflation convergence was observed. Silva & Vieira (2013) analyzed inflation persistence in several important Brazilian cities, such as Belem, Fortaleza, Recife, Salvador, Belo Horizonte, Rio de Janeiro, Sao Paulo, Curitiba, Porto Alegre, Brasilia and Goiania. The authors found evidence of inflation persistence but with characteristics of stationarity and long-run mean reversion. Banco Central do Brasil (2017) highlighted regional price persistence with significant variations across regions. The institution used data from the CPI index of the cities of Belem, Fortaleza, Recife, Salvador, Belo Horizonte, Rio de Janeiro, Sao Paulo, Curitiba, Porto Alegre, Brasilia and Goiania, revealing that the country's Southern region experienced faster inflation reduction compared to the North and Northeast. Results showed heterogeneity in inflation persistence, with the cities of Belem and Sao Paulo exhibiting the highest and lowest inflation rates, respectively.

2.2 Economic and Price Convergence

Economic convergence is the hypothesis that economies with lower per capita incomes will grow more rapidly than those with higher incomes, eventually reaching a similar income level. This concept, introduced by Solow (1956) and Myrdal (1957), has undergone various approaches over time. Baumol (1986) was pioneering in introducing the idea of convergence clubs, which describe convergence among specific groups of economies. Barro & Sala-i-Martin (1997) expanded the economic growth model by incorporating technological diffusion and advocating for conditional income convergence.

Quah (1996) developed a Markov chain model to analyze the evolution of income distribution, identifying convergence clubs. Le Gallo & Dall'erba (2006) used the Getis-Ord statistic to detect regional convergence clubs, while Corrado *et al.* (2005) introduced multivariate stationarity tests to identify regional clusters. Phillips & Sul (2007, 2009) proposed a time-varying factor model and the $log-t$ test to identify convergence clubs, addressing issues of heterogeneity and stationarity. Their methodologies provided a more robust analysis of economic trajectories and club formation.

Recently, the notion of convergence clubs has been explored in various areas, such as CO_2 emissions (Panopoulou & Pantelidis, 2009), eco-efficiency (Camarero *et al.*, 2013), housing prices (Montanes & Olmos, 2013), corporate taxes (Regis *et al.*, 2015), as well as regional inflation analysis (Nagayasu, 2011) and the analysis of price indices and their groups (Christou *et al.*, 2019; Aginta, 2020).

Price convergence is associated with the law of one price. Which refers to the notion that, in an efficient market, the price of identical goods must be the same when expressed in a common currency. Evidence of that remains a subject of debate and is considered a puzzle in macroeconomics.

The analysis of price convergence within a country may have significant policy implications. In the context of monetary policy, for example, regional price convergence analysis can be useful for understanding the impacts of monetary policy on regional inflation (Cecchetti *et al.*, 2000). Furthermore, the analysis could be used to understand structural features such as the degree of market integration among regions, the regional composition of input factors, and productivity differentials.

Phillips & Sul (2007) and Phillips & Sul (2009), aiming to capture and model heterogeneous agent behavior, developed an econometric approach that allows the systematic idiosyncratic element to evolve over time and tests the convergence of time-varying idiosyncratic components. Making use of the Phillips & Sul (2007, 2009) methodology Nagayasu (2011) analyzed the convergence and spillover effects of house prices across United Kingdom regions. It was found that house prices across United Kingdom regions can be grouped into four clusters, which highlighted the heterogeneity and complexity of the United Kingdom housing market.

Cuestas *et al.* (2016) test for convergence in the inflation rate of Central and Eastern European Countries. They found that, for the sample, most countries converge to a common steady-state inflation rate. Fan *et al.* (2023), through the log-t convergence test, examined whether international food price inflation was converging over time. The results suggested limited evidence of overall convergence.

In the Brazilian context, this approach has been applied in studies on income (Gondim *et al.*, 2007; Coelho & Figueiredo, 2007; Penna & Linhares, 2017; Rosa & Figueiredo, 2023), well-being (Penna *et al.*, 2013), and heterogeneous technological progress (Penna & Linhares, 2017). However, a gap remains in the literature regarding the regional analysis of inflation for the price index and its groups using the econometric approach of Phillips & Sul (2007) and Phillips & Sul (2009). In this regard, the present study aims to contribute to the understanding of this phenomenon.

3 Data

Our econometric estimations will work with monthly data for the period from 2003M1 to 2024M11 (% month). The following variables are:

- $\pi_t^L, \quad L = 1, \ldots, 12$: Consumer Price Index - CPI (Brazil[1], Rio de Janeiro[2], Sao Paulo[3], Belo Horizonte[4], Brasilia[5], Fortaleza[6], Recife[7], Salvador[8], Belem[9], Goiania[10], Curitiba[11], Porto Alegre[12]; seasonally adjusted). Source: IBGE.
- $E_t\pi_{t+1}$: Inflation Expectations (one-month ahead; seasonally adjusted). Source: BCB.
- y_t: Central Bank's Economic Activity Index – IBC-Br (seasonally adjusted; Log; HP filter). Source: BCB.
- Δe_t: Real Effective Exchange Rate (2020=100; seasonally adjusted; Log; first difference). Source: BIS.

The Brazilian Consumer Price Inflation (CPI-IPCA) covers 16 cities and metro areas from the five regions of the country: i) North (Belem, Rio Branco); ii) Northeast (Aracaju, Fortaleza, Recife, Salvador, São Luís); iii) Central-West (Brasilia, Campo Grande, Goiania); iv) Southeast (Belo Horizonte, Rio de Janeiro, Sao Paulo,Grande Vitoria); v) South (Curitiba, Porto Alegre). Some of these cities were incorporated into the CPI-IPCA basket in more recent periods. This was the case of Aracaju, Campo Grande, Rio Branco, São Luís, and Grande Vitória, whose databases are shorter and make it difficult to perform some econometric calculations. As a result, these cities were not included in the estimates presented here. Though it would be better to examine all locations, the 11 remaining cities, which are going to be investigated in our research, represent about 93 percent of the CPI-IPCA basket.

Table 1 – Regional CPI-IPCA Inflation (% month) - Descriptive Statistics and Regional Weights

Sample	Mean	Median	Max	Min	Std. Dev.	Regional Weights (%)
CPI - Brazil	0.475	0.427	1.959	-0.563	0.310	100.00
CPI - Rio de Janeiro	0.483	0.465	2.020	-0.310	0.348	9.43
CPI - Sao Paulo	0.466	0.411	2.176	-0.516	0.319	32.28
CPI - Belo Horizonte	0.494	0.464	2.126	-0.762	0.351	9.69
CPI - Brasilia	0.469	0.428	1.986	-0.907	0.412	4.06
CPI - Fortaleza	0.495	0.441	1.911	-0.625	0.384	3.23
CPI - Recife	0.483	0.464	2.130	-1.203	0.380	3.92
CPI - Salvador	0.468	0.430	2.400	-0.955	0.407	5.99
CPI - Belem	0.485	0.470	1.572	-1.212	0.364	3.94
CPI - Goiania	0.471	0.476	1.824	-1.880	0.454	4.17
CPI - Curitiba	0.471	0.446	2.074	-1.401	0.443	8.09
CPI - Porto Alegre	0.468	0.432	1.828	-0.801	0.393	8.61
Inflation Expectations	0.415	0.420	1.186	-0.098	0.126	—
Real Exch. Rate (Δe_t)	0.001	0.003	0.094	-0.154	0.031	—
Economic Activity (y_t)	0.000	0.350	4.487	-18.801	2.666	—

Source: IBGE. Note: Regional weights not considered in the research: CPI -Aracaju (1.03), CPI -Campo Grande (1.57), CPI - Rio Branco (0.51), CPI - São Luís (1.62), CPI - Grande Vitória (1.86).

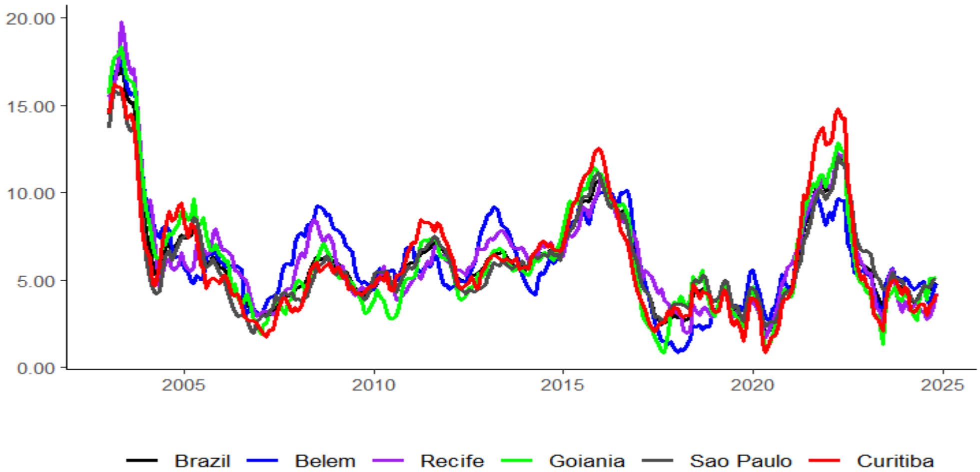
The rightmost column in Table 1 shows the regional weights of the Brazilian CPI-IPCA for the month of April/2025. The sum of the weights does not add up to 100 because the aforementioned cities are not included. Table 1 also reports the descriptive statistics for regional inflation in Brazil, together with the control variables which are going to be used in the estimations. There is significant heterogeneity in inflation between cities. Fortaleza has the highest average inflation (0.495), while Sao Paulo has the lowest (0.466). Goiania stands out for its highest volatility (0.454), which may indicate greater sensitivity to economic shocks.

Figure 1 plots the accumulated 12-month CPI-IPCA for one city representing each of the 5 geographical regions in Brazil: i) North (Belem); ii) Northeast (Recife), iii) Central-West (Goiania); iv) Southeast (Sao Paulo); v) South (Curitiba). The locations were chosen according to their standard deviations reported in Table 1.

The national CPI-IPCA is also plotted as a benchmark. There are differences and similarities in the Brazilian regional inflation rates, though their trajectories follow a similar pattern. The peaks of high inflation rates are known episodes.

The first one, in 2002, was related to concerns over the 2002 presidential race and a widespread disbelief in future actions taken by the incoming President during his first term in office. The second, in 2016, was related to the failure of the so-called New Macroeconomic Matrix, an unsuccessful attempt to promote public growth that only caused price increases. Last, the Covid-19 pandemic also affected inflation in all Brazilian regions (Gomes da Silva & Fishlow, 2021).

