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# Unveiling the Dynamics of Irregular Migration and Border Mission Expenditures at the Serbian - Romanian Frontier: A Wavelet-Based Approach

**Iliuta Cumpanasu[*], Mihai Mutascu[**]**

**Abstract:** This study examines the dynamic relationship between irregular and smuggled migration flows and border mission expenditures at the Serbian - Romanian frontier using wavelet methods, over January 2018 to April 2025. Baseline wavelet analyses reveal that the interactions between migration flows and border mission expenditures are predominantly short-run, high-frequency and time-varying, with no evidence of persistent long-run relationships. The results identify clear lead-lag patterns, showing that sudden increases in irregular and smuggled migration are typically followed by higher border mission expenditures, reflecting reactive policy responses, whereas increased expenditures subsequently contribute to reducing migration flows, indicating a corrective feedback mechanism. Medium-run interactions are also observed, particularly for smuggled migration, suggesting that structural policy interventions gradually influence migration dynamics. Robustness checks using wavelet cohesion and partial wavelet coherency confirm the stability of these dynamic relationships while highlighting the moderating effects of geopolitical shocks, economic uncertainty, regulatory changes and weather conditions. These findings support the adoption of a multi-horizon policy strategy that combines rapid operational responses, medium-term adaptive resource allocation and strengthened transnational cooperation to combat migrant smuggling. Future research should extend the analysis to multiple border regions using disaggregated data and complementary causal approaches.

**Keywords:** Serbian - Romanian frontier; irregular migration; border mission expenditures; co-movements; wavelet.

**JEL classification:** F22; H56; C14.

[*] Faculty of Economics and Business Administration, West University of Timisoara, Romania; e-mail: *iliuta.cumpanasu78@e-uvt.ro*.
[**] Faculty of Economics and Business Administration, West University of Timisoara, Romania; e-mail: *mihai.mutascu@e-uvt.ro* (corresponding author).

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## 1. INTRODUCTION

Since 2015, Europe has experienced unprecedented migration pressures, driven primarily by armed conflicts and persecution in countries such as Syria, Afghanistan and Iraq, political instability in Libya, and persistent poverty, insecurity and environmental degradation across the Sahel and Sub-Saharan Africa. These interconnected push factors have made migration one of the most significant humanitarian, political and socio-economic challenges facing Europe.

In this context, immigrants arriving in Europe have originated predominantly from conflict-affected countries in the Middle East, including Syria, Afghanistan, and Iraq; from North and Sub-Saharan Africa, notably Morocco, Tunisia, Nigeria, Eritrea, Sudan, Mali and Guinea; from South Asia, particularly Pakistan and Bangladesh; and from Latin America, especially Venezuela and Colombia (EUAS, 2025). Since 2022, Ukraine has also become a major country of origin following Russia's full-scale invasion.

In addition to these humanitarian drivers, economic incentives play a significant role in attracting migrants to Europe. Higher wages, better employment opportunities, and improved living standards encourage individuals to seek work in countries such as Germany, France and Netherlands, where labour markets offer greater economic prospects than many countries of origin. Moreover, demographic aging and labour shortages have increased demand for migrant workers in sectors including healthcare, construction, agriculture, manufacturing and information technology. For example, Germany has actively recruited healthcare professionals and engineers, while Italy and Spain continue to rely on seasonal migrant labour in agriculture. Together with access to high-quality education, healthcare and comprehensive social protection systems, these economic opportunities make Europe an attractive destination for both skilled and low-skilled migrants.

At the same time, migration has become politically controversial in Europe because it intersects with sensitive issues such as border security, national sovereignty, economic integration and humanitarian obligations. Frontline countries such as Greece, Italy and Spain received a disproportionate number of arrivals, leading to disputes over the distribution of asylum seekers among member states. Differences in national approaches, with some countries advocating greater solidarity and others prioritizing stricter border controls, have hindered the development of a common Europe migration policy. Moreover, rapid migration flows can place pressure on housing, healthcare, education and social welfare systems, while concerns about irregular migration, security and the integration of newcomers continue to shape political debates. These challenges have also fuelled the rise of populist and nationalist parties, which often portray migration as a threat to national identity and security, contributing to increasing political polarization across Europe.

