Regional Monetary Policy Dynamics: Estimating a Taylor Rule for Colombia's Departments

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Abstract

This study examines regional monetary policy dynamics in Colombia by estimating a Taylor Rule tailored to subnational economic conditions. Using a unique panel dataset spanning 1980 to 2023 for 24 departments, we adapt the traditional Taylor Rule framework to incorporate regional heterogeneity in inflation and output gaps. The output gap is derived through the Hodrick-Prescott filter, while robust panel estimation techniques, such as Driscoll-Kraay standard errors, account for cross-sectional dependence and temporal autocorrelation. This methodology reveals the regional variability in monetary policy transmission, highlighting differences in economic responsiveness across Colombia's geographic and economic regions. By uncovering the spatial dimensions of monetary policy impacts, this research provides valuable insights for central banks seeking to enhance policy effectiveness in economies characterized by significant regional disparities. The findings underscore the importance of designing adaptive monetary frameworks to address localized inflationary pressures and output dynamics.

Keywords: Regional Taylor Rule, Monetary Policy, Inflation Gap, Output Gap, Colombia, Regional Disparities, Panel Data Analysis, Driscoll-Kraay Standard Errors, Hodrick-Prescott Filter.

JEL Classification: E31, E52, O54

1 Introduction

Monetary policy is a powerful instrument for stabilizing prices and fostering economic growth, yet its impact is rarely uniform across all regions within a single country. A growing literature underscores how regional differences—such as industrial composition, financial infrastructure, and demographic characteristics—can modify the effectiveness of monetary policy (Carlino and DeFina, 1999; Beraja et al., 2019; Aginta and Someya, 2022). Regions that rely heavily on manufacturing or services with robust credit channels often exhibit strong interest-rate sensitivity. In contrast, areas dominated by agriculture or informal employment may respond more weakly (Kashyap and Stein, 2000; Bernanke and Gertler, 1995).

In many advanced economies, researchers have documented a link between local economic structures and differential monetary policy transmission. Carlino and DeFina (1998) find that regional variations in industrial composition can lead to disparate outcomes in the United States. In contrast, Claussen (2001) illustrates how the exact mechanism plays out in the European Monetary Union. In developing economies, these divergences can be even sharper due to pervasive inequalities and more segmented financial markets (Otero, 2018; Avci et al., 2017). Consequently, monetary authorities in such settings face a heightened challenge: crafting national policy directives that do not unintentionally widen inter-regional gaps.

Colombia offers a valuable case study of these dynamics. Although the Central Bank of Colombia (Banco de la República) implements a uniform inflation-targeting policy (Banco de la República, 2024a), its diverse geography and uneven development complicate the transmission process. Urbanized departments, such as Bogotá and Valle del Cauca, possess sophisticated financial sectors and diverse economic bases, enabling a quicker reaction to interest-rate changes. By contrast, resource-rich yet less financially integrated areas—like Meta or parts of the Amazon—may exhibit less elasticity in output

or employment responses, complicating the Central Bank's goal of stable growth across the national territory (Lozano-Espitia and Arias-Rodríguez, 2022; Gómez-González et al., 2021b).

This study examines these regional disparities by estimating a Taylor Rule that accounts explicitly for subnational differences in inflation and output. Building on the frameworks of Taylor (1993) and Clarida et al. (2000), we incorporate panel techniques and robust standard errors to handle cross-sectional dependence (Driscoll and Kraay, 1998). We then apply the Hodrick-Prescott filter to estimate output gaps at the department level, mindful that different filtering approaches can alter how the gap affects policy decisions (Christiano and Fitzgerald, 2003; Ravn and Uhlig, 2002).

Our results show wide variation in how changes to the policy rate propagate through local economies, reflecting each region's unique blend of industrial specialization, informal labor markets, and financial depth. These findings provide fresh evidence that a one-size-fits-all approach to monetary policy may overlook key heterogeneities—an insight with essential implications for emerging markets seeking inclusive growth. The remainder of this paper proceeds as follows: after reviewing the literature on regional monetary policy transmission Section 4, describe the data sources and empirical strategy Section 5, present results Section 6 and then discuss policy implications and conclusions (Section 7).

2 Literature Review

2.1 Theoretical Framework

The Taylor Rule provides a foundational framework for understanding monetary policy decisions, emphasizing the systematic adjustment of interest rates in response to deviations in inflation and output from their respective targets. Since its formulation by John B. Taylor in 1993, the rule has become a cornerstone in monetary economics, both as a practical policy tool and as a theoretical benchmark for analyzing monetary policy effectiveness. This section outlines the evolution of the Taylor Rule, the channels through which monetary policy is transmitted across regions, and the spatial dimensions

influencing its efficacy.

2.1.1 Taylor Rule Fundamentals and Evolution

The Taylor Rule is formally expressed as:

$$i_t = r^* + \pi_t + \phi_\pi(\pi_t - \pi^*) + \phi_y(y_t - \bar{y}_t), \tag{1}$$

where i_t is the nominal interest rate, r^* represents the neutral real interest rate, π_t is the inflation rate, π^* is the target inflation rate, and $(y_t - \bar{y}_t)$ denotes the output gap—the difference between actual and potential output. The coefficients ϕ_π and ϕ_y reflect the central bank's responsiveness to inflation and output deviations, respectively.

Over time, the rule has been adapted to include additional variables such as exchange rates, financial stability indicators, and external shocks to address the complexities of open economies and financial globalization (Taylor, 1999; Woodford, 2001). These extensions highlight the flexibility of the rule in accommodating varying economic conditions while maintaining its core objective of stabilizing inflation and output.

2.2 Regional Monetary Policy Transmission Channels

The effectiveness of monetary policy varies across regions due to differences in economic structures, financial systems, and consumer behavior. Key transmission channels include:

1. **Interest Rate Channel:** Changes in policy rates influence borrowing and lending rates, affecting consumption and investment decisions. However, regional disparities in credit markets, such as access to banking services, can lead to heterogeneous responses to interest rate adjustments (Bernanke & Gertler, 1995).

2. **Credit Channel:** The bank-lending and balance-sheet channels amplify monetary policy effects through changes in credit supply. Well-capitalized banks are less sensitive to policy shocks, resulting in uneven credit access across regions with varying financial structures (Kashyap & Stein, 2000).

3. **Housing and Wealth Channel:** Variations in housing equity and real estate markets across regions influence the refinancing channel of monetary policy. For instance, regions with higher housing equity are more responsive to interest rate cuts, affecting household spending and consumption patterns (Beraja et al., 2019).

4. **Exchange Rate Channel:** In open economies, exchange rate adjustments affect trade balances and inflation rates, with regional implications for export- or import-dependent areas. Exchange rate pass-through can vary significantly depending on regional trade exposure and industrial composition (Taylor, 1993).

The spatial dimensions of monetary policy introduce further complexities, as regional spillovers and spatial interdependencies shape how policy effects propagate. Key considerations include:

1. **Regional Heterogeneity:** Differences in industrial composition, income levels, and demographic characteristics lead to varied responses to monetary policy. For example, regions with a high share of manufacturing tend to exhibit stronger reactions to interest rate changes due to the sector's sensitivity to borrowing costs (Carlino & DeFina, 1998).

2. **Spatial Spillovers:** Geographical proximity can amplify or mitigate policy effects through trade linkages and labor market integration. Spatial econometric models, such as spatial vector autoregressions (SVARs), have been employed to capture these dynamics, highlighting the role of neighboring regions in shaping local responses (Giacinto, 2003).

3. **Financial Integration:** Regions with more integrated financial markets experience more uniform policy transmission, while fragmented markets can exacerbate disparities. In Europe, the adoption of the euro has highlighted both the benefits and challenges of unified monetary policy in addressing regional heterogeneities (Claussen, 2001).

4. **Policy Coordination:** The interplay between national and regional policies can influence the effectiveness of monetary interventions. In Colombia, regional economic disparities necessitate tailored approaches to monetary policy that account for local conditions while maintaining national policy coherence (Ospina-Tejeiro & Romero-Chamorro, 2024).

2.3 Empirical Evidence

Empirical studies on monetary policy transmission have evolved considerably over the years, shedding light on how regional disparities influence the effectiveness of economic policy. Early research focused on national-level dynamics, treating monetary policy as a uniform tool with homogenous impacts across regions. However, as economists delved deeper into the mechanisms of policy transmission, it became apparent that economic structures, financial systems, and institutional arrangements play a critical role in determining regional responses to monetary shocks.

A significant body of research has explored regional differences in monetary policy effects in developed economies. In the United States, Carlino and DeFina (1998, 1999) were among the first to highlight how industrial composition and banking systems influence regional sensitivity to monetary shocks. States with a higher concentration of interest rate-sensitive industries, such as manufacturing, exhibited more pronounced output and employment responses to policy changes.

In Europe, introducing the euro provided a unique context to examine regional asymmetries in policy transmission. Spatial econometric approaches, such as those employed by Giacinto (2003) and Dewachter et al. (2012), revealed significant spatial spillovers in monetary policy effects. These studies showed that the economic conditions of neighboring regions influenced local responses to policy shocks, emphasizing the interconnectedness of regional economies within the European Monetary Union.

Emerging markets present more complex cases due to their diverse economic structures and institutional frameworks. In Indonesia, Aginta and Someya (2022) examined how sectoral composition influences regional responses to monetary policy. Provinces with

a higher share of manufacturing or mining exhibited stronger inflationary responses to policy shocks than service-dominated regions, demonstrating the pivotal role of economic structure in policy transmission.

With its diverse economic geography and institutional dynamics, Colombia offers a unique context for examining regional monetary policy effects. Otero (2018) documented significant regional disparities in policy transmission, particularly in the Pacific and Caribbean regions. These areas, characterized by distinct industrial compositions and greater dependence on external factors such as oil prices, exhibited heightened sensitivity to monetary shocks. Gómez-González et al. (2021) explored the bank-lending channel, revealing that better-capitalized banks were less sensitive to policy shocks, particularly during periods of economic contraction.

Despite these contributions, the empirical literature on regional monetary policy in Colombia remains limited, particularly concerning the application of regional Taylor Rules. While most studies focus on aggregate national impacts, they overlook the significant heterogeneities across regions that can shape policy effectiveness.

3 Colombian Regional Economic Context

The Colombian economic landscape exhibits marked heterogeneity across its 32 departments, characterized by distinct patterns of sectoral specialization and institutional development (Araújo et al., 2023). This heterogeneity creates varying conditions for monetary policy transmission, necessitating a careful examination of regional economic structures and their implications for policy effectiveness.

The Andean region, particularly the economic triangle formed by Bogota, Antioquia, and Cundinamarca, represents the core of Colombia's economic activity. Econometric analysis reveals significant concentration patterns, with Bogot'a contributing 25.3 percent of the national GDP, followed by Antioquia at 14.8 percent and Cundinamarca at 5.7 percent (Tovar et al., 2007). These regions demonstrate advanced economic diversification, with services accounting for 65 percent of value-added, manufacturing comprising

22 percent, and financial services representing 13 percent. The economic density in these areas exceeds the national average by a factor of 2.4, measured by GDP per square kilometer (Baquero and Santolino, 2022).

Statistical analysis of regional economic structures reveals three distinct clusters, each with unique characteristics influencing monetary policy transmission. The metropolitan core, encompassingBogotaa, Antioquia, and Valle, exhibits substantial financial sector depth, with banking assets representing 85 percent of regional GDP (Baquero and Santolino, 2022). This concentration of economic activity creates efficient channels for monetary policy transmission, as evidenced by regression coefficients indicating substantial interest rate pass-through.

Resource-intensive departments, notably Meta and Casanare, present a contrasting economic profile. These regions derive 45-60 percent of their GDP from extractive industries, resulting in high export concentration indices (0.78 on the Herfindahl-Hirschman scale) (Baquero and Santolino, 2022). Recent studies indicate significant commodity price elasticity, suggesting these regions' economic performance remains vulnerable to external shocks and potentially less responsive to conventional monetary policy tools (Vargas et al., 2017).

The Caribbean and Pacific regions form a third distinct cluster, characterized by agricultural and tourism activities (Martínez Viloria et al., 2014). Primary sector activities account for approximately 35 percent of economic output, with tourism generating substantial multiplier effects (1.8 for indirect/direct impacts). These regions demonstrate higher sensitivity to weather-related shocks ($\sigma = 0.42$), which can complicate monetary policy transmission by introducing additional volatility into regional economic conditions (Sever and Perez-Archila, 2021).

The institutional framework, shaped by the 1990s decentralization reforms, has produced heterogeneous outcomes across regions (Ordoñez-Callamand et al., 2017). High-capacity regions demonstrate superior fiscal autonomy ratios (0.75) and investment efficiency indices (0.82), facilitating more effective policy implementation. In contrast, resource-constrained departments exhibit higher fiscal dependency (0.65) and lower in-

vestment efficiency (0.45), potentially hampering policy transmission mechanisms (Giacinto, 2003).

These structural patterns create distinct channels for monetary policy transmission across regions, as analyzed by Uribe (2020). Econometric evidence suggests varying degrees of interest rate pass-through between urban ($\beta = 0.85$) and rural ($\beta = 0.45$) areas. Sectoral sensitivities also differ significantly, with manufacturing displaying the highest elasticity to policy changes (-1.2), followed by services (-0.8) and agriculture (-0.4). Regional integration measures indicate substantial economic linkages, with inter-regional trade flows accounting for 35 percent of GDP and financial market correlations of 0.72 (Uribe, 2020).

The empirical evidence presented here suggests that monetary policy transmission operates through region-specific channels, with effectiveness primarily determined by local economic structures and institutional capacity (Gómez-González et al., 2021b). These findings have important implications for the design and implementation of monetary policy in Colombia, particularly regarding the need to account for regional heterogeneity in policy formulation.

3.1 Regional Economic Disparities

Despite progress in economic diversification and decentralization, Colombia continues to experience pronounced regional disparities. The Andean region consistently outperforms others in terms of GDP per capita, productivity, and employment opportunities. Conversely, departments in the Pacific and Amazon regions face persistent challenges, including high poverty rates, inadequate infrastructure, and limited access to public goods. Geographic isolation further exacerbates these disparities by restricting market access and economic opportunities (Toscano and Salinas, 2021).