Figure 1 – Brazil - CPI Inflation (% 12 months)



Finally, besides disaggregating the CPI-IPCA regionally, we will also disaggregate each city inflation into its nine components: i) food and beverage; ii) housing; iii) household items; iv) clothing; v) transportation; vi) health and personal care; vi) personal expenses; viii) education; iv) communication. Besides that, we disaggregated the "Food and Beverage" component into "food at home" and "food away from home" to see the difference in food prices related to typical demand-side shocks (food away from home) and supply-side shocks (food at home).

4 Econometric Approach

4.1 Time-Varying Parameter (Kalman Filter)

We estimate a Augmented Phillips Curve model represented by the following equation:

$$\pi_t^L = \alpha_0 + \alpha_1 \pi_{t-1} + \alpha_2 E\pi_{t+1} + \alpha_3 \Delta e_{t-4} + \alpha_4 y_t + \varepsilon_t, \quad L = 1, \ldots, 12 \tag{1}$$

The coefficient α_0 represents the constant term in the model. The coefficient α_1, related to lagged inflation π_{t-1}, captures the persistence of inflation from the previous period. The coefficient α_2, related to the one-month ahead inflation expectations $E\pi_{t+1}$, captures the role of expectations in influencing current inflation. The coefficient α_3, related to the change in the exchange rate Δe_{t-4}, represents the impact of exchange rate movements from four months prior on inflation. The coefficient α_4, associated with economic activity y_t, reflects the relationship between economic output and inflation. The error term ε_t captures other unobserved factors influencing inflation.

The choice of GMM (Generalized Method of Moments) and TVP (Time-Varying Parameters) via Kalman Filter in the estimation of Equation 1 aims to address endogeneity issues and parameter instability over time, while capturing the dynamics of the explanatory variables and regional effects. The GMM is a robust methodology that handles endogeneity in temporal and cross-sectional data by using appropriate instruments to mitigate the correlation between errors and explanatory variables. The benchmark GMM estimations provide initial values, variances, and lags of the explanatory variables for the measurement equations, with no significant bias in the estimated parameters (Hamilton, 1994; Elliott & Timmermann, 2016).

The TVP via Kalman Filter proposed by Kalman (1960) is applied to capture the variability of parameters over time, adjusting them as economic conditions change. The Kalman Filter efficiently estimates these variations, providing an adaptive and precise representation of economic relationships, such as in the Phillips Curve, where the relationship between inflation and explanatory variables may change over time due to economic shocks and policy shifts (Hamilton, 1994). We will first estimate a GMM model, followed by a TVP model via the Kalman Filter for Brazil and its 11 regions using Equation 1.

4.2 Club Convergence

Then, we perform a convergence/divergence analysis using the methodology of Phillips & Sul (2007, 2009) (PS), focusing on the overall CPI-IPCAand product/service groups. The PS technique determines club convergence by forming clubs endogenously in a panel, estimating relative convergence and correcting biases related to unit root properties. It does not rely on stationarity and identifies multiple steady states. In our case, the Broad Consumer Price Index (CPI) is denoted by P_{it} for cities $L = 2, \dots, 12$ over the time period $t = 1, \dots, 263$. A factor model proposed by PS is:

$$\pi_t^L = \delta_{it}\mu_t, \quad L = 2, \dots, 12 \tag{2}$$

where δ_{it} is a time-varying factor coefficient that quantifies the idiosyncratic deviation between the common factor μ_t and the systematic group of π_t^L, which represents consumer price index data. The Equation 2 can be used to analyze convergence by testing whether the factor δ_{it} converges or not. Phillips & Sul (2007) proposed modeling the transition elements by:

$$h_{it} = \frac{\pi_t^L}{\frac{1}{N}\sum_{i=t}^{N}\pi_t^L} = \frac{\delta_{it}}{\frac{1}{N}\sum_{i=t}^{N}\delta_{it}} \tag{3}$$

where h_{it} is the relative transition path and traces out an individual trajectory for each i. The null hypothesis of convergence the authors proposed derives from:

$$\delta_{it} = \delta_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}} \tag{4}$$

where δ_{it} is fixed, $\sigma_i > 0$, ξ_{it} i.i.d (0,1) across i and weakly dependent on t and L tends to infinity as t grows. The L function takes the log-t form. ξ_{it} captures the time-varying and region-specific groups of the model. The size of α determines the behavior of convergence or divergence of δ_{it}. The null hypothesis can be written as:

$$H_0 : \delta_i = \delta, \text{ and } \alpha \geq 0 \tag{5}$$

The alternative hypothesis assumes the following form:

$$H_A : \delta_i = \delta, \text{ for all i with } \alpha < 0 \tag{6a}$$

$$H_A : \delta_i \neq \delta \text{ for some i with } \alpha \geq 0, \text{ or } \alpha < 0 \tag{6b}$$