Between 2018 and 2025, Europe's immigrant population reached a record high of 64.2 million, while irregular border crossings declined after 2023 due to strengthened external border management and enhanced migration control measures (Vallentine *et al.*, 2025). Germany remains the largest destination country in Europe, hosting nearly 18 million foreign-born residents, who account for approximately 21% of its total population (Jones, 2025). Spain has recorded one of the fastest increases in its immigrant population, adding around 700,000 immigrants in recent years to reach approximately 9.5 million foreign-born residents (Martinez, 2026). Together, Germany, France, Spain and Italy host nearly 70% of the foreign-born population in the European Union (Ruda, 2025). In relative terms, however, smaller

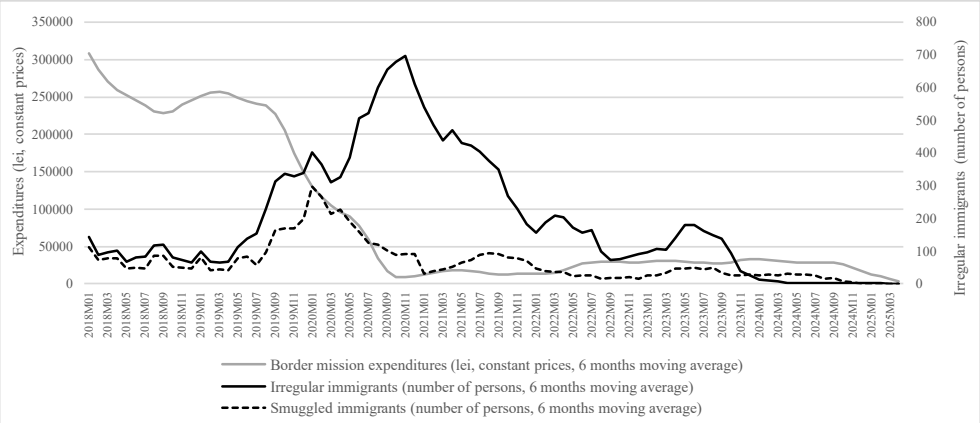
states, such as Luxembourg, Malta and Cyprus, have the highest shares of immigrants, with foreign-born residents constituting a substantial proportion of their populations.

The dynamics of irregular migration and border management have become increasingly central to contemporary policy debates, particularly in regions situated along major migration corridors. The Serbian - Romanian frontier represents a critical node in the broader European migration system (EC, 2025), where irregular and smuggled migration flows interact with institutional responses shaped by security priorities, fiscal constraints and external shocks.

Irregular migrants often rely on smuggling networks because legal pathways to enter Europe are limited or inaccessible, particularly for individuals fleeing conflict, persecution, or severe economic hardship. Strengthened border controls, combined with persistent migration pressures, have increased the demand for smuggling services despite the significant financial costs and risks to migrants' safety (UNODC, 2025).

In recent years, migration patterns in this region have been influenced by a combination of structural drivers, such as economic disparities and labour market conditions as well as transitory shocks, including geopolitical tensions, regulatory changes and extreme weather events. These factors contribute to a highly volatile environment in which migration flows fluctuate rapidly and policy responses must continuously adapt. In this context, border mission expenditures are not only a reflection of policy priorities but also a key instrument through which states attempt to manage and influence migration dynamics. However, the effectiveness of such expenditures remains an open question, particularly in terms of their timing, persistence and interaction with different types of migration flows.

Understanding how these flows evolve over time and how public expenditures respond to them, is essential for designing effective and adaptive border policies. Figure no. 1 illustrates the dynamics of irregular immigrants, smuggled immigrants and border mission expenditures at the Serbian - Romanian border, over January 2018 - April 2025, presented as six-month moving averages.




Source: author's calculations based on TIBPT (2025).

**Figure no. 1 – Irregular immigrants, smuggled immigrants and border mission expenditures at the Serbian - Romanian border, over January 2018 - April 2025**

Figure no. 1 shows that public mission expenditures decline steeply from 2018 to 2021, while irregular and smuggled migration surge, indicating a strong inverse relationship that peaks during 2020-2021. This spike aligns with disruptions from the COVID-19 pandemic, when border controls, economic stress and reduced enforcement capacity likely altered migration dynamics and increased reliance on smuggling networks. After 2021, both irregular and smuggled flows fall markedly, even though expenditures remain low, suggesting the easing of pandemic pressures, restoration of controls, and adaptive policy responses. A modest rebound in 2023 reflects lingering post-pandemic volatility but remains far below peak levels. By 2024-2025, flows converge to minimal levels, consistent with tighter coordination and regulatory reinforcement under the updated Schengen Borders Code, which likely contributed to stabilizing migration pressures.