Labor market outcomes reflect these economic disparities. Departments with diversified economies, such as Bogot'a and Antioquia, exhibit lower unemployment rates and higher formal employment levels compared to regions reliant on agriculture or extractive industries. In contrast, areas like Choc'o and La Guajira struggle with high levels of

poverty and informality, creating barriers to economic integration and reinforcing the development gap (Gómez-González et al., 2021b).

Fiscal capacities also vary widely among regions. Wealthier departments generate higher tax revenues and attract more excellent private investment, enabling them to finance infrastructure projects and social programs. Conversely, less developed areas remain heavily dependent on national government transfers, which are often insufficient to meet their development needs. This fiscal imbalance perpetuates inequitable growth and undermines national efforts to reduce regional inequalities (Toscano and Salinas, 2021).

3.2 Monetary Policy Framework in Colombia

Colombia's monetary policy framework, anchored in inflation targeting since 2000, has been pivotal in stabilizing inflation and fostering macroeconomic stability. Under this regime, the Central Bank of Colombia (Banco de la Republica) seeks to maintain inflation at 3 percent, with a tolerance range of ± 1 percentage point (Banco de la República, 2024a). The policy interest rate is the primary instrument used to influence inflation and aggregate demand, with adjustments based on deviations from inflation and output targets.

A flexible exchange rate regime complements the inflation-targeting framework by enhancing the economy's resilience to external shocks, such as fluctuations in capital flows and commodity prices. This flexibility allows for countercyclical monetary policy responses, although the Central Bank occasionally intervenes in foreign exchange markets to stabilize the currency when necessary (Banco de la República, 2024a).

Despite these advances, figure 1 reveals episodes of divergence from the target due to external shocks. For instance, inflation spikes in 2015-2016 and during the COVID-19 pandemic highlight the challenges posed by global supply chain disruptions and commodity price volatility. These deviations underline the need for flexibility in monetary policy to address short-term shocks while maintaining credibility and long-term price stability.

Recent contributions to the Colombian application of the Taylor Rule emphasize its

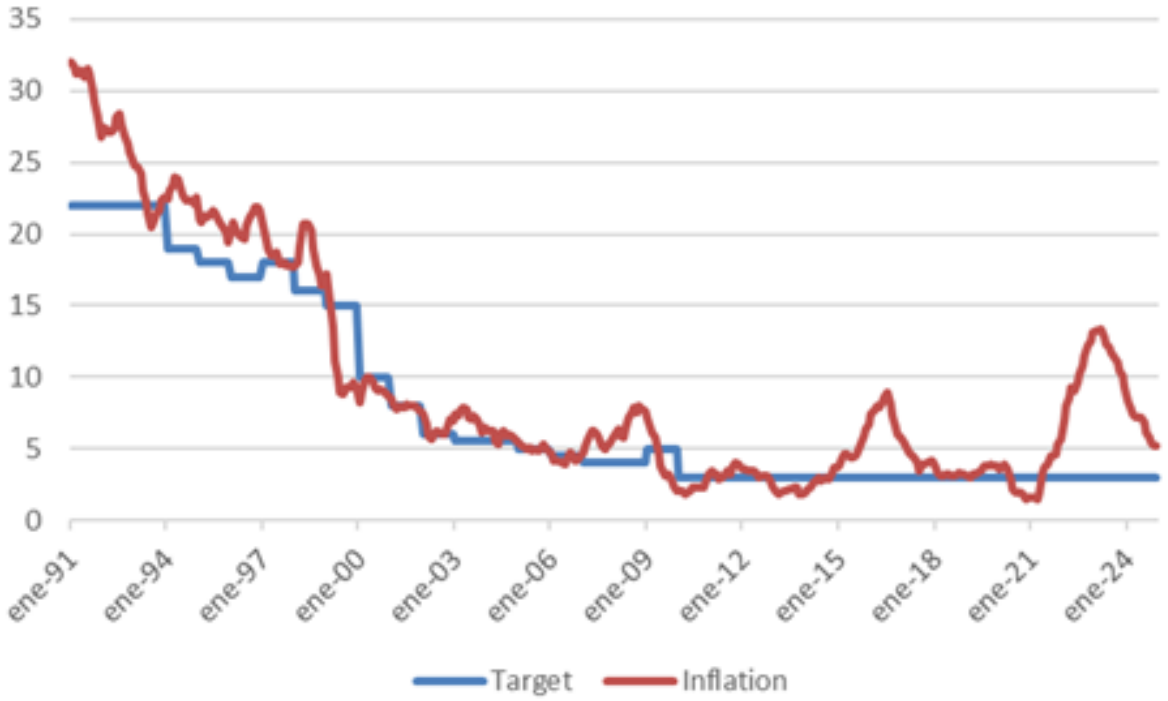


Figure 1: Evolution of inflation and the Central Bank of Colombia's inflation target

adaptability to the nation's unique economic conditions and the role of regional heterogeneity in policy transmission. Villa et al. (2015) analyze the inflation-targeting framework adopted in Colombia since 2000, demonstrating its alignment with the Taylor principle. They highlight how the Banco de la República reacts more aggressively to inflationary deviations than to output gaps, reflecting the priority placed on stabilizing price levels. This nuanced approach has fostered macroeconomic stability but underscores the persistent challenge of addressing regional disparities in policy transmission. Complementing this analysis, Giraldo et al. (2017) employ a nonlinear LSTAR model to show that the Central Bank's responses differ across economic regimes. Their findings reveal stronger responses during inflationary periods than during recessions, a behavior consistent with neo-Keynesian theories of price stickiness. Such asymmetries suggest that national-level policies may mask significant regional differences in economic outcomes. Building on this, Pabón and Bedoya (2016) explore the stability of Taylor Rule parameters over time and their relevance to Colombia's economic structure. While their study confirms the Central Bank's consistent focus on inflation and output stabilization, they

emphasize the limited role of variables like exchange rates in the policy function. This omission is notable, given the significant regional disparities in trade dependence and exposure to external shocks. Together, these studies underscore the need for greater regional granularity in monetary policy design. Despite the central bank's success in achieving national inflation targets, regional disparities in financial depth, industrial composition, and economic performance remain underexplored. Incorporating these regional dynamics through spatial econometric techniques or regional Taylor Rules could provide a more comprehensive understanding of Colombia's monetary policy effectiveness. These findings align with the broader literature emphasizing the importance of tailoring monetary policies to the specific conditions of diverse economic regions. The transmission of monetary policy depends on local economic conditions, including labor market structures, credit accessibility, and the responsiveness of businesses and households to interest rate changes. Regions with underdeveloped financial markets and high informality often experience weaker monetary policy transmission, limiting the framework's ability to achieve equitable economic outcomes (Ospina-Tejeiro and Romero-Chamorro, 2024).

4 Data and Methodology

4.1 Data Description

This study employs a rich dataset combining macroeconomic and department-level indicators to investigate the regional effects of monetary policy in Colombia. We include information on inflation, monetary policy interest rate, and GDP at the department level from 1998 to 2023.

The dataset combines information from multiple sources. Economic data, including GDP and inflation, are sourced from Colombia's National Administrative Department of Statistics (DANE). Monetary policy variables, including the policy interest rate, are obtained from the Central Bank of Colombia (Banco de la República).

Economic indicators at the departmental level capture the heterogeneity across Colombia's 24 main departments. These include:

- **GDP per capita**: Reflects the economic performance of each department and provides insights into regional income disparities.

- **Output gap**: Estimated using initially the Hodrick-Prescott (HP) filter, the output gap is calculated as the difference between actual and potential GDP for each department. This serves as a measure of economic slack.

- **Inflation rate**: Department-level inflation rates are used to capture regional price dynamics and their responsiveness to monetary policy.

The primary monetary policy variable is the policy interest rate with annual periodicity. This variable serves as the dependent variable in the empirical model, capturing the Central Bank's policy stance. Lagged policy rates are included to account for persistence in monetary policy decisions, reflecting the Central Bank's gradualist approach to interest rate adjustments. The inflation gap, defined as the difference between actual inflation and the Central Bank's target, and the output gap are key explanatory variables consistent with the Taylor Rule framework.

4.2 Summary

The descriptive statistics in Table 1 provide an overview of the regional economic disparities in Colombia as captured through GDP in logarithmic terms (ln(GDP)) and inflation rates.

The Andean region, including key departments such as Bogotá and Antioquia, exhibits the highest average GDP (9.9838) and the widest range, reflecting its economic dominance and diverse industrial base. In contrast, the Amazon region reports the lowest (7.8986), emphasizing its marginal contribution to national economic output. Inflation rates demonstrate moderate variability across regions, with the Caribbean and Pacific regions displaying slightly higher standard deviations (0.0629 and 0.1042, respectively), indicating greater price volatility. The Andean region maintains relatively stable inflation with a mean of 0.0713 and lower variability (0.0557). The Amazon region, while economically smaller, exhibits similar inflation stability (mean of 0.0682, SD 0.0386).

Table 1: Summary Statistics for GDP in Logarithms and Inflation by Region (1999–2023)

Region	Variable	Obs	Mean	Std. Dev.	Min	Max	# Departments
Bogotá	ln(GDP)	26	9.9838	1.0321	8.3440	12.4748	1
	Inflation	26	0.0713	0.0557	-0.1315	0.5966	
Andean	ln(GDP)	260	9.6057	1.0248	7.5149	12.4748	10
	Inflation	260	0.0723	0.0670	-0.2003	0.5966	
Caribbean	ln(GDP)	182	9.3587	0.6261	8.1908	10.7080	7
	Inflation	182	0.0718	0.0629	-0.2003	0.3174	
Pacific	ln(GDP)	104	9.3819	1.1511	7.5149	11.4864	4
	Inflation	104	0.0784	0.1042	-0.1574	0.5665	
Orinoquía	ln(GDP)	26	9.7774	0.5624	9.0007	10.3516	1
	Inflation	26	0.0670	0.0364	0.0213	0.1613	
Amazon	ln(GDP)	26	7.8986	0.2517	7.5409	8.2440	1
	Inflation	26	0.0682	0.0386	0.0043	0.1604	
Overall	ln(GDP)	624	9.6057	1.0248	7.5149	12.4748	24
	Inflation	624	0.0723	0.0670	-0.2003	0.5966	

Note: The table presents summary statistics for GDP (logarithmic transformation) and inflation for Colombian regions from 1999 to 2023. The number of departments in each region is indicated in the last column. The departments included in each region are as follows:
- Bogotá: Bogotá D.C.
- Andean Region: Antioquia, Boyacá, Caldas, Cundinamarca, Huila, Meta, Nariño, Norte de Santander, Santander, Tolima
- Caribbean Region: Atlántico, Bolívar, Cesar, Córdoba, La Guajira, Magdalena, Sucre
- Pacific Region: Cauca, Chocó, Nariño, Valle del Cauca
- Orinoquía Region: Casanare
- Amazon Region: Amazonas

These disparities are better represented in Figure 2. Notably, the Andean region, which likely includes economically dominant areas, shows relatively stable inflation trends compared to other regions. The Amazon and Orinoquía regions demonstrate significant variability, reflecting economic volatility or differing responses to national monetary policies. In recent years, brighter hues in some areas indicate periods of elevated inflation, possibly influenced by external shocks or regional-specific factors.

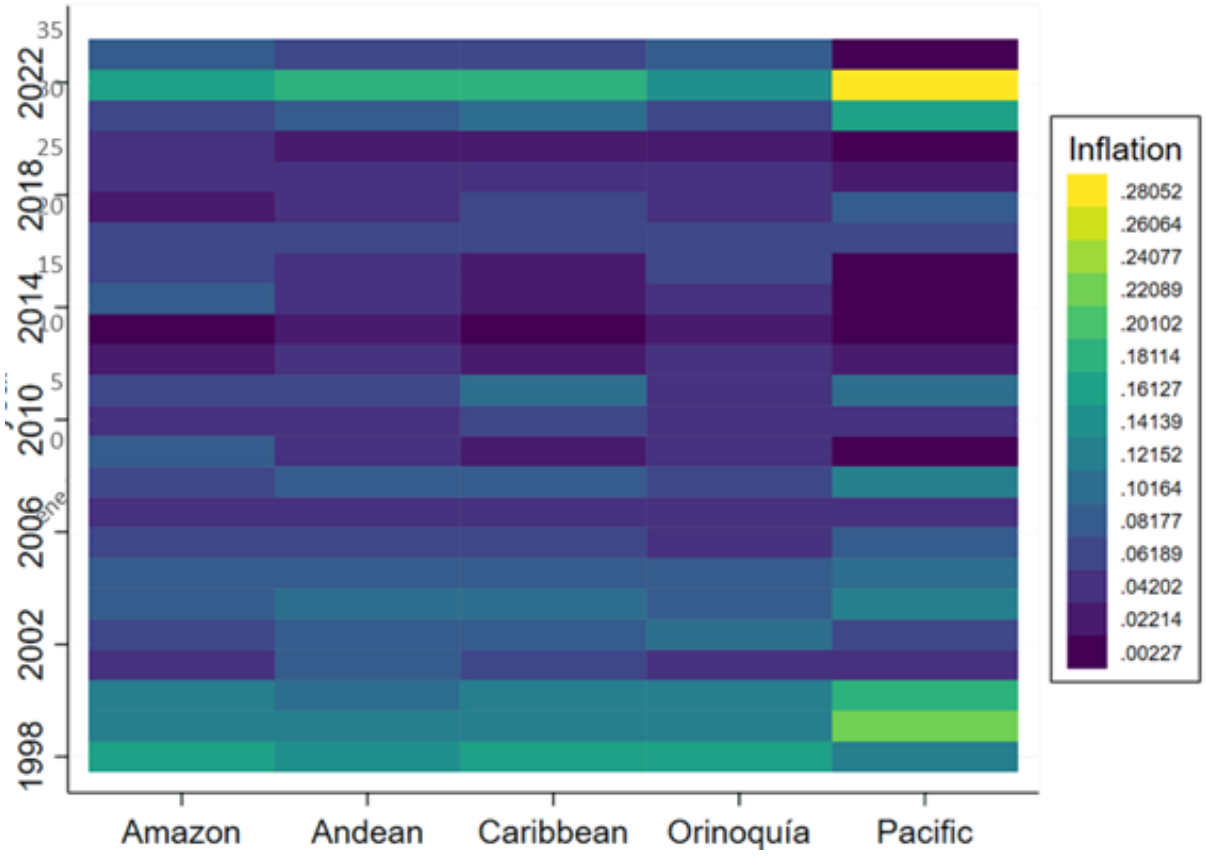


Figure 2: Heatmap on inflation by region and year

Underscore the importance of considering regional economic contexts when assessing the transmission of monetary policy. The variations in GDP and inflation suggest that national-level policy may have uneven effects across regions, further supporting the need for a nuanced and regionally sensitive approach to economic and monetary policy analysis.

4.3 Empirical Strategy

To analyze the regional transmission of monetary policy in Colombia, this study estimates a panel vector autoregression (PVAR) model incorporating a regional Taylor Rule

framework. The PVAR approach is particularly suitable for capturing the dynamic interdependencies among monetary policy, inflation, and output fluctuations while accounting for cross-sectional heterogeneity (Canova and Ciccarelli, 2013). This model enables the examination of how monetary policy shocks propagate across departments, considering their unique economic structures and spatial interdependencies.

The regional Taylor Rule extends the classical formulation (Taylor, 1993) by incorporating spatial heterogeneity, recognizing that monetary policy transmission is not uniform across regions. In line with previous research on economic policy in developing economies (Caporale et al., 2018), this study specifies the policy rate as a function of the inflation gap (the deviation of observed inflation from its target) and the output gap (the deviation of actual output from its potential level). The output gap is estimated using alternative filtering techniques to ensure robustness.

4.4 Model Specification

The baseline specification of the regional Taylor Rule follows:

$$i_{j,t} = \alpha_j + \beta_1 i_{j,t-1} + \beta_2(\pi_{j,t} - \pi^*) + \beta_3(y_{j,t} - \bar{y}_{j,t}) + \varepsilon_{j,t}, \tag{2}$$

Where:

- $i_{j,t}$ represents the cleaned policy rate for department j at time t.
- $\pi_{j,t}$ is the observed inflation rate in department j at time t, while π^* is the central bank's inflation target.
- $(y_{j,t} - \bar{y}_{j,t})$ is the output gap for department j, where $y_{j,t}$ is actual GDP and $\bar{y}_{j,t}$ is potential output.
- α_j captures department-specific fixed effects.
- $\varepsilon_{j,t}$ is an idiosyncratic error term.

Potential output $\bar{y}_{j,t}$ is estimated using different filtering techniques to verify the robustness of the results. The baseline specification employs the Hodrick-Prescott (HP)

filter, which has been widely used in monetary policy analysis (Ravn and Uhlig, 2002). In addition, we apply the Christiano-Fitzgerald band-pass filter (Christiano and Fitzgerald, 2003) and the Butterworth time-series filter (Ghoshray and Pundit, 2021) to assess whether alternative methods of detrending GDP yield consistent policy transmission estimates.

4.5 Estimation Methodology

Given the presence of heteroskedasticity and cross-sectional dependence, we adopt a robust estimation approach. We use Driscoll-Kraay standard errors to account for cross-sectional dependence, heteroskedasticity, and autocorrelation (Driscoll and Kraay, 1998; Hoechle, 2007). This estimator ensures that the statistical inferences remain valid even in the presence of spatial and temporal dependence, a key concern in regional monetary policy studies (Crespo Cuaresma et al., 2011).

To examine the dynamic responses of inflation and output to monetary policy shocks, we estimate a Panel Vector Autoregression (PVAR) model. PVAR models have been extensively used in macroeconomic research to analyze monetary policy transmission (Love and Zicchino, 2006; Canova and Ciccarelli, 2013). The general specification follows:

$$X_{j,t} = A_0 + A_1 X_{j,t-1} + A_2 X_{j,t-2} + ... + A_p X_{j,t-p} + u_{j,t}, \tag{3}$$

Where:

- $X_{j,t}$ is a vector containing the endogenous variables $(i_{j,t}, \pi_{j,t}, y_{j,t} - \bar{y}_{j,t})$.
- A_0 is a vector of constant terms.
- A_p represents coefficient matrices for each lagged term.
- $u_{j,t}$ is a vector of structural shocks.

Following the literature on regional monetary policy spillovers (Montoro and Ortiz, 2022), we extend the baseline PVAR model by including regional interaction terms, capturing spillovers across neighboring departments.

4.6 Robustness Checks

To ensure the robustness of our findings, we conduct additional analyses:

1. Alternative Output Gap Measures: The cyclical component of GDP is estimated using three filtering techniques: HP filter, Christiano-Fitzgerald filter, and Butterworth filter. This allows us to confirm that the observed monetary policy responses are not driven by a specific method of extracting the output gap.

2. Regional Heterogeneity: We estimate separate PVAR models for each economic region in Colombia (Andean, Caribbean, Pacific, Orinoquía, and Amazon) to assess whether monetary policy effects differ across regions with distinct economic structures.

3. Structural Break Analysis: The COVID-19 pandemic introduced significant macroeconomic disruptions. To examine whether monetary policy responses changed during this period, we estimate the models separately for pre-pandemic and post-pandemic periods.

4. Granger Causality Tests and Impulse Response Functions (IRFs): We test for causality among policy rates, inflation, and output gaps to determine whether regional monetary policy adjustments are primarily reactive or anticipatory.

The empirical strategy builds upon previous research that has emphasized the role of regional asymmetries in monetary policy transmission (Beraja et al., 2019). The inclusion of spatial economic linkages reflects the argument that monetary policy effects are not geographically isolated but propagate through interregional trade, financial flows, and labor mobility (Gerlach and Smets, 1995; Carlino and DeFina, 1998). These considerations align with findings in emerging market economies, where financial fragmentation often leads to heterogeneous policy transmission (Kuttner and Posen, 2001; Mishkin, 2007).

By incorporating PVAR modeling, this study contributes to the growing literature on dynamic monetary policy interactions at the regional level (Canova and Ciccarelli, 2013; Montoro and Ortiz, 2022). The identification of region-specific effects within the Taylor

Rule framework advances the understanding of monetary policy effectiveness in heterogeneous economic environments, particularly in developing economies such as Colombia.

5 Results

Columns 1–3 of Table 2 show that the lagged policy rate carries a positive and significant coefficient across all filters, confirming partial adjustment or "interest rate smoothing." This inertia suggests that monetary authorities adjust interest rates gradually rather than making abrupt changes. The coefficient on lagged inflation is also positive and highly significant (at the 1% level), indicating that when inflation rises above the target, policymakers respond by raising the policy rate in the next period.

Table 2: Panel Vector Autoregression (PVAR) Estimates: Policy Rate, Inflation, and Output Gap

	HP Filter	**CF Filter**	**Butterworth Filter**
Equation: Policy Rate (Δi_t)			
Δi_{t-1}	0.030** (0.011)	0.121*** (0.010)	0.035** (0.011)
$\Delta \pi_{t-1}$	0.028*** (0.007)	0.037*** (0.007)	0.036*** (0.007)
$\Delta y_{t-1}^{\text{gap}}$	0.126*** (0.031)	-0.100*** (0.025)	-1.849*** (0.487)
Equation: Inflation ($\Delta \pi_t$)			
Δi_{t-1}	-0.386*** (0.068)	-0.349*** (0.074)	-0.316*** (0.070)
$\Delta \pi_{t-1}$	-0.011 (0.113)	-0.007 (0.112)	-0.005 (0.114)
$\Delta y_{t-1}^{\text{gap}}$	0.146*** (0.042)	0.058 (0.087)	0.406 (0.909)
Equation: Output Gap (Δy_t^{gap})			
Δi_{t-1}	0.066 (0.045)	0.024 (0.035)	-0.003*** (0.001)
$\Delta \pi_{t-1}$	0.047*** (0.016)	0.041*** (0.014)	0.0003 (0.0002)
$\Delta y_{t-1}^{\text{gap}}$	-0.274*** (0.081)	-0.197** (0.078)	1.027*** (0.011)
Observations		552	
Number of Panels		24	
GMM Criterion $Q(b)$	HP: 1.81×10^{-33}, CF: 7.43×10^{-34}, BW: 3.38×10^{-32}		

Notes: This table presents estimated coefficients from a Panel Vector Autoregression (PVAR) model with one lag, using the Generalized Method of Moments (GMM). The dependent variables are policy rate (Δi_t), inflation ($\Delta \pi_t$), and output gap (Δy_t^{gap}), estimated via three different filters: Hodrick-Prescott (HP), Christiano-Fitzgerald (CF), and Butterworth (BW). Standard errors appear in parentheses. Significance: ***p < 0.01, **p < 0.05, *p < 0.1.

Notably, the effect of the lagged output gap on policy rates varies by filter. Under the Hodrick-Prescott (HP) filter, the coefficient is positive and significant (0.126), implying

that higher economic activity elicits a tighter monetary stance. However, under the Christiano-Fitzgerald (CF) and Butterworth (BW) filters, the effect is negative. These discrepancies highlight the sensitivity of gap-based policy rules to different methods for extracting cyclical components.

Estimates from the second panel in Table 2 show a consistent negative relationship between lagged policy rates and current inflation. In all three filtering approaches, the coefficient is statistically significant and indicates that higher interest rates dampen subsequent price growth. This is in line with standard monetary transmission mechanisms: as policymakers tighten, aggregate demand cools, thus moderating inflationary pressures.

By contrast, lagged inflation itself does not significantly predict current inflation once the policy response is included, suggesting limited inflation persistence at the department level. Meanwhile, the output gap boosts inflation in the HP specification (0.146) but has an insignificant coefficient under CF and BW. One potential explanation is that the HP filter may better capture short-run demand pressures in these data, whereas CF and BW filters produce different cyclical dynamics.

The last panel of Table 2 examines how output responds to monetary and inflationary shocks. Under the HP and CF filters, lagged policy rates do not significantly affect the current output gap. In the BW column, however, the policy rate coefficient is small but negative and significant. This finding implies that higher interest rates can restrict actual activity, but the effect is sensitive to the filtering method used to isolate cyclical fluctuations.

Past inflation affects the output gap positively under HP and CF, potentially reflecting short-run production or demand responses when prices rise. Under BW, this coefficient is negligible and insignificant. Finally, the gap's autoregressive component diverges across filters: harmful under HP and CF (indicating mean reversion) versus positive under BW (suggesting more persistent cycles). These differences underscore the challenges of measuring potential output in volatile regional datasets.

Taken as a whole, the estimates point to three clear findings:

1. **Policy Inertia and Inflation Response:** The Central Bank of Colombia adjusts

interest rates gradually but systematically reacts to inflation deviations, consistent with a Taylor-type rule.

2. **Monetary Control of Inflation:** Tighter policy successfully lowers inflation in the short term. When the policy rate rises, inflation decreases in the following period, supporting the case for interest-rate-based stabilization.

3. **Dependence on Output-Gap Measurement:** The sign and significance of output-gap coefficients differ across HP, CF, and BW filters. Researchers and policymakers should, therefore, interpret gap-driven policy rules with caution, especially in regions where data limitations or structural volatility affect potential output estimates.

5.1 Regional Results

Estimates from Table 2 show a consistent fulfillment of the Taylor rule by regions in Colombia.

These regional regressions reveal that Colombia's monetary policy displays both common patterns and region-specific nuances. Across most areas, an increase in past inflation typically prompts tighter policy, consistent with a Taylor-type rule. Tighter policy, in turn, tends to reduce future inflation, reflecting the broader effectiveness of the country's inflation-targeting framework. However, notable variations emerge regarding how monetary policy and inflation affect actual activity. For instance, Orinoquía and the Caribbean show more robust policy-output feedback loops than the Pacific or Andean regions.

Taken as a whole, these findings underscore the importance of regional economic structures in shaping monetary transmission. While a uniform policy stance exists at the national level, local heterogeneities—such as reliance on specific export commodities, degree of financial development, or the prevalence of informal labor—yield distinct responses in inflation and output. Policymakers aiming for inclusive growth should thus be mindful that a "one size fits all" policy may generate uneven outcomes across Colombia's diverse economic landscapes.

Table 3: Regional PVAR Estimates (One Lag, GMM), Three-Decimal Precision

	Bogotá	**Caribbean**	**Pacific**	**Orinoquía**
Equation: Δpolicy_t				
L1. Δpolicy	-0.105*** (0.000)	0.035** (0.015)	0.046* (0.025)	0.071*** (0.000)
L1. $\Delta\pi$	0.137*** (0.000)	0.027*** (0.009)	0.042*** (0.012)	0.061*** (0.000)
L1. $\Delta\ln(\text{GDP}_{\text{cycle}})$	0.291*** (0.000)	0.092** (0.041)	0.129* (0.075)	0.058*** (0.000)
Equation: $\Delta\pi_t$				
L1. Δpolicy	-0.183*** (0.000)	-0.474*** (0.157)	-0.427* (0.243)	-0.173*** (0.000)
L1. $\Delta\pi$	-0.405*** (0.000)	-0.073** (0.030)	0.007 (0.225)	-0.393*** (0.000)
L1. $\Delta\ln(\text{GDP}_{\text{cycle}})$	0.488*** (0.000)	0.101 (0.062)	0.187 (0.168)	0.037*** (0.000)
Equation: $\Delta\ln(\text{GDP}_{\text{cycle}})_t$				
L1. Δpolicy	-0.091*** (0.000)	0.221*** (0.060)	-0.029 (0.091)	-0.032*** (0.000)
L1. $\Delta\pi$	0.001*** (0.000)	0.070** (0.035)	0.021 (0.018)	-0.019*** (0.000)
L1. $\Delta\ln(\text{GDP}_{\text{cycle}})$	-0.019*** (0.000)	-0.439*** (0.062)	0.003 (0.169)	-0.258*** (0.000)

Notes: This table presents regional PVAR estimates (GMM, one lag) for the changes in the monetary policy rate (Δpolicy_t), changes in inflation ($\Delta\pi_t$), and the cyclical component of GDP ($\Delta\ln(\text{GDP}_{\text{cycle}})_t$). Columns correspond to: **Bogotá (region_num = 0)**, **Caribbean (2)**, **Pacific (3)**, **Orinoquía (4)**. Standard errors appear in parentheses; significance: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.2 Comparing Pre- and Post-COVID Estimates

Table 4 shows that the relationships among the policy rate, inflation, and output differ noticeably before and after the onset of the COVID-19 pandemic. In the *Pre-COVID* period, lagged policy rates are modestly persistent (positive coefficient), and tighter policy reduces inflation, consistent with a gradualist approach to monetary policymaking. Moreover, inflation exhibits mode negative dependence on its own lag, pointing to a mean-reverting price process.

In contrast, the *Post-COVID* estimates suggest more pronounced and sometimes counterintuitive adjustments, likely driven by the unique economic disruptions of the pandemic. Specifically, the policy rate equation turns strongly negative with respect to its own lag, indicating a shift in the policy stance from gradual smoothing to sharper changes. Meanwhile, a substantial negative coefficient on the policy rate in the inflation equation (-3.528) implies that once rates do move significant impact on inflation can be considerable—though the heightened uncertainty of the period and the small sample size

Table 4: Pre- vs. Post-COVID Panel VAR Estimates (One Lag, GMM)

	Pre-COVID	**Post-COVID**
Equation: Δpolicy_t		
L1. Δpolicy	0.042*** (0.013)	-0.258** (0.115)
L1. $\Delta\pi$	-0.021 (0.016)	0.179* (0.099)
L1. $\Delta \ln(\text{GDP}_{\text{cycle}})$	-0.061* (0.031)	0.357*** (0.092)
Equation: $\Delta\pi_t$		
L1. Δpolicy	-0.264*** (0.089)	-3.528*** (1.324)
L1. $\Delta\pi$	-0.261*** (0.033)	1.046 (0.989)
L1. $\Delta \ln(\text{GDP}_{\text{cycle}})$	-0.050 (0.075)	0.143 (0.206)
Equation: $\Delta \ln(\text{GDP}_{\text{cycle}})_t$		
L1. Δpolicy	0.089 (0.054)	-0.631*** (0.098)
L1. $\Delta\pi$	-0.004 (0.016)	0.111 (0.090)
L1. $\Delta \ln(\text{GDP}_{\text{cycle}})$	-0.175 (0.111)	-0.268** (0.115)

Notes: This table compares the Panel VAR (PVAR) coefficients from a one-lag GMM estimation for two samples: **Pre-COVID** (through 2019, $n = 456$) and **Post-COVID** (from 2020 onward, $n = 48$). Three endogenous variables are: Δpolicy_t (the change in the monetary policy rate), $\Delta\pi_t$ (the change in inflation), and $\Delta \ln(\text{GDP}_{\text{cycle}})_t$ (the cyclical component of GDP in logs). Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

(only two-time observations per panel) caution again actual interpretation.

Finally, real activity (output gap) also responds more strongly to the policy ratadverse2020, with a significant negative effect in the post-pandemic sample (-0.631). This suggests more profound monetary changes have had a deeper impact on local economic conditions during a time marked by heightened volatility, supply disruptions, and shifts in demand. Overall, these findings underscore the potential need for more flexible policy frameworks during systemic shocks, as well as the importance of careful sample-split analyses to capture regime shifts in economic relationships.

6 Additional Panel VAR Diagnostics

6.1 Eigenvalue Stability Check

A necessary condition for valid inference in Panel VAR models is that all eigenvalues lie inside the unit circle. Table 5 reports the estimated eigenvalues for the current specifica-

tion.

Table 5: Eigenvalue Stability Condition

Eigenvalue	**Real**	**Imaginary**	**Modulus**
1	-0.3310351	0.0000000	0.3310351
2	0.0378107	0.1173136	0.1232564
3	0.0378107	-0.1173136	0.1232564

Note: All eigenvalues lie strictly inside the unit circle, indicating that the PVAR satisfies the stability condition.

The largest eigenvalue in modulus is approximately 0.3310, which is below 1.0. Therefore, the estimated model meets the stability criterion commonly required in VAR analyses.

6.2 Impulse Response Functions (IRFs)

Figure 3 shows the IRFs generated by the `pvarirf` command, focusing on how the monetary policy variable (Δpolicy) responds to exogenous shocks in inflation ($\Delta\pi$) and the output gap ($\Delta \ln(\text{GDP}_{\text{cycle}})$). In the left panel, the output gap shock initially raises the policy rate but then converges near zero, reflecting moderate policy feedback to economic fluctuations. In the right panel, a shock to inflation produces a small but positive response in the policy rate, consistent with a Taylor-type mechanism.

6.3 Granger Causality Tests

Table 6 reports the results of Granger causality (Wald) tests for each equation in the PVAR. In these tests, the null hypothesis is that an excluded variable does *not* Granger-cause the dependent variable. A significant p-value (typically $p < 0.05$) rejects the null in favor of causality.

Key inferences from Table 6 include:

- $\Delta \ln(\text{GDP}_{\text{cycle}})$ Granger-causes Δpolicy (p-value = 0.000). In other words, output gap fluctuations help predict subsequent changes in the policy rate.

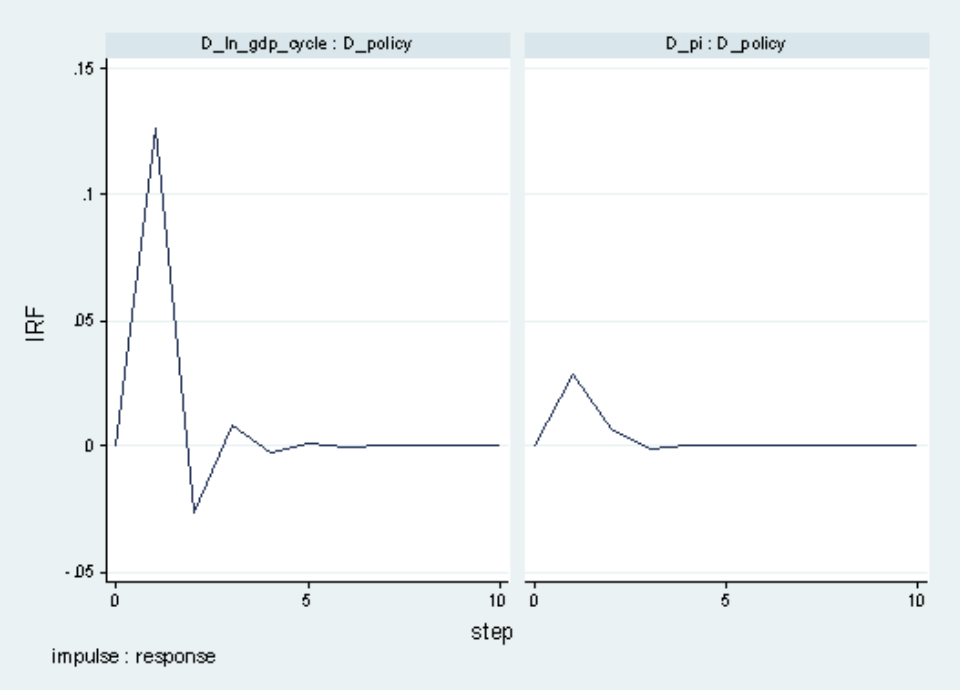


Figure 3: Impulse Responses of Δpolicy to Innovations in $\Delta\pi$ and $\Delta \ln(\text{GDP}_{\text{cycle}})$

Table 6: Panel VAR – Granger Causality Wald Tests

Equation	**Excluded**	**chi2**	**df**	**p-value**	**Decision**
Δpolicy	$\Delta\pi$	2.000	1	0.157	Fail to reject H_0
	$\Delta \ln(\text{GDP}_{\text{cycle}})$	16.129	1	0.000	Reject H_0
	ALL	17.550	2	0.000	Reject H_0
$\Delta\pi$	Δpolicy	19.150	1	0.000	Reject H_0
	$\Delta \ln(\text{GDP}_{\text{cycle}})$	1.557	1	0.212	Fail to reject H_0
	ALL	21.529	2	0.000	Reject H_0
$\Delta \ln(\text{GDP}_{\text{cycle}})$	Δpolicy	2.366	1	0.124	Fail to reject H_0
	$\Delta\pi$	4.168	1	0.041	Reject H_0
	ALL	6.712	2	0.035	Reject H_0

Notes: Under the null hypothesis, the excluded variable does not Granger-cause the dependent variable. A significant test statistic (e.g., $p < 0.05$) leads to a rejection of the null.

- Δpolicy Granger-causes $\Delta\pi$ (p-value = 0.000), indicating that monetary tightening or easing has predictive power for future inflation.

- $\Delta\pi$ Granger-causes $\Delta \ln(\text{GDP}_{\text{cycle}})$ (p-value = 0.041). Higher (or lower) inflation leads to changes in real activity, consistent with a short-run Phillips-curve-like mechanism.

Overall, the Panel VAR diagnostics confirm that the estimated system is stable, and the impulse responses behave in line with standard macroeconomic priors: output is sensitive to monetary policy, and policy innovations affect future inflation. The Granger causality results suggest a bidirectional linkage between real activity and policy, with inflation also playing a key mediating role.

7 Discussion

Our findings shed light on several critical dimensions of Colombia's regional monetary policy transmission and complement the growing literature that examines heterogeneity within emerging economies (e.g., Beraja et al., 2019; Aginta and Someya, 2022; Otero, 2018). First, the Central Bank of Colombia's behavior aligns closely with a Taylor Rule framework, indicating a systematic response to deviations in inflation. This is consistent with studies of advanced economies where inflation targeting helps anchor price expectations, as demonstrated by Clarida et al. (2000) and Woodford (2001). However, the varied responses to the output gap across different filtering methods echo concerns raised by Ravn and Uhlig (2002) and Christiano and Fitzgerald (2003) about how sensitive policy assessments can be to detrending approaches. Such measurement issues are especially relevant in developing economies with volatile data and persistent structural shifts.

Second, our results suggest that inflation responds negatively to policy-rate increases, reflecting standard transmission channels highlighted by Bernanke and Gertler (1995) and Kashyap and Stein (2000). Yet, the magnitude and persistence of this effect differ by region, pointing to structural heterogeneities in financial market development, sectoral composition, and local labor market dynamics. Indeed, Carlino and DeFina (1998, 1999)

emphasized that varying regional industrial bases can significantly alter the potency of monetary interventions. Our regional panel results corroborate these observations, particularly in departments dominated by interest-sensitive industries like manufacturing or services.

Third, we observe substantial cross-regional asymmetries. The Caribbean and Orinoquía regions exhibit pronounced policy-output feedback loops, whereas the Pacific region shows weaker responses. These findings align with Otero (2018), which documents substantial spatial heterogeneity in Colombia's monetary transmission due to differences in institutional capacity and dependency on extractive sectors. Similar patterns appear in other emerging markets, such as Indonesia (Aginta and Someya, 2022), reinforcing the view that structural disparities, including a higher share of agriculture or informality, may attenuate interest-rate effects.

A further layer of heterogeneity emerges in the post-COVID sample, where the shift toward more abrupt interest-rate changes suggests a heightened policymaker response under extraordinary circumstances. Beraja et al. (2019) highlight that systemic shocks can amplify regional disparities in policy outcomes, as regions vary in their resilience and access to credit. While our post-pandemic observations are limited, the results support the broader narrative that crisis conditions may induce more forceful monetary actions as policymakers confront rapid shifts in global and local demand.

Finally, the Granger causality tests and IRFs confirm a bidirectional linkage between real activity and policy, echoing Gómez-González et al. (2021b) and Love and Zicchino (2006) in showing that local economic conditions inform policy changes, which then shape inflation and output. This cyclical interplay has critical policy implications. On the one hand, a unified inflation-targeting approach provides a clear nominal anchor, contributing to national-level stability (Taylor, 1993; Clarida et al., 2000). On the other hand, ignoring local structural variations may leave some regions systematically under- or over-reacting to policy changes, as Carlino and DeFina (1998) and Lozano-Espitia and Arias-Rodríguez (2022) highlight in similar contexts.

In sum, our results underscore the complexity of tailoring a single policy instrument

to vastly different regional economies. Policymakers may benefit from supplementary region-specific measures, such as targeted credit facilities or labor market policies, to ensure that national monetary policy achieves its objectives equitably across Colombia's diverse geography (Ospina-Tejeiro and Romero-Chamorro, 2024; Isaza and Flórez, 2018).

8 Conclusion

This paper contributes to the growing body of research on monetary policy heterogeneity by applying a Taylor Rule framework to Colombian departments. Our empirical evidence reaffirms that inflation-targeted monetary policy is effective in reducing price pressures overall. Still, the strength of this response varies with local sectoral structures and the method used to capture cyclical economic slack (Christiano and Fitzgerald, 2003). Where manufacturing or services prevail, policy interventions appear to transmit more robustly, whereas agriculture-dependent and informal economies display muted responses (Carlino and DeFina, 1998; Aginta and Someya, 2022).

The results further highlight notable differences before and after the COVID-19 pandemic, suggesting that in times of heightened uncertainty and systemic shocks, central banks may deviate from gradual interest-rate smoothing toward more forceful and rapid adjustments. This phenomenon aligns with the evidence provided by Beraja et al. (2019b) and Lozano-Espitia and Arias-Rodríguez (2022) that large shocks can expose and potentially exacerbate regional disparities in policy outcomes.

From a policy perspective, our findings imply that achieving uniform outcomes with a single policy instrument in an inherently heterogeneous environment can be challenging. While inflation targeting helps preserve overall price stability, it may not fully address the nuanced needs of regions with different economic profiles, particularly in developing economies like Colombia. Future work could build on this analysis by examining how complementary tools—such as targeted fiscal interventions, local credit programs, or region-specific regulatory changes—could mitigate disparities and enhance the overall efficacy of monetary policy (Gómez-González et al., 2021b; Ospina-Tejeiro and Romero-

Chamorro, 2024).

Taken together, these insights reinforce the importance of incorporating spatial and structural considerations into monetary policymaking. As Colombia continues to pursue stable inflation, policymakers might consider employing region-tailored strategies—or at least acknowledging the distinct channels through which policy operates—to ensure that national objectives align with equitable regional growth.

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