Equations 6a and 6b describe the alternative hypothesis, which accounts for both divergence and club convergence. According to Phillips & Sul (2007), the model's hypothesis can be tested as follows:

$$\log(H_1/H_t) - 2\log L(t) = \hat{\alpha} + \hat{\beta}\log t + u_t, \text{ for } t = [rT], [rT]+1, \ldots, T, \text{ with } r > 0. \quad (7)$$

where r is the first fraction of the data used in the regression, meaning that a fraction r of the data is discarded. For sample sizes $T \leq 50$, Phillips & Sul (2007) suggest $r = 0.3$. Under Equation 7, a one-sided t-test is used to test convergence, where the null hypothesis of convergence is rejected when $\hat{t} < -1.65$. If the log-t test is rejected for the entire sample, Phillips & Sul (2007) developed an algorithm to identify convergent and divergent clubs. One of the main advantages of the model presented in Equation 7 is its ability to identify multiple club convergences within a specific subset, even in the absence of general convergence for the entire set. Phillips & Sul (2009), Schnurbus *et al.* (2017), Du (2017) and Sichera & Pizzuto (2019) developed an innovative data-driven method to detect these multiple club convergences. The steps are:

Order the N members of the panel by the last observation. Identify a core group of countries with the highest convergence t-statistic $t_{\hat{\beta},k} > 1.65$. Add countries to the core group if the t-statistic exceeds a critical value $t_{\hat{\beta}>c^*}$. Form a second convergence club if the null hypothesis is not rejected for the diverging countries. If rejected, repeat steps 1-3 for the remaining countries to find subgroups or identify divergent behavior.

5 Results

5.1 Unit Root Tests and GMM Estimations

The validation of stationarity of the time series at level I(0) is crucial for subsequent econometric modeling. Unit root tests were conducted, including the Augmented Dickey-Fuller (ADF) Test, Phillips-Perron (PP), Augmented Dickey-Fuller Generalized Least Squares (ADF-GLS), and Kwiatkowski-Phillips-Schmidt-Shin (KPSS), on all the series analyzed, as presented in Table 2.

Table 2 – Unit Root Test - CPI Inflation

Test	**ADF**	**PP**	**ADF-GLS**	**KPSS**	**Integration**
Variables	**t statistic**	**t statistic**	**t statistic**	**LM statistic**	**Order**
CPI - Brazil	-9.198*	-9.097*	-0.548	0.084	I(0)
CPI - Rio de Janeiro	-10.552*	-10.465*	-0.186	0.135	I(0)
CPI - Sao Paulo	-9.905*	-9.978*	-0.823	0.067	I(0)
CPI - Belo Horizonte	-11.276*	-11.356*	-0.449	0.264	I(0)
CPI - Brasilia	-13.500*	-13.403*	-0.434	0.213	I(0)
CPI - Fortaleza	-10.418*	-10.347*	-1.023	0.071	I(0)
CPI - Recife	-11.036*	-10.997*	-0.502	0.136	I(0)
CPI - Salvador	-13.384*	-13.616*	-0.482	0.084	I(0)
CPI - Belem	-10.754*	-10.679*	-0.623	0.232	I(0)
CPI - Goiania	-11.375*	-11.465*	-0.613	0.122	I(0)
CPI - Curitiba	-10.237*	-10.356*	-1.618	0.060	I(0)
CPI - Porto Alegre	-10.577*	-10.555*	-0.312	0.120	I(0)
Inflation Expectations	-3.877*	-6.414*	-0.789	0.353	I(0)
Real Exch. Rate (Δe_t)	-12.562*	-12.618*	-2.369*	0.453	I(0)
Economic Activity (y_t)	-6.629*	-5.589*	-5.871*	0.022	I(0)

Note: * statistical significance at 5%. ADF, PP, DF-GLS: H_0 = unit root; KPSS: H_0 = stationarity. CPI for Brazil and regions.

The results indicate that all variables are stationary at level I(0), validating the suitability of these variables for economic analyses. This procedure establishes a solid foundation for investigating inflation persistence in 11 Brazilian cities and metro areas.

Table 3 presents the GMM estimations of the regional Phillips Curves related to the 11 cities and metro areas analyzed, with the J test confirming instrument validity. Inflation persistence (inertia) is statistically significant (at 5%) in all estimated models, ranging from 0.116 (Brasilia) to 0.392 (Fortaleza).

This is the first indication of some disparity in inflation persistence across regions in Brazil, but with mean reversion. Further investigation will be required in the following estimations to deepen our analysis of regional inflation dynamics in the country. As for CPI inflation expectations, it is statistically significant (at 5%) in 5 out of the 12 estimations. The exchange rate coefficient is significant in 9 estimations, whilst the output estimated parameter came out significant in only one estimation.

Table 3 – GMM Estimations

Dependent	Independent Variables (coefficients and standard errors)					Stat. J (p-value)
Variables	Intercept	$\pi_{t-1}^{\text{Brazil}}$	$E_t\pi_{t+1}$	Δe_{t-4}	y_t	
CPI - Brazil	-0.127	0.370*	1.042	-1.631*	0.007	2.071 (0.558)
	(0.303)	(0.120)	(0.868)	(0.507)	(0.007)	
CPI - Rio de Janeiro	0.099	0.296*	0.553*	-2.109*	2.143*	6.090
	(0.070)	(0.070)	(0.184)	(0.614)	(0.753)	(0.107)
CPI - Sao Paulo	0.102	0.453*	0.365	-1.448*	0.779	1.642
	(0.073)	(0.065)	(0.193)	(0.383)	(0.714)	(0.440)
CPI - Belo Horizonte	0.010	0.248*	0.858	-1.741*	1.037	2.443
	(0.466)	(0.097)	(1.213)	(0.792)	(0.982)	(0.118)
CPI - Brasilia	0.138	0.116*	0.655*	-1.885*	-0.147	1.648
	(0.123)	(0.058)	(0.297)	(0.803)	(2.028)	(0.439)
CPI - Fortaleza	0.409	0.392*	-0.324	-0.973	0.758	3.666
	(0.371)	(0.080)	(0.985)	(0.703)	(1.230)	(0.300)
CPI - Recife	-0.269	0.275*	1.530	-1.481*	-0.166	1.681
	(0.312)	(0.087)	(0.833)	(0.655)	(1.205)	(0.641)
CPI - Salvador	0.166	0.130*	0.550	-1.737*	1.810	2.480
	(0.108)	(0.058)	(0.291)	(0.801)	(1.035)	(0.477)
CPI - Belem	0.293	0.381*	0.010	-1.006	0.393	1.390
	(0.392)	(0.077)	(1.032)	(0.610)	(0.975)	(0.708)
CPI - Goiania	-0.034	0.199*	0.994*	-1.859	1.697	1.763
	(0.118)	(0.063)	(0.294)	(0.974)	(1.251)	(0.414)
CPI - Curitiba	-0.018	0.358*	0.768*	-2.305*	0.583	3.946
	(0.125)	(0.071)	(0.306)	(0.650)	(1.193)	(0.139)
CPI - Porto Alegre	0.049	0.293*	0.678*	-1.975*	1.582	1.095
	(0.122)	(0.082)	(0.339)	(0.647)	(0.965)	(0.778)

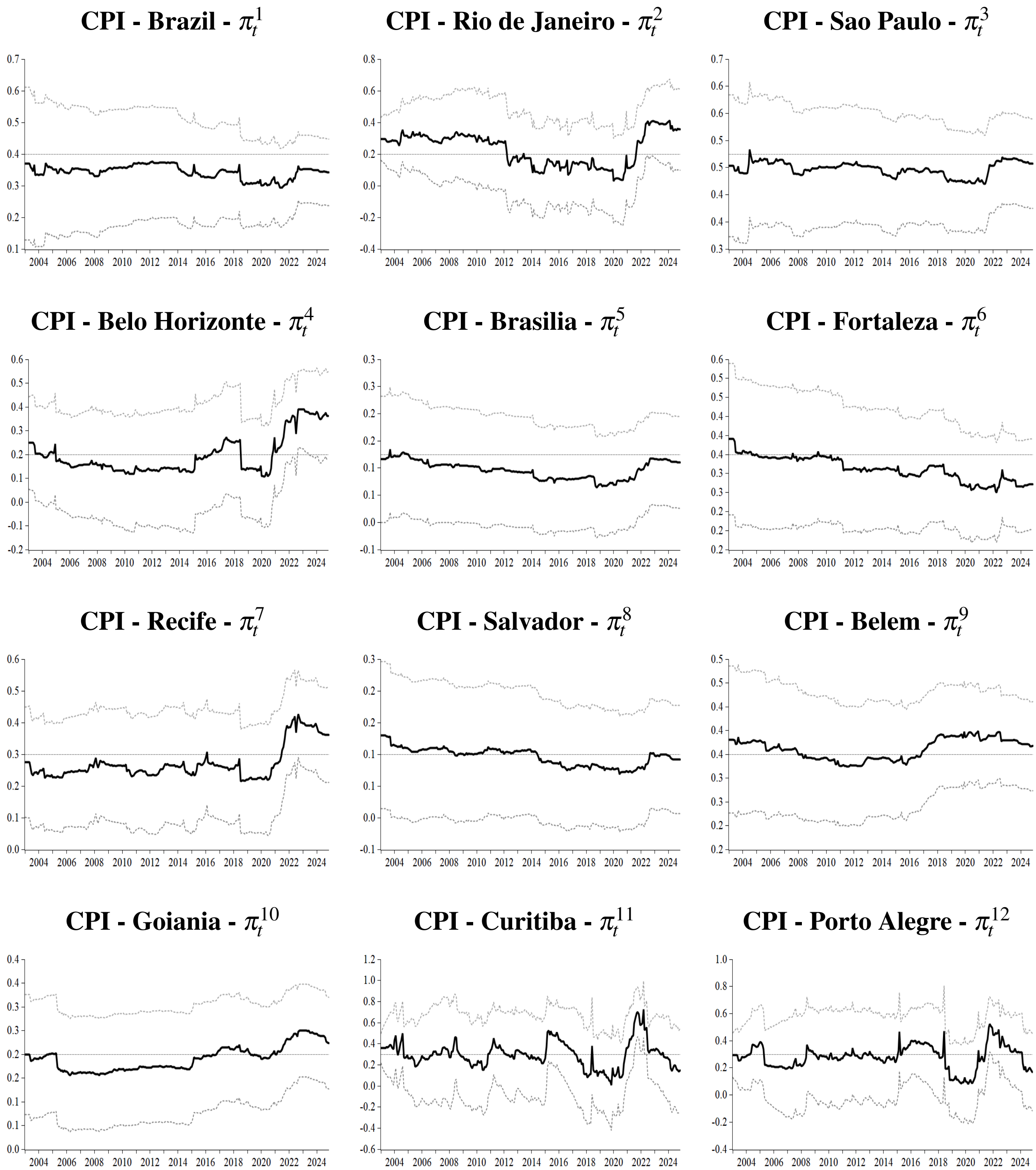
Note: * Statistical significance at 5%. H_0 (J Test): Instruments are valid. CPI for Brazil and 12 regions.

The next step is to use Kalman filter estimations to generate Time-Varying Parameters (TVPs) of each regional hybrid Phillips Curve for the analyzed Brazilian cities and metro areas. To do so, we make use of the estimated coefficients and standard errors obtained from the GMM regressions, as detailed in the previous section, to determine the magnitude and variance of the state. Confidence intervals for the parameters are calculated by multiplying the root mean square error (RMSE) by two.

5.2 Time-Varying Parameter Results

The dynamics of the inflation persistence coefficient, as shown in Equation 1, are presented in Figure 2. Other estimated parameters are not displayed due to space limitations but are available upon request.

Figure 2 – Regional Inflation Persistence (π_t^L, Kalman Filter Estimation)



A gradual decline in inflation persistence was observed in some regions, differing from the behavior of the national CPI, corroborating previous studies such as those by Silva & Vieira (2013) and **?**, which highlight regional inflation heterogeneity. Understanding these levels of persistence is crucial for monetary policy, as it reveals the speed of inflation adjustment after deviations and how regional variations affect the effectiveness of control policies.

5.3 Club Convergence Results

For the regional headline CPI-IPCA, Table 4 shows that there is no global convergence once the null hypothesis of convergence is rejected. It is an indication that the CPI-IPCA inflation of the 11 cities in Brazil does not converge to the same steady state. Although overall convergence towards a common equilibrium is rejected for the Brazilian regional inflation rates, the transition paths of individual cities' price movements might suggest the existence of local convergence clubs, which is our next examination. In this case, Table 4 shows that for the regional headline CPI-IPCA, the null hypothesis of convergence is not rejected in four cases. However, the coefficients of these four convergence clubs formed are all negative, which can be interpreted as a transitional divergence and turn-around phase as in Phillips & Sul (2009). Mendez (2020) interprets these cases as an indication of local weak convergence (transitional divergence and turn-around phase). In any of these interpretations, the meaning is the same: the dynamic process observed in these clubs falls in the no-rejection area of convergence, but the negative coefficient indicates a period of potential divergence, followed by a period of transition and a turn-around phase, which can either lead to some strong convergence, or not. The four clubs formed are: i) Club 1: Rio de Janeiro and Belem; ii) Club 2: Goiania and Curitiba; iii) Club 3: Sao Paulo and Fortaleza; iv) Club 4: Brasilia, Recife, Salvador, Porto Alegre. Belo Horizonte (Southeast region) is the only city with no inflation convergence at all with no other place in Brazil.

We found no convergence in the regional headline CPI-IPCA and four cases of weak convergence. However, results can be different when we investigate the components of the CPI-IPCA basket. As mentioned previously, eleven sectoral regional inflation rates are analyzed: food and beverage, food at home, food away from home, housing, household items, clothing, transportation, health and personal care, personal expenses, education, communication. In general terms, the results point to global convergence in the cases of household items and transportation, once the coefficient is positive and the null hypothesis of club convergence is not rejected ($\hat{\beta} > -1.65$). This indicates that the disparities found among these sectoral regional inflation rates are decreasing overtime, making them converge to the same steady state. Global weak convergence is detected for communication, food and beverage, and food at home, the null hypothesis of convergence is not rejected, but the estimated coefficient is negative. One has to bear in mind that Phillips & Sul (2009) calls this case of transitional divergence, once the coefficient remains within the null hypothesis region, but with a negative sign. It means that the regional inflation rate disparities are gradually aligning toward a common trend over time.

The other components of regional inflation are characterized by the formation of clubs with weak convergence. In the Housing component, three distinct local weak convergence (transitional divergence and turn-around phase) clubs are observed: i) Club 1: Recife and Curitiba; iii) Club 3: Fortaleza and Salvador, both located in the Northeast; and iv) Club 4: Goiania and Porto Alegre. Club 2 (Rio de Janeiro, Sao Paulo, and Belem) is locally convergent, due to its positive and no rejection of the null. In fact, this is the only case of strong local club convergence found. Finally, Belo Horizonte and Brasilia remain outside these components, suggesting divergent inflationary dynamics.

Table 4 – Club Convergence Results (Club Merging) for Groups and Subgroups

Sample	Cities	$\hat{\beta}$ *coeff*	SE	*t-Stat*
Global Convergence (Headline)	All cities	-1.217*	0.469	-2.597
Club 1	Rio, Belem	-0.989^{T}	0.799	-1.237
Club 2	Goiania, Curitiba	-1.208^{T}	0.743	-1.625
Club 3	Sao Paulo, Fortaleza	-0.800^{T}	0.657	-1.219
Club 4	Brasilia, Recife, Salvador, Porto Alegre	-1.081^{T}	0.696	-1.553
Global Convergence (Household items)	All cities	1.628	0.860	1.893
Global Convergence (Transportation)	All cities	0.627	0.651	0.963
Global Convergence (Communication)	All cities	-0.001^{T}	0.638	-0.002
Global Convergence (Food and Beverage)	All cities	-0.901^{T}	0.560	-1.610
Global Convergence (Food at home)	All cities	-0.388^{T}	0.621	-0.625
Global Convergence (Housing)	All cities	-1.409*	0.436	-3.233
Club 1	Salvador, Curitiba	-1.483^{T}	0.941	-1.576
Club 2	Rio, Sao Paulo, Belem	0.028	0.552	0.051
Club 3	Fortaleza, Recife	-0.741^{T}	0.684	-1.082
Club 4	Goiania, Porto Alegre	-1.135^{T}	0.814	-1.394
Club Merging Test (Club 2 + 3)		-0.521^{T}	0.573	-0.908
Global Convergence (Clothing)	All cities	-1.607*	0.653	-2.461
Club 1	Belo Horizonte, Salvador, Curitiba	-0.698^{T}	0.587	-1.188
Club 2	Rio, Brasilia, Recife, Goiania, Porto Alegre	-1.227^{T}	0.796	-1.541
Club Merging Test (Club 1 + 2)		-0.846^{T}	0.627	-1.350
Global Convergence (Health, Personal Care)	All cities	-1.564*	0.347	-4.502
Club 1	Brasilia, Goiania	-1.161^{T}	0.724	-1.604
Club 2	Belo Horizonte, Porto Alegre	-0.409^{T}	0.600	-0.681
Club 3	Recife, Salvador	-0.912^{T}	0.582	-1.569
Global Convergence (Personal Expense)	All cities	-0.814*	0.481	-1.694
Club 1	Rio, Sao Paulo, Brasilia, Fortaleza, Recife, Salvador, Goiania, Porto Alegre	-0.757^{T}	0.471	-1.608
Club 2	Belo Horizonte, Belem, Curitiba	-0.503^{T}	0.585	-0.861
Global Convergence (Education)	All cities	-0.776*	0.459	-1.690
Club 1	Rio, Sao Paulo, Fortaleza, Salvador, Belem, Porto Alegre	-0.162^{T}	0.527	-0.306
Club 2	Belo Horizonte, Brasilia, Recife	-0.813^{T}	0.509	-1.595
Club 3	Goiania, Curitiba	-0.487^{T}	0.823	-0.592
Club Merging Test (Club 1 + 2)		-0.791^{T}	0.480	-1.647
Global Convergence (Food away from home)	All cities	-1.889*	0.580	-3.260
Club 1	Rio, Belo horizonte, Goiania, Porto Alegre	-0.605^{T}	0.582	-1.040
Club 2	Recife, Belem	-0.898^{T}	0.650	-1.382
Club 3	Brasilia, Fortaleza	-0.661^{T}	0.635	-1.041

Note: * indicates rejection of the null hypothesis of convergence and club merging at the 5% significance level. ^{T} indicates transitional divergence and turn-around phase. SE is the standard error.

As mentioned by Phillips & Sul (2009), Von Lyncker & Thoennessen (2017) and Mendez (2020), the algorithm developed by Phillips & Sul (2007) may over-predict the quantity of clubs. Therefore, the suggestion is to perform a sequential club merging testing. Following the analysis of the Housing component, the merge between Clubs 2 and 3 cannot be rejected by the data, though the coefficient is negative, which might be suggesting a transitional divergence and turn-around phase (weak convergence). Thus, the regional sectoral inflation related to the Housing component can be characterized by three convergence clubs: Club 1, Club (2+3) and Club (4).

In the analysis of the clothing component, two distinct local weak convergence (transitional divergence and turn-around phase) clubs are observed: i) Club 1: Belo Horizonte, Salvador and

Curitiba; ii) Club 2: Rio de Janeiro, Brasilia, Recife, Goiania and Porto Alegre. Finally, Sao Paulo and Fortaleza remain outside these components, suggesting divergent inflationary dynamics. Furthermore, the merge between Clubs 1 and 2 cannot be rejected by the data, though the coefficient is negative, which might be suggesting a weak convergence. Thus, the regional sectoral inflation related to the Clothing component can be characterized by one convergence club: Club (1 + 2).

As for the Health and Personal Care component, three distinct local weak convergence (transitional divergence and turn-around phase) clubs are observed: i) Club 1: Brasilia and Goiania, both in the Midwest region; ii) Club 2: Belo Horizonte and Porto Alegre; iii) Club 3: Recife and Salvador, both in the Northwest region. Finally, Rio de Janeiro, Sao Paulo, Fortaleza, Belem and Curitiba remain outside these components, suggesting divergent inflationary dynamics.

The Personal Expenses component is characterized by two distinct local weak convergence (transitional divergence and turn-around phase) clubs are observed: i) Club 1: Rio de Janeiro, Sao Paulo, Brasilia and Fortaleza; ii) Club 2: Recife, Salvador, Goiania, Porto Alegre, Sao Paulo, Belem and Curitiba.

The Education component's results show three distinct local weak convergence (transitional divergence and turn-around phase) clubs are observed: i) Club 1: Rio de Janeiro, Sao Paulo, Fortaleza, Salvador, Belem and Porto Alegre; ii) Club 2: Belo Horizonte, Brasilia and Recife; iii) Club 3: Goiania and Curitiba. Furthermore, the merge between Clubs 1 and 2 cannot be rejected by the data, though the coefficient is negative, which might be suggesting a weak convergence. Thus, the regional sectoral inflation related to the Clothing component can be characterized by two convergence club: Club (1 + 2) and Club 3.

In the Food away from home component, three distinct local weak convergence (transitional divergence and turn-around phase) clubs are observed: i) Club 1: Rio de Janeiro, Belo Horizonte, Goiania and Porto Alegre; ii) Club 2: Recife and Belem; and iii) Club 3: Brasilia and Fortaleza. Finally, Sao Paulo, Salvador and Curitiba remain outside these components, suggesting divergent inflationary dynamics.

As a means of comparison, Christou *et al.* (2019) identified fewer convergence clusters in housing prices compared to the overall index in 50 US states, between 1960 and 2007. Aginta (2020) found fewer convergence clusters in housing and education prices compared to the overall index in 82 cities in Indonesia between 2014 and 2019. Fan *et al.* (2023) found little evidence of convergence in food price inflation across 198 countries and regions between 2000 and 2020. On the other hand, Cuestas *et al.* (2016) found convergence in the inflation rates of most Central and Eastern European countries, for the period 1997-2015.

Therefore, based on the results presented in Table 4, and considering that Brazil is a country of continental dimensions, with regions with income disparities and with different development levels, there is weak evidence that regional inflation converges to the same steady-state level. There is no doubt that the lack of global convergence may also reflect the relevance of economic growth and socio-economic development among Brazilian cities and metro areas. However, when the analysis is focused not on the headline regional inflation but on its 11 disaggregated groups, some interesting results emerge. There is a global strong convergence in the cases of household items and transportation. On the other hand, the sectoral inflation rates related to communication and food and beverage, food at home are characterized by what Phillips & Sul (2009) calls “transitional divergence and turn-around phase”.

This study also found that the speed of panel convergence varies across the groups and sub-groups, and in this sense, it is important to mention that this variation in the speed of convergence between different groups and sub-groups may have contributed to the lack of general convergence at the Brazil level. However, this depends on the disparities between the groups and sub-groups, their relative positions in household budgets, and their respective speeds of convergence. The results also indicate that some cities, in some way, have used their resources and capabilities to develop their infrastructure and catch up with cities that already more economically advanced.

6 Conclusion

This article investigated the CPI-IPCA inflation persistence phenomenon and the case of price convergence across 11 Brazilian cities and metropolitan areas from January 2003 to November 2024. The methodology employed involved applying the Time-Varying Parameters technique (Kalman, 1960) for the analysis of regional CPI-IPCA inflation persistence, as well as the Convergence-by-Clubs methodology (Phillips & Sul, 2007, 2009) for group convergence investigation. The objective was to fill a gap in the Brazilian literature by offering a detailed analysis of regional inflation persistence and club convergence, providing a comprehensive view of their differences and similarities.

The combination of these methodologies provided a robust and detailed analysis of the regional inflation dynamics in the cities under study. The results revealed significant heterogeneity in inflation persistence among Brazilian regions, with low persistence in Sao Paulo, Salvador, Belem, and Brasilia, and high persistence in Curitiba. For instance, the city of Salvador, in the Northeast region, exhibited very low inflation inertia, indicating short-memory inflation. On the other hand, the city of Curitiba, located in Brazil’s Southern region, showed high price inertia, characterizing long-memory inflation. When focusing on the Covid-19 pandemic period, Recife (Northeast Region), together with Belo Horizonte and Rio de Janeiro (Southeast Region), as well as Curitiba, exhibited episodes of considerable increase in inflation persistence. This indicates that current prices were strongly influenced by past events, initially related to supply chain disruptions, followed by increased demand-side pressures.

Regarding club convergence, the results did not find evidence of overall convergence to the same long-run equilibrium among the 11 regional inflation series in Brazil. Instead, only clubs characterized by the transitional divergence and turn-around phase were identified. However, when the regional inflation rates were disaggregated into 11 components, global convergence was found in household items and transportation. The sectoral inflation results related to communication, food and beverages, and food at home also indicated no rejection of the null hypothesis of convergence. Yet, the negative coefficients make them better defined as in the transitional divergence and turn-around phase (or weaker convergence). This transitional phase was also predominant in the definition of the clubs formed by the remaining components of the regional inflation rates.

Therefore, the results suggest that analyzing disaggregated data uncovers important aspects of price convergence that are not evident in the analysis of the aggregated national CPI-IPCA index.

Despite Brazil's continental dimensions, the components of its inflation rates display idiosyncratic behaviors that may lead to partial or sectoral convergence. The presence of convergence clubs indicates that policies aimed at inflation control and the reduction of regional disparities should consider these specific characteristics.

This study highlighted that the inflation persistence phenomenon is relevant not only nationally but also regionally, since similarities and differences must always be taken into account. Understanding price convergence and divergence is crucial for effective economic policy formulation and for comprehending regional price dynamics. Further research is needed to explore the economic and social determinants behind the regional patterns of inflation inertia and price convergence in Brazil. Moreover, given the significant number of detected weak convergence cases, future investigations may deepen the analysis using the specific weak σ-convergence methodology proposed by Kong *et al.* (2019).

This research directly contributes to Sustainable Development Goal (SDG) 8 – Decent Work and Economic Growth, particularly Target 8.5, which seeks to achieve full and productive employment and decent work for all, by identifying regional disparities and convergence patterns in inflation dynamics that inform more targeted inflation control policies fostering economic stability and sustainable growth across Brazilian regions. Additionally, it relates to SDG 10 – Reduced Inequalities, especially Target 10.2, which emphasizes empowering and promoting social, economic, and political inclusion for all; by revealing heterogeneity and club convergence in regional inflation, the study underscores the importance of addressing diverse regional economic realities in policy-making to promote inclusive growth and reduce inequalities, ensuring no region or social group is left behind in Brazil's economic development.

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