The relationship between immigration and border mission expenditures operates through two theoretical channels: a proactive (control) channel, in which higher expenditures lead to subsequent declines in migration flows (negative co-movement), and a reactive (adaptive) channel, in which increases in migration flows prompt subsequent increases in expenditures (positive co-movement).

The literature on irregular migration and border enforcement expenditures remains relatively limited, with most major contributions focusing on the classical push-pull determinants of migration (Kuhnt, 2019). While these studies shed light on the economic, social and political factors influencing migration flows, there is a notable gap in research examining how these determinants intersect with government spending on border security, migration control strategies and the cost-effectiveness of various enforcement policies.

Even so, two strands of literature can be identified. First strand treats the interaction between the irregular immigration and border mission expenditures. For example, Akkerman (2023) highlights that in recent years, the United States (US) has allocated more funding to immigration enforcement than at any other time in its history. He notes that these enforcement budgets have been rising consistently over an extended period, regardless of which political party controls the federal government. Similarly, Bier *et al.* (2023) argue that immigration enforcement reflects the costs of excluding immigrants rather than inherent costs of immigration, with political opposition - not immigrants - driving these expenditures. Unlike them, Jones *et al.* (2023) claim that the adoption of new technologies in migration and asylum management is closely tied to expanding state control over non-European Union (EU) citizens. This trend has fuelled the growth of the EU's security and surveillance industry, supported by public funding, Frontex-led research and projects and the repeated use of crisis narratives to justify exceptional measures. In a different approach, some researchers have contended that the humanitarian roles assigned to EU maritime missions serve to obscure the real human toll of the EU's border enforcement (Tazzioli, 2016; Pallister-Wilkins, 2017; Cusumano, 2019). Even though, D'Alfonso (2021) notes that while these policy areas still account for a small portion of the EU budget - 2.1%, excluding Next Generation EU funds - their funding has grown markedly compared to 2014-2020. In the same vein, Zardo (2025) shows that since 2000, EU development funds have grown unevenly, with the largest increases in protection and development, despite rising support for border control and returns.

The second strand of literature, though limited, focuses on the relationship between smuggled migrants and spending on border missions. Smuggling of migrants is a

transnational industry that, for payment, enables irregular and typically unlawful entry into a country (MacKellar, 2022).

In this context, Gathmann (2008) examines how intensified border enforcement shapes the illicit migration market along the Mexico - US border. By merging panel data on unauthorized migrants with enforcement records, she finds that stricter controls have only modest impacts: the fees charged by smugglers, or "coyotes," rose by 17 percent. Moreover, overall demand for their services remained stable, while the border patrol's budget has increased sevenfold since 1986, underscoring the resilience of smuggling networks despite intensified enforcement. Although the Serbian - Romanian border experiences substantially lower migration flows than the US - Mexico border, both corridors share similar migration dynamics. While the US - Mexico route is driven primarily by economic disparities, violence, and political instability in Latin America, the Serbian - Romanian border forms part of the Western Balkans route, serving migrants mainly from Syria, Afghanistan, Iraq, Pakistan, Bangladesh and several African countries fleeing conflict, persecution and poverty. In both cases, migrants rely on smuggling networks to circumvent strengthened border controls. However, unlike the US - Mexico border, which is governed through bilateral cooperation, the Serbian - Romanian corridor is embedded within the EU's multilevel migration and asylum governance framework.

For De Haas (2015), the billions spent on militarizing borders have largely failed to stop migration. According to author, the research and recent crises show that stricter controls mainly redirect flows, deepen reliance on smugglers, and amplify the financial and human costs of crossing. Along the same lines, Suber (2025) emphasizes that migrant smuggling networks adapt to border enforcement by specializing in certain routes, coordinating between groups and creating roles, such as the "reberie," responsible for safely guiding migrants across borders.

Within this framework, the study examines the relationship between irregular, smuggled, and total migration flows and border mission expenditures from January 2018 to April 2025. Moving beyond traditional theoretical models and classical time-series approaches, it employs wavelet-based techniques to analyse co-movements across both time and frequency. This methodological approach is particularly suited to capturing the dynamic, non-linear nature of migration systems, where relationships shift across time horizons in response to evolving economic, geopolitical and climatic conditions.

The empirical analysis reveals that the interaction between migration flows and expenditures is neither stable nor unidirectional, