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Analyzing Fiscal Sustainability in Latin American Countries: A Time–Frequency Perspective

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Abstract: This study examines fiscal sustainability in Latin American countries from a unique time–frequency perspective, focusing on Brazil, Chile, Colombia, Peru, and Mexico from 1997 to 2022. Using wavelet coherence analysis, it uncovers dynamic relationships between government revenue and expenditure over different time horizons, revealing varying causality patterns across countries and periods. The findings underscore the importance of balanced fiscal planning and resource allocation to ensure fiscal sustainability and support economic growth. This research contributes to a deeper understanding of Latin America's economic landscape and provides valuable insights for policymakers, economists, and stakeholders concerned with the region's economic stability and development.

Keywords: fiscal sustainability; wavelet analysis; economic stability; fiscal policy; economics

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1. Introduction

In the realm of fiscal sustainability, understanding the dynamic relationship between government revenue and expenditure across various the countries is crucial for fostering fiscal stability, effective resource allocation, informed policy formulation, prudent debt management, and building economic resilience (Cascio 2015; Magazzino and Mutascu 2019; Sun et al. 2023).

Drawing inspiration from studies on fiscal sustainability in various countries, including the United States, China, and Italy, this research shifts attention to the dynamic economies of Latin America. Despite the importance of understanding these nuances, existing literature often overlooks the time-varying and frequency-dependent nature of the revenue-expenditure nexus in Latin America. By employing novel wavelet methods, we aim to fill this gap and provide fresh insights into fiscal sustainability dynamics in the region (Linhares et al. 2021; Narayan and Narayan 2006; Payne 2003). In this way, Latin American countries serve as an intriguing case study due to their significant role in global economic dynamics, as well as the substantial reforms and policy changes they have experienced over the years.

This study aims to analyze fiscal sustainability using innovative time–frequency analysis techniques, building on previous research in diverse global contexts (Cascio 2015; Jaén-García 2020; Magazzino et al. 2022). By focusing on Latin America, we seek to address the unique economic challenges faced by the region and contribute to a deeper understanding of fiscal dynamics. Hence, this study reevaluates the interplay between public revenue and expenditure ratios as a percentage of GDP from 1997 to 2022. Given the distinct economic landscapes and challenges across Latin American countries, such as Brazil, Chile, Colombia, Peru, and Mexico, this research is essential for comprehending the

dynamics of fiscal stability within the region. This study is motivated by two key economic considerations: first, the revenue-expenditure relationship varies across different time horizons, reflecting short-term economic fluctuations and long-term fiscal sustainability concerns (Bystrov and Mackiewicz 2020; Hakkio and Rush 1991); second, the selected Latin American economies demonstrate state-dependent variations in this relationship, influenced not only by demographic trends and political factors (Karlsson 2020; Linhares et al. 2021; Quintos 1995) but also by broader economic shocks. This consideration underscores the need to examine a wider range of influences on the dynamics of public revenue and expenditure ratios within the region.

This study represents the pioneering application of wavelet analysis to fiscal data in the context of Latin American countries. Through this approach, we aim to illuminate the nuanced challenges and opportunities associated with fiscal sustainability in Latin America across the short, medium, and long run, contributing to a more comprehensive understanding of the region's economic landscape. The implementation of a time–frequency framework to analyze the dynamics of government revenues and expenditures is based on three economic theories: business cycle theory, fiscal policy dynamics, and adaptive policymaking. These theories rationalize the use of the time–frequency model by emphasizing the cyclical nature of economic activity and the need for adaptive fiscal policies to respond effectively to different phases of the business cycle. By incorporating these theories, the study aims to improve understanding of how fiscal variables fluctuate over time and how policymakers can adjust fiscal policies accordingly.

The paper's structure is as follows: Section 2 delves into the background and conducts a bibliometric analysis of fiscal sustainability; Section 3 details the data, descriptive statistics, and methodologies employed; the subsequent section, Section 4, analyzes the obtained results; and the paper concludes with Section 5, where key findings are summarized and concluding remarks are presented.

2. Context of the Analysis and Literature Review

2.1. Context of the Analysis

The fiscal systems of Brazil, Chile, Colombia, Mexico, and Peru share several key similarities. First, all these countries employ a progressive income tax system together with a value-added tax (VAT). Income taxes were the primary driver behind the increase in tax revenues, playing a crucial role in most countries. While VAT also contributed, its impact on revenue growth was less pronounced compared to income taxes. Notably, VAT played a significant role in countries like Colombia (Economic Commission for Latin America and the Caribbean (ECLAC) 2023c). This commonality reflects a shared commitment to generating revenue based on income levels and consumption, establishing a foundational similarity in their tax structures. Secondly, social security contributions are mandatory for both employees and employers across all these countries, underscoring a collective responsibility for funding welfare programs (Economic Commission for Latin America and the Caribbean (ECLAC) 2023c). This approach ensures a unified effort in sustaining social security systems.

However, Table 1 provides a comprehensive overview of the notable distinctions within the fiscal systems of Brazil, Chile, Colombia, Mexico, and Peru. It delineates disparities in major reforms, corporate tax rates, consumption taxes, and recent fiscal policy trends among these countries.

Table 1 identifies each aspect contributing to the broader picture of fiscal sustainability in Brazil, Chile, Colombia, Mexico, and Peru. The major tax reforms across Brazil, Chile, Colombia, Mexico, and Peru have shaped their fiscal landscapes. In Brazil, substantial reforms occurred in 2001 and 2017, reflecting a commitment to adapt the tax system to evolving economic conditions. With ongoing reforms, Chile underscores its dedication to maintaining a dynamic and responsive fiscal framework. Colombia witnessed significant changes in 2016, indicating a recent push for tax adjustments to align with emerging economic challenges. Mexico's comprehensive reforms in 2014 signify a strategic approach

to fostering economic sustainability through tax policies (Economic Commission for Latin America and the Caribbean (ECLAC) 2018). Peru, experiencing reforms in 2012 and 2019, emphasizes its commitment to adaptability, ensuring that the tax system remains resilient in the face of evolving fiscal demands (Economic Commission for Latin America and the Caribbean (ECLAC) 2019). These major tax reforms collectively demonstrate the responsiveness of these countries to economic shifts and their commitment to fostering fiscal sustainability.

Table 1. Overview of fiscal systems in Brazil, Chile, Colombia, Mexico, and Peru.

Aspect	Major Tax Reforms	Corporate Tax Rates	Consumption Taxes	Recent Fiscal Policy Trends
Brazil	2001 and 2017	Gradual reduction, currently 15%	VAT 12–17%	Emphasis on reducing fiscal deficit
Chile	Ongoing tax reforms	Progressive rates, up to 27%	VAT 19%	Focus on fiscal responsibility law
Colombia	2016	Progressive rates, up to 33%	VAT 19%	Fiscal consolidation measures
Mexico	Comprehensive tax reforms in 2014	Progressive rates, up to 30%	VAT 16%	Fiscal austerity measures
Peru	2012 and 2019	Progressive rates, up to 29.5%	VAT 18%	Efforts to strengthen fiscal position

Source: Authors based on information from reports from the Economic Commission for Latin America and the Caribbean (ECLAC).

Furthermore, Table 1 outlines the major corporate tax rates in Brazil, Chile, Colombia, Mexico, and Peru. Notably, each country adopts a progressive tax structure, with rates varying based on income levels. Brazil has gradually reduced corporate tax rates, reaching 15%. In contrast, Chile employs progressive rates up to 27%, while Colombia and Mexico set their upper limits at 33% and 30%, respectively. Peru follows suit with a progressive rate of 29.5% (Economic Commission for Latin America and the Caribbean (ECLAC) 2023b). These variations reflect nuanced policy decisions aimed at balancing revenue generation with economic competitiveness across the five countries. Additionally, the differences in VAT rates reflect distinct policy choices, balancing the need for revenue generation with considerations for consumer spending and economic dynamics. The variations in consumption tax rates contribute to the diversity of fiscal approaches across the five Latin American countries.

Concerning recent developments in fiscal policy in the Latin American context, in July and August 2022, Chile and Colombia embarked on ambitious tax reform endeavors to strengthen revenue bases and enhance progressivity and efficiency within their respective tax systems. The reforms were pivotal in forging new social compacts to address underlying inequalities and social protection deficiencies. Colombia's "Tax Reform for Equality and Social Justice", introduced in early August 2022 by the new government, pivoted around four key pillars: reduction of tax exemptions for higher-income earners, optimization of resource allocation efficiency, broadening revenue sources by mitigating environmental and health externalities, and initiatives to combat tax evasion and avoidance. Despite facing challenges, the project, approved on 11 November 2022, underwent adjustments, particularly concerning the taxation framework for oil and coal extraction activities (Economic Commission for Latin America and the Caribbean (ECLAC) 2022).

The reform in Chile, aimed at fortifying tax progressivity and base broadening, presented several noteworthy provisions. Among these were adjustments to income tax rates for high-income individuals, reinforcement of capital gains taxation, and the introduction of a wealth tax targeting net assets. Other significant measures included the deductibility of rental costs for low-income households and the abolishment of exemptions for owners of "affordable housing." Both reforms were crafted to bolster tax revenues and channel resources

toward vital social protection initiatives and decentralized governance structures. They also reviewed tax treatments for investment funds and corporate income, proposing new preferential schemes for specific sectors such as caregiving, research, and development. Furthermore, the reform in Chile focuses on combating tax evasion and enhancing enforcement, including legal modifications, beneficiary registration, and the introduction of anonymous informants. Investment in tax agencies aims to translate these measures into revenue gains, projecting a 0.4% GDP increase in the first year and a gradual rise to 3.3% GDP by 2026 (Economic Commission for Latin America and the Caribbean (ECLAC) 2022).

Finally, regarding recent fiscal policy trends, the analyzed countries exhibit variations. Brazil and Mexico have focused on reducing fiscal deficits, while Chile emphasizes fiscal responsibility. Colombia has pursued fiscal consolidation, and Peru has strengthened its fiscal position. Each country adapts its tax policies to suit its economic goals and challenges. The diverse fiscal policy trends in Brazil, Chile, Colombia, Mexico, and Peru underscore the importance of tailoring strategies to unique national circumstances while addressing economic challenges. The commitment to fiscal responsibility, consolidation, austerity, and strengthening fiscal positions reflects a shared recognition of the need for sustainable fiscal policies. In the context of Latin American countries, where economic conditions and challenges can vary significantly, these nuanced fiscal approaches contribute to the ongoing discourse on achieving and maintaining fiscal sustainability. It highlights the necessity for adaptive and context-specific fiscal measures to ensure the long-term economic health and stability of each country in the region.

The time–frequency framework offers a comprehensive and adaptive approach to analyzing government revenue and expenditure dynamics, leveraging key economic theories to inform effective fiscal policy decisions. First, we address business cycle theory: This framework aligns with business cycle theory, which posits that economies experience fluctuations in output and employment over time. By applying time–frequency analysis, researchers can capture the cyclical nature of government revenue and expenditure. This approach allows for the identification of short-term fluctuations in fiscal variables, providing insights into how fiscal policies respond to different phases of the business cycle. Moreover, to the that extent discretionary fiscal policy is heavily used in recessions to stimulate aggregate demand, the key empirical question is how the effects of fiscal shocks vary over the business cycle (Auerbach and Gorodnichenko 2012). This understanding is crucial for policymakers in designing stabilization strategies and can help reconcile conflicting predictions about fiscal shocks across different types of macroeconomic models (Auerbach and Gorodnichenko 2012).

Second, fiscal policy dynamics: Economic theories on fiscal policy dynamics emphasize the importance of understanding how government spending and taxation policies evolve in response to economic conditions (Tiony 2023). The time–frequency framework enables the examination of dynamic changes in fiscal variables over various time horizons. By analyzing these dynamics, policymakers gain valuable insights into the effectiveness of fiscal policy interventions and their impact on economic stability.

Third, adaptive policymaking: The concept of adaptive policymaking suggests that governments should adjust their policies in response to changing economic circumstances (Walker et al. 2001). The time–frequency analysis supports adaptive policymaking by revealing the evolving relationship between government revenue and expenditure across different time scales. This knowledge enables policymakers to implement timely and targeted fiscal measures that support sustainable economic growth and fiscal stability.

2.2. Literature Review

In conducting a comprehensive literature review, articles were selected through targeted searches using Scopus and Web of Science (WoS) databases in March 2024. For both databases, the search queries utilized were ["Fiscal sustainab*"] and ["Public debt"], resulting in 208 and 206 initial articles, respectively. After removing 133 duplicate articles, 281 unique and relevant articles remained for further analysis. This rigorous search strat-

egy ensured a comprehensive selection of literature relevant to the intersection of fiscal sustainability, with a special emphasis on public debt, forming the foundation for a robust and inclusive review of pertinent scholarly works.

The analysis was performed using CiteSpace, a powerful tool developed by Professor Chen Chaomei at Drexel University in the United States, known for its robust capabilities in document co-citation analysis (Chen 2016). This application of bibliometric methods was crucial for gaining insights into the structure of scholarly communication, specifically through examining modularity (Q value) and the weighted mean silhouette (S value). Modularity measures the strength of community structure, with values ranging from 0 to 1; a Q value greater than 0.3 signifies a significant community structure. The S-weighted mean silhouette (S) represents average silhouette values, where $S > 0.5$ indicates reasonable clustering and $S > 0.7$ indicates efficient and convincing clustering (Li et al. 2022).

This analytical approach not only enhances methodological rigor but also underscores the importance of leveraging bibliometric techniques to inform evidence-based research and scholarly discourse. By assessing mapping impact with modularity (Q value) and the weighted mean silhouette (S value), we were able to evaluate network structure and clustering clarity, providing a deeper understanding of interconnections among research topics and publications. This integrated methodological approach contributes to a comprehensive analysis, emphasizing the value of leveraging bibliometric tools to inform evidence-based research and scholarly discourse.

Then, the keyword clustering graph exhibited a Q value of 0.9061, indicating a highly significant structure (see Figure 1). The corresponding S value was 0.9862, surpassing the threshold for efficient clustering at 0.7. The average silhouette value of 0.9445 further corroborated the efficiency and persuasiveness of the cluster analysis. Such robust clustering results, characterized by significant structure and high efficacy, are instrumental for comprehensively analyzing and understanding the overarching characteristics and developmental trends in fiscal sustainability.

The identified clusters in this study shed light on key thematic areas, encompassing topics such as "#0 Euro area countries", "#1 India", "#2 European countries", "#3 subnational fiscal sustainability risk sharing", "#4 welfare", "#5 sub-national level", "#6 policy asymmetries", "#7 local government", and "#8 opportunities". This nuanced clustering provides valuable insights into the multidimensional aspects of fiscal sustainability, offering a comprehensive view of the relevant issues and their interconnections in the present analysis.

For instance, clusters #0, #1, #2, #3, and #4 focus on studies related to fiscal sustainability across different regions, primarily within European countries. These studies collectively contribute to analyzing fiscal sustainability, each offering unique insights and methodologies tailored to specific regional contexts.

Cluster #0 examines the fiscal sustainability of Eurozone countries, highlighting regional variations and concerns about long-term fiscal health, especially in the Southern Eurozone group (Lee et al. 2018).

Cluster #1 delves into fiscal sustainability challenges and policies in India, emphasizing the complexities of healthcare policy and age-specific considerations (Sen 2012; Narayana 2016).

Cluster #2 focuses on public finance sustainability in Central and Eastern European (CEE) countries, exploring long-term revenue-expenditure relationships and potential threats to public finances (Krajewski et al. 2016).

Cluster #3 investigates the sustainability of public finances within the Eurozone post-2007 financial crisis, revealing heterogeneity in managing public finances among Eurozone countries (Afonso and Jalles 2015; Paniagua et al. 2017).

Cluster #4 challenges conventional notions about public debt costs and assesses welfare implications, particularly in the context of fiscal consolidation (Blanchard 2019; Futagami and Konishi 2018).

The decision to focus exclusively on clusters #0 to #4 is deliberate. These clusters encapsulate studies that specifically address fiscal sustainability issues within distinct

regions, providing detailed insights and methodologies relevant to the European context. By narrowing our scope to these clusters, we aim to emphasize the regional-specific nuances and challenges associated with fiscal sustainability, ensuring a focused and comprehensive analysis aligned with the objectives of this study.

Further studies examining fiscal dynamics in other regions, such as those in Latin America, are notably absent in the identified clusters, as highlighted by Marín-Rodríguez et al. (2023c). Understanding fiscal dynamics in Latin America is critical due to unique economic challenges and socioeconomic characteristics, which can provide valuable insights for global fiscal policies. Future research should aim to address these gaps to provide a comprehensive understanding of fiscal sustainability across diverse regions.

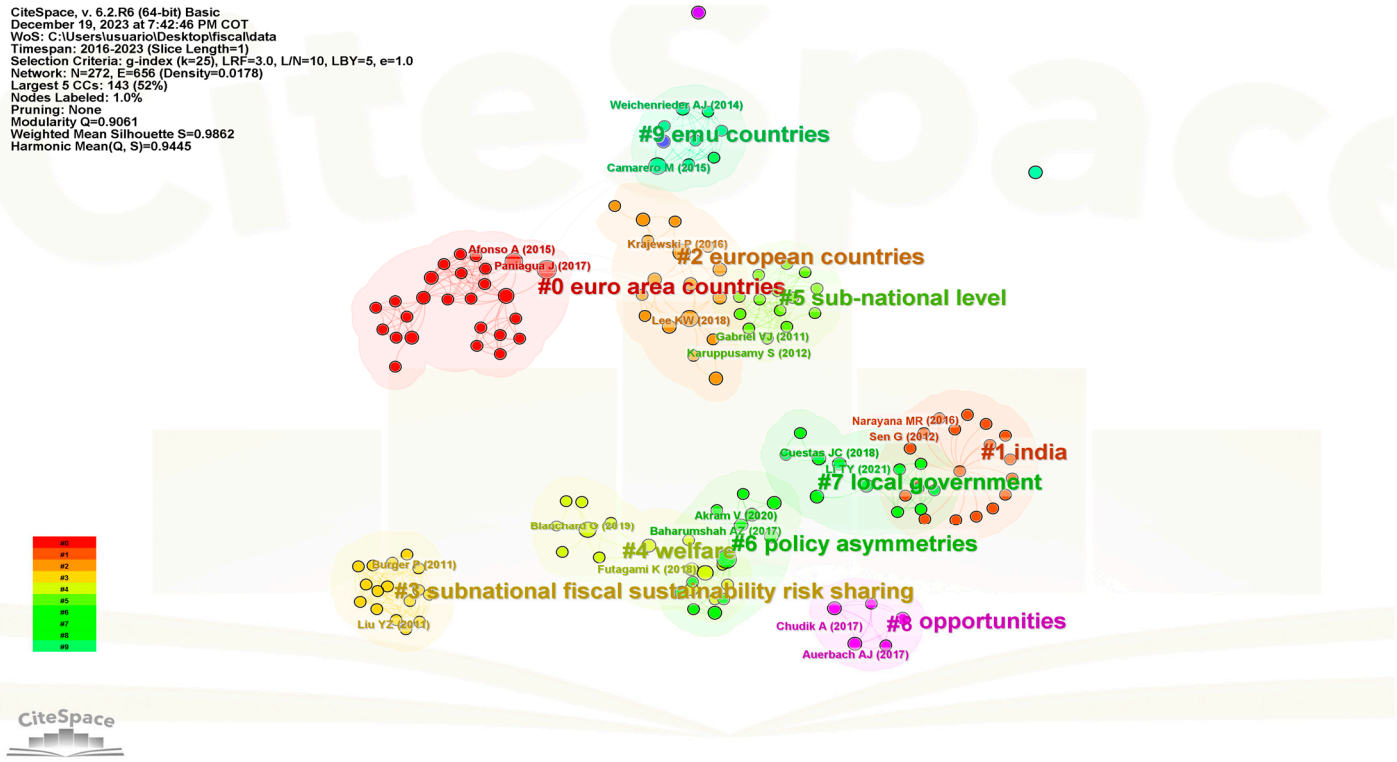


Figure 1. Keywords clustering and principal authors by cluster. Source: Authors' own research using CiteSpace (Weichenrieder and Zimmer 2014; Camarero et al. 2015; Afonso and Jalles 2015; Paniagua et al. 2017; Krajewski et al. 2016; Lee et al. 2018; Gabriel and Sangduan 2011; Karuppusamy and Carr 2012; Narayana 2016; Sen 2012; Cuestas and Regis 2018; Li and Du 2021; Burger et al. 2011; Liu and Zhao 2011; Blanchard 2019; Futagami and Konishi 2018; Akram and Rath 2020; Baharumshah et al. 2017; Chudik et al. 2017; Auerbach and Gorodnichenko 2017).

3. Methodology

3.1. The Dataset

We collect yearly data on national fiscal income and expenditure as a share of national GDP from 1997 to 2022. The data come from the respective central government websites of each country. Figure 2 shows a close dependency relationship between fiscal revenues and expenditures as a percentage of GDP during the period under analysis.

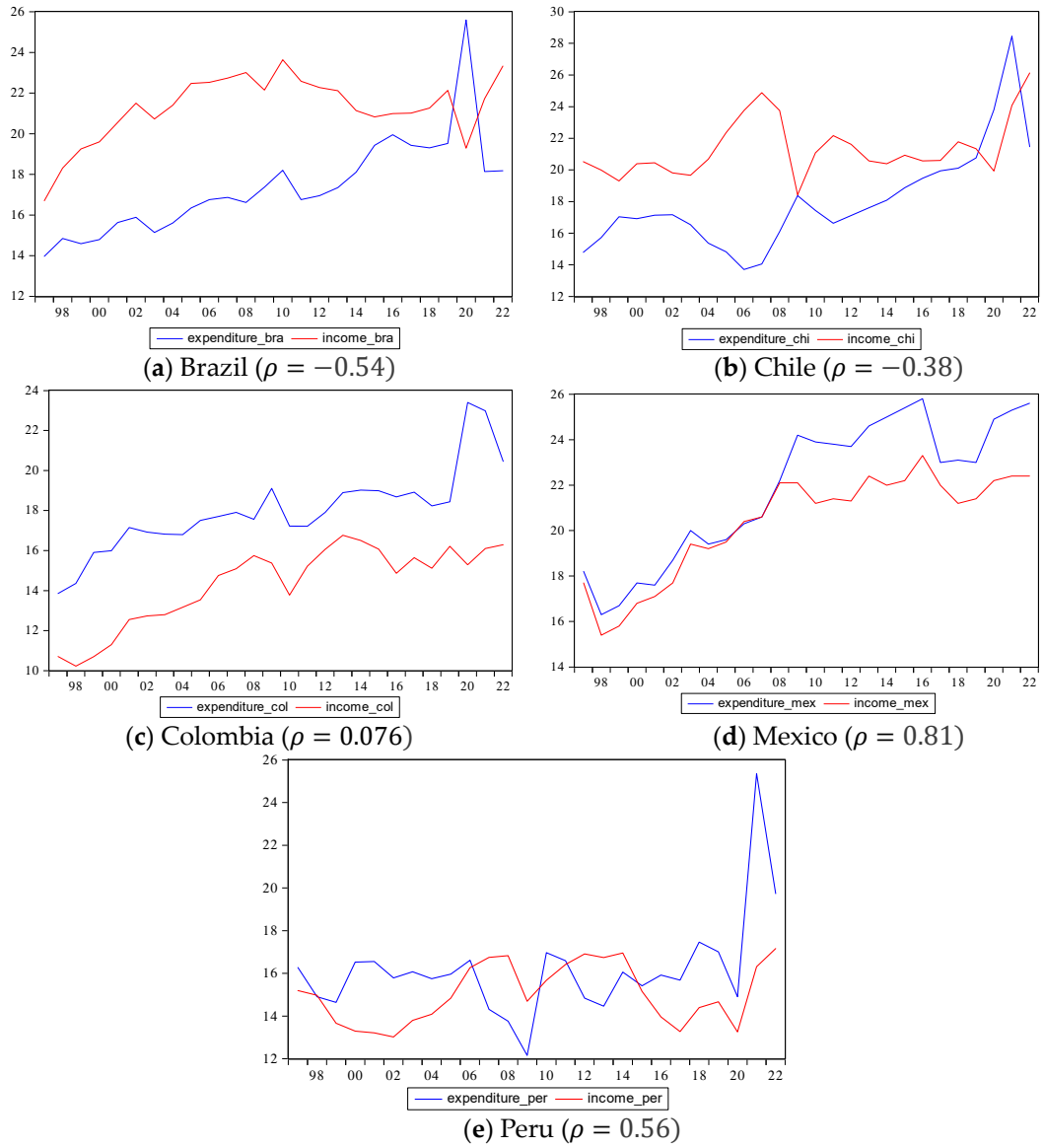


Figure 2. National fiscal income (solid red) and expenditure (solid blue) as a percentage of national GDP in the period 1997–2022 for the analyzed countries: (**a**) Brazil; (**b**) Chile; (**c**) Colombia; (**d**) Mexico; and (**e**) Peru. Note: the correlation coefficient appears in parentheses. Source: Authors' own research using data from government websites.

Among the examined countries, Brazil and Chile demonstrate negative correlations between income and expenditure, although with varying strengths. Brazil exhibits a moderate negative correlation ($\rho = -0.54$), suggesting that income increases are associated with decreases in expenditure and vice versa. Chile, on the other hand, shows a weaker negative correlation ($\rho = -0.38$), indicating a less pronounced relationship between income and expenditure. In contrast, Mexico and Peru display positive correlations between income and expenditure. Mexico exhibits a strong positive correlation ($\rho = 0.81$), implying that income increases coincide closely with expenditure increases, while Peru demonstrates a moderate positive correlation ($\rho = 0.56$), indicating a somewhat less direct relationship between income and expenditure. Interestingly, Colombia's correlation coefficient is very close to zero ($\rho = 0.076$), suggesting a minimal association between income and expenditure in the country.

These findings underscore the diverse dynamics of fiscal behavior across Latin American countries, with some demonstrating clear relationships between income and expenditure, while others exhibit more nuanced or even negligible associations.

The results in Table 2 indicate the outcomes of the augmented Dickey–Fuller (ADF) unit root tests conducted on income and expenditure variables for each country. A unit root test assesses whether a time series variable is stationary or exhibits a unit root, which implies non-stationarity. In the context of fiscal analysis, non-stationarity in income and expenditure variables can complicate correlation analysis and pose challenges for interpreting their relationships. Based on the results, it is evident that for most countries, both income and expenditure variables do not reject the null hypothesis of having a unit root, except for expenditure in Brazil, Colombia, and Peru, where the null hypothesis is rejected. This suggests that income and expenditure variables in these countries may exhibit non-stationary behavior, potentially affecting the validity of correlation analyses. Therefore, further investigation, such as wavelet coherence analysis, is warranted to explore the dynamic relationships between income and expenditure in each country. These findings underscore the importance of employing appropriate methods to analyze fiscal dynamics comprehensively and accurately, especially in the presence of non-stationary variables.

Table 2. Results for unit roots.

Country	Variable	ADF Unit Root Test	5% Critical Values	Prob.	Null Hypothesis
Brazil	Income	−2.98	−3.60	0.1549	Not Rejected
	Expenditure	−4.99	−3.61	0.0027	Rejected
Chile	Income	−2.84	−3.61	0.1958	Not Rejected
	Expenditure	−2.53	−3.60	0.3137	Not Rejected
Colombia	Income	−1.95	−3.60	0.5955	Not Rejected
	Expenditure	−4.32	−3.61	0.0118	Rejected
Mexico	Income	−1.83	−3.60	0.6581	Not Rejected
	Expenditure	−2.01	−3.60	0.5691	Not Rejected
Peru	Income	−2.02	−3.60	0.5652	Not Rejected
	Expenditure	−3.99	−3.60	0.0226	Rejected

Notes: The augmented Dickey–Fuller (ADF) test. The unit root tests were conducted considering both constant and trend, as the trend was found to be significant for all the variables analyzed. The null hypothesis states that the variable has a unit root.

The use of a time–frequency approach with annual data, despite its association with high-frequency contexts, is justified by the unique capabilities of wavelet analysis to uncover hidden patterns and relationships over extended periods. This method allows for the detection of time-varying dynamics and cyclical patterns that may not be evident with traditional time series approaches. The studies of Cascio (2015), Magazzino and Mutascu (2019), and Sun et al. (2023) demonstrate the effectiveness of wavelet analysis in reassessing fiscal sustainability, revealing insights into debt dynamics and government responses to fiscal challenges across historical periods. These analyses underscore the applicability of wavelet techniques to annual data, providing valuable insights into long-term fiscal dynamics and policy implications.

3.2. Wavelet Analysis

In the economic literature, the predominant approach to studying time series is through time domain analysis, capturing the evolution of individual variables and assessing multivariate relationships over time. However, an alternative strand of literature delves into the frequency domain, and the application of wavelet analysis reconciles both approaches (Magazzino and Mutascu 2019).

Wavelet analysis, which was introduced by Ramsey and Lampart (1998) in the realm of applied economics, is a powerful tool used to explore the intricate connections among various macroeconomic variables on a global scale. This analytical approach enables a detailed examination of how these variables interact and evolve over time, providing valuable insights into the complex dynamics of the global economic landscape. For the

analysis of economic variables, this innovative methodology allows for the differentiation between short-, medium-, and long-term dynamics, offering a comprehensive view across the entire sample period (Marín-Rodríguez et al. 2023a, 2023b).

The wavelet transform, a potent tool in signal analysis, finds application in various fields, including the efficient handling of non-stationary signals, much like the economic dynamics prevalent in Latin American countries. Recognizing the characteristic long-term trends (backgrounds) and short-term anomalies (edges), in economic signals, the wavelet transform becomes particularly valuable in capturing the intricate dynamics of fiscal sustainability (Cascio 2015; Magazzino and Mutascu 2019; Sun et al. 2023). Its ability to implement time–frequency localization, its provision of a multi-resolution representation, and its ease of implementation through a filter bank make it a robust analytical instrument.

This section introduces wavelet methods for analyzing the time–frequency relationship between government revenue and expenditure in the context of Latin American countries. For an in-depth exploration, readers are referred to Aguiar-Conraria and Soares (2014).

3.2.1. Morlet Mother Wavelet

Employing a mother wavelet, small waves are generated, characterized by their dependence on both time (t) and scale (s). The mathematical expression for this mother wavelet is defined as follows:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right), \tag{1}$$

where τ represents a translation parameter. The inclusion of a normalization factor $\frac{1}{\sqrt{s}}$ ensures a consistent and comparable transformation across various scales throughout the temporal domain.

In the realm of existing literature, multiple wavelets have been proposed for the decomposition of time series, with the selection contingent upon the specific focus of the research. This study, in the analysis of the fiscal sustainability in Latin American countries, opts for the Morlet wavelet to capture both the amplitude and phase information of cycles, similar to Marín-Rodríguez et al. (2023a, 2023b).

The Morlet wavelet has garnered recognition for its efficacy in achieving a harmonious balance between temporal and frequency localization (Addison 2017). Research findings have highlighted that the Morlet wavelet's Fourier period closely aligns with the employed scale (Grinsted et al. 2004). The Morlet wavelet function, denoted as $\psi^M(t)$, is mathematically expressed as follows:

$$\psi^M(t) = \frac{1}{\pi^{1/4}} e^{i\omega_0 t} e^{-t^2/2}. \tag{2}$$

In this equation, ω_0 signifies the central frequency of the wavelet. Consistent with the methodology adopted by previous studies (Bouri et al. 2020; Marín-Rodríguez et al. 2023a, 2023b), this research adopts a specific value of $\omega_0 = 6$ for the Morlet wavelet. The deliberate choice of this central frequency facilitates optimal information localization across the time and frequency domains, ensuring a nuanced and accurate analysis and interpretation of the dataset.

3.2.2. Wavelet Power Spectrum

We utilize continuous wavelet transforms (CWT) to examine the evolution of revenue–expenditure nexuses at both national and regional levels. The CWT of a time series $x(t)$ using wavelet ψ is defined as follows:

$$W_{x;\psi}(\tau, s) = \int_{-\infty}^{\infty} x(t) \frac{1}{\sqrt{|s|}} \psi^*\left(\tfrac{t-\tau}{s}\right) dt. \tag{3}$$

Here, ψ^* denotes complex conjugation, s is a scaling or dilation factor, and τ is a translation parameter. This transform provides simultaneous insights into the time and frequency domains.

The local wavelet power spectrum (WPS) is defined as follows:

$$\mathrm{WPS}_x(\tau, s) = |W_x(\tau, s)|^2. \tag{4}$$

Nevertheless, the wavelet cross spectrum, although commonly used, may not be suitable for rigorous significance testing of the interrelation between two processes due to various pitfalls and challenges identified in the study of Maraun and Kurths (2004). Instead, wavelet coherency is recommended as a more appropriate method for assessing the relationship between time series data (Maraun and Kurths 2004).

3.2.3. Wavelet Coherence

We employ cross-wavelet power, wavelet coherency, and phase difference to analyze the relationship between two variables over time and frequency. The cross-wavelet transform W_{xy} of two time-series $x(t)$ and $y(t)$ is defined as follows:

$$W_{xy}(\tau, s) = W_x(\tau, s) W_y^*(\tau, s). \tag{5}$$

The wavelet coherency $R^2_{xy}(\tau, s)$ is calculated as follows:

$$R^2_{xy}(\tau, s) = \frac{\left|S\left(W_{xy}(\tau, s)\right)\right|^2}{S\left(|W_{xx}(\tau, s)|^2\right) S\left(|W_{yy}(\tau, s)|^2\right)}. \tag{6}$$

This metric gauges the similarity between two variables in the time–frequency domain. The phase difference $\phi_{x,y}$ between two variables is computed using the following cross-wavelet transform:

$$\phi_{xy}(\tau, s) = arctan \frac{\Im\{W_{xy}(\tau, s)\}}{\Re\{W_{xy}(\tau, s)\}}, \phi_{x,y} \in [-\pi, \pi]. \tag{7}$$

The phase difference provides information about the lead–lag relationship between the two variables of interest. Within this framework, the parameters $\Im$ and $\Re$ delineate the imaginary and real components of the smooth power spectrum, respectively. A critical aspect is interpreting a zero-degree phase difference, signifying synchronization between $x(t)$ and $y(t)$ at a specific time–frequency point. Notably, wavelet coherence plots visually represent $\phi_{xy}(\tau, s)$ through black arrow signs, each indicating distinct associations within statistically significant regions. The direction of these arrows—rightward, leftward, upward, or downward—carries specific implications. Rightward arrows denote in-phase synchronization, suggesting a positive association with minimal or no time lag, while leftward arrows indicate an out-of-phase synchronization with a negative association.

Moreover, the orientation of arrows in the upward or downward direction signifies the lead–lag relationship between the two series. An upward-pointing arrow indicates that the first series leads the second by $\pi/2$ (with the period varying based on the wavelet coherence chart's frequency/scale), while a downward-pointing arrow indicates the reverse. Additionally, insights from previous research (Kirikkaleli and Güngör 2021; Marín-Rodríguez et al. 2023a, 2023b) underscore that upward, right-up, or left-down arrows suggest the second variable influencing the first, while downward, right-down, or left-up arrows suggest the reverse.

The graphical representation of wavelet coherence results incorporates time and scale (or frequency) on their respective axes. The coherences are visually depicted using a color spectrum, where warmer colors (red) denote significant co-movements, indicating robust associations, and cooler colors (blues) suggest weaker co-movements between the series. It is essential to note that wavelet coefficient estimates beyond the black line cone or cone of influence are considered statistically insignificant at the 5% significance level and are therefore excluded from the analysis.

Wavelet analysis offers several advantages, including the ability to handle non-linearity, structural breaks, and non-stationarity. However, while coherence provides valuable insights

into linear relationships at different frequencies, it may not fully capture the complexity of non-linear associations. It allows for simultaneous consideration of time and frequency variations without imposing a priori assumptions about time horizons. Moreover, wavelet analysis provides a unified framework for testing intertemporal relationships between government revenues and expenditures, accommodating shifts caused by extraordinary events, electoral cycles, and institutional changes (Cascio 2015; Magazzino and Mutascu 2019; Sun et al. 2023). This approach facilitates a comprehensive understanding of the revenue–expenditure nexus, contributing clarity to the tax–spend debate.

Specifically, according to Sun et al. (2023), wavelet coherency and phase differences help identify key hypotheses: (1) significant coherence with government revenue leading expenditure supports the tax-and-spend hypothesis; (2) strong coherence with expenditure leading supports the spend-and-tax hypothesis; (3) significant coherence with zero phase difference supports the fiscal synchronization hypothesis; and (4) non-significant coherence supports the institutional separation hypothesis.

4. Application and Results

4.1. Wavelet Coherence Approach

Using wavelet coherence analysis, this study examined how changes in income influenced corresponding changes in expenditure, highlighting short-term, medium-term, and long-term dynamics. Figure 3 and its table illustrate the causal relationships between the selected countries' income and expenditure over different periods. It depicts how changes in one variable influence another, indicating whether the relationship is positive or negative, and whether it occurs in the short-term (ST), medium-term (MT), or long-term (LT). Thus, we realize the analysis of Figure 3 and its table by country to gain a better understanding of the obtained results.

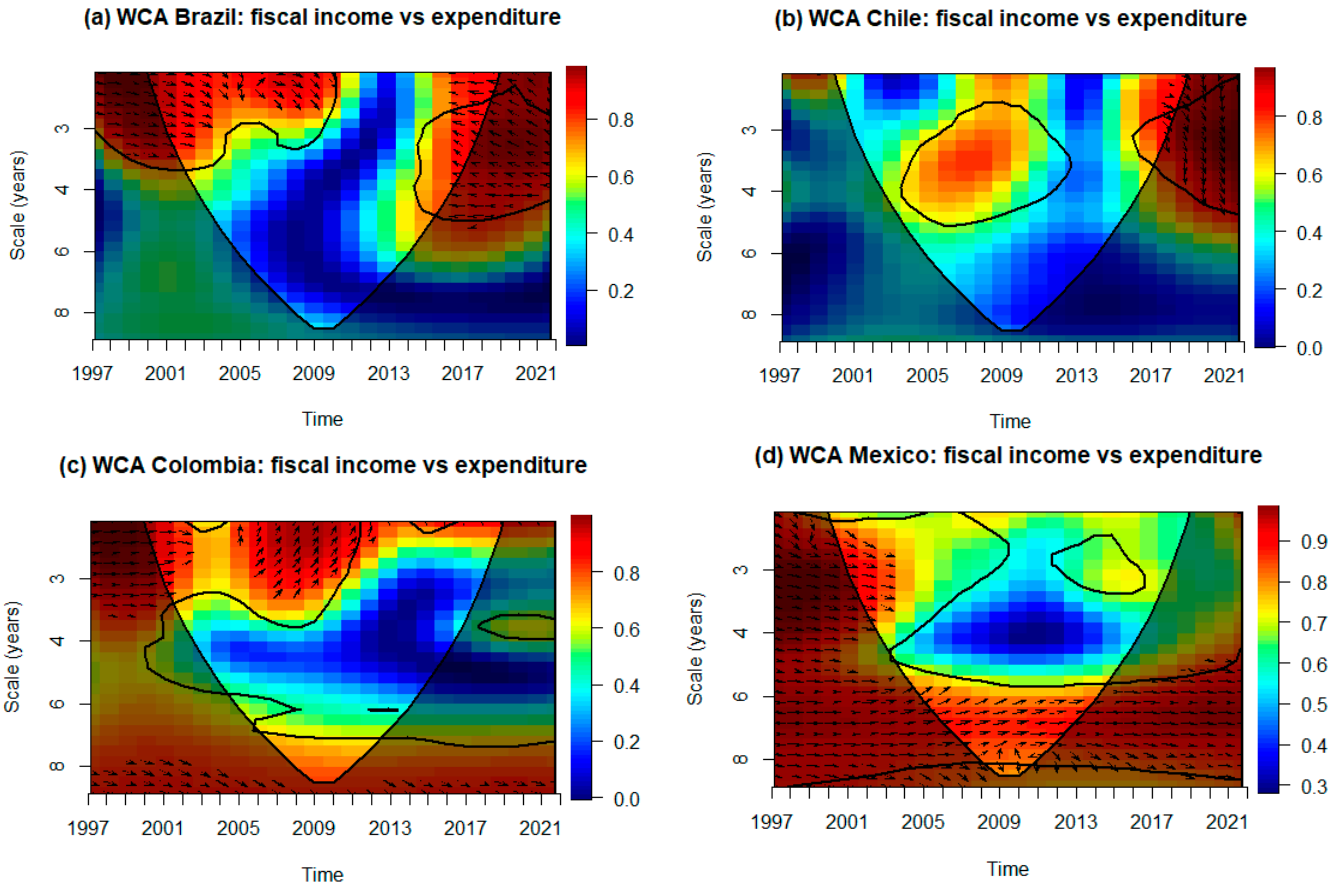
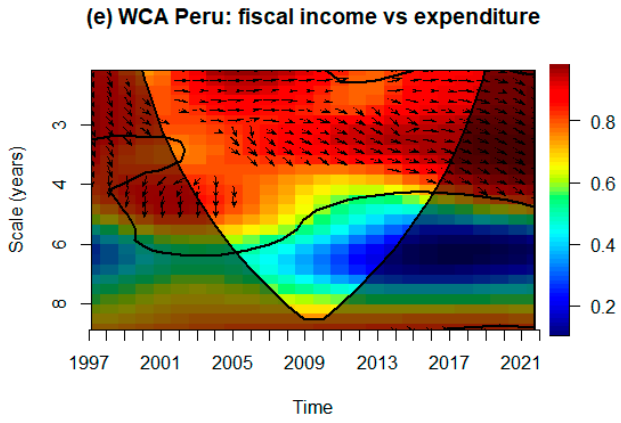


Figure 3. *Cont.*



Causality/Period	1997–2002	2003–2005	2006–2011	2012–2018	2019–2020	2020–2022
Brazil						
Income significantly caused expenditure	Positive ST		Positive ST		Negative ST, MT	Negative ST, MT
Expenditure significantly caused income		Positive ST				
Chile						
Income significantly caused expenditure					Positive ST	Positive ST
Colombia						
Income significantly caused expenditure	Positive ST, LT	Positive ST, LT	Positive LT	Positive LT	Positive LT	Positive LT
Expenditure significantly caused income		Positive ST	Positive ST	Positive ST		
Mexico						
Income significantly caused expenditure	Positive ST, MT, LT	Positive LT		Positive MT, LT	Positive MT, LT	Positive MT, LT
Expenditure significantly caused income		Positive MT	Positive MT			
Peru						
Income significantly caused expenditure	Positive ST	Positive ST	Positive ST	Positive ST	Positive ST, MT	Positive ST, MT
Expenditure significantly caused income	Negative MT	Negative MT				

Figure 3. Wavelet coherence analysis between income and expenditure in Brazil, Chile, Colombia, Peru, and Mexico across various time periods. Data from government websites were utilized, with coherence values visually represented using a color scale spanning from blue (representing low coherence) to red (representing high coherence). The results depicted the time–frequency domain, showcasing the phase relationship between income and expenditure. The study identified significant coherence regions and categorized signals into short-term (ST), medium-term (MT), and long-term (LT) patterns to provide insights into the fiscal dynamics of the selected countries.

4.1.1. Brazil

In Brazil, the relationship between income and expenditure has varied over time. From 1997 to 2005, there was a positive short-term causality, indicating that changes in income were followed by corresponding changes in expenditure in the short term, a pattern consistent with Keynesian economic theory. However, from 2006 onwards, this relationship turned negative in both the short and medium terms, suggesting that income changes led to opposite expenditure changes, contrary to Keynesian principles. Then, the changing

relationship between income and expenditure in Brazil suggests a complex fiscal dynamic. The shift from a positive to a negative causality between income and expenditure indicates potential challenges in fiscal planning and budget execution.

Furthermore, this shift in the relationship between income and expenditure may indicate a departure from expansionary fiscal policies towards more contractionary measures, possibly driven by concerns about inflation, public debt levels, or changes in political priorities. Policymakers must navigate these dynamics carefully to ensure fiscal sustainability and effective resource allocation, balancing the need for economic stimulus with the imperative of fiscal discipline to maintain macroeconomic stability.

4.1.2. Chile

The consistent positive short-term causality between income and expenditure in Chile over the observed periods suggests a stable fiscal environment. This means that when there are changes in income, such as fluctuations in tax revenues or economic growth, there is a corresponding adjustment in government expenditure in the short term. This alignment between income and expenditure indicates efficient fiscal management as it allows policymakers to respond to economic changes quickly. For instance, during periods of economic expansion where income increases, the government can adjust its expenditure to support growth or invest in infrastructure projects. Similarly, the government can implement fiscal stimulus measures during economic downturns by increasing expenditure to stimulate demand and support economic activity. This relationship provides policymakers with a useful tool for predicting and reacting promptly to economic fluctuations, enhancing the effectiveness of fiscal policy in stabilizing the economy and promoting sustainable growth.

The implications of this short-term relationship in Chile are significant. It means that the government quickly adjusts spending based on immediate changes in income. This helps manage money effectively and respond in the short-term to economic shifts. However, this short-term response might not be sustainable over time. While it is suitable for reacting swiftly to economic changes, there is a need for long-term plans to ensure stability. Policymakers should think about ways to balance short-term actions with strategies that work well in the long run. This includes finding ways to boost income, manage spending, and deal with ongoing financial challenges to keep the economy strong in the future.

Finally, the lack of directional connections over longer periods may require further exploration to understand the implications for sustained fiscal stability. Policymakers could benefit from balancing short-term responsiveness with long-term fiscal strategies to ensure enduring economic strength.

4.1.3. Colombia

Colombia exhibits a positive short-term causality between income and expenditure across all periods studied. This suggests that changes in income in Colombia led to corresponding changes in expenditure in the short term. Then, the positive short-term causality between income and expenditure in Colombia highlights the responsiveness of fiscal policy to economic fluctuations. This suggests that changes in income lead to immediate adjustments in expenditure, allowing for agile fiscal management. Policymakers should continue to leverage this relationship to ensure fiscal stability and support economic growth.

4.1.4. Mexico

In Mexico, there was a positive relationship between income and expenditure in the short, medium, and long terms from 1997 to 2018. This indicates that changes in income were typically followed by corresponding changes in expenditure across all time frames. However, from 2019 to 2022, while the relationship remained positive, it was observed mainly in the medium term. In this way, the consistent positive relationship between income and expenditure in Mexico underscores the close link between economic activity and government spending. This suggests that income changes drive expenditure across various time frames, indicating a dynamic fiscal policy environment. Policymakers

should maintain a balanced approach to fiscal management to ensure stability and support sustainable economic development.

4.1.5. Peru

Peru showed a consistent positive short-term causality between income and expenditure for all periods considered. This suggests that changes in income per capita in Peru were typically followed by corresponding changes in expenditure per capita in the short term. Additionally, a positive medium-term causality was observed for 2012–2018 and 2019–2020, indicating a sustained relationship beyond the short term. The consistent positive short-term causality between income and expenditure in Peru indicates a robust fiscal policy framework. Then, the results suggest that changes in income are quickly reflected in corresponding changes in expenditure, allowing for effective fiscal planning and resource allocation. Policymakers can utilize this relationship to implement targeted fiscal measures to support economic growth and social development.

In general, recognizing the direction of the causality between income and expenditure highlights the importance of maintaining a balanced fiscal stance. Policymakers can use this insight to adjust spending and taxation policies to ensure sustainable public finances.

5. Conclusions

The analysis of causal relationships between income and expenditure in selected Latin American countries reveals nuanced dynamics over time, each presenting distinct fiscal challenges and opportunities. Brazil's transition from positive to negative short-term causality underscores the imperative for meticulous fiscal planning to manage fluctuations effectively (Magazzino and Mutascu 2019). Conversely, Chile's sustained positive short-term causality reflects a stable fiscal environment and efficient management of economic changes, providing policymakers with valuable predictive tools (Cascio 2015). Colombia's consistent positive short-term causality highlights agile fiscal management, indicating responsiveness to immediate changes in income (Sun et al. 2023). Mexico's positive relationship between income and expenditure underscores the close link between economic activity and government spending, emphasizing the need for balanced fiscal management (Magazzino and Mutascu 2019). Similarly, Peru's consistent positive short-term causality suggests a robust fiscal policy framework supporting economic growth and social development (Sun et al. 2023). These divergent cross-country results underscore the importance of region-specific fiscal policies and dynamic responses to economic fluctuations in achieving lasting fiscal stability and sustainability.

To address the region's fiscal challenges and foster sustainable development, prioritizing the establishment of a sustainable public finance framework is crucial (Economic Commission for Latin America and the Caribbean (ECLAC) 2023b). This framework should focus on boosting tax revenues for welfare, investment, and environmental needs through more effective tax collection and measures to reduce inequalities (Economic Commission for Latin America and the Caribbean (ECLAC) 2023a). Enhancing personal income tax and expanding wealth taxes are essential steps, especially for non-renewable resource-producing countries, updating fiscal frameworks to address evolving economic realities. Strategic public spending, particularly on programs with high economic, social, and environmental returns, should prioritize quality employment, gender equality, and transforming the production structure (Economic Commission for Latin America and the Caribbean (ECLAC) 2023a). Investments in energy transition, circular economy, digital transformation, and sustainable tourism hold significant promise for driving long-term economic growth and social welfare (Economic Commission for Latin America and the Caribbean (ECLAC) 2023a).

Despite efforts to address fiscal gaps and debt sustainability, challenges persist in managing fiscal policy within a complex macrofinancial environment (Economic Commission for Latin America and the Caribbean (ECLAC) 2023a). High public debt levels relative to GDP remain a concern, exacerbated by internal and external factors such as fiscal deficits, GDP growth rates, interest rates, and exchange rates. Prioritizing strategies to reduce

public debt and manage public liabilities effectively ensures macroeconomic stability and sustainable fiscal policies over the long term (Economic Commission for Latin America and the Caribbean (ECLAC) 2023a). Furthermore, in the case of Chile, understanding the lack of directional connections over longer periods is crucial to comprehending the implications for sustained fiscal stability. Policymakers could benefit from adopting an approach that balances short-term responsiveness with long-term fiscal strategies to ensure enduring economic strength. This involves implementing policies that not only address immediate economic fluctuations but also lay the foundation for robust fiscal health and resilience in the face of evolving macroeconomic conditions.

While this study provides valuable insights into causal relationships between revenues and expenditures in Latin American countries, it has limitations. For example, relying on aggregate data may miss nuanced subnational characteristics that affect fiscal dynamics differently. Focusing solely on aggregate data may lead to an incomplete understanding of the relationship between revenues and expenditures within a country. Future research could delve deeper into disaggregated data and explore the long-term implications of fiscal policies on economic development and social welfare. Incorporating qualitative analysis or case studies could provide a richer understanding of contextual factors influencing fiscal dynamics in Latin America. Investigating the effectiveness of selected fiscal policy interventions in addressing economic challenges and promoting sustainable development could provide practical insights for regional policymakers.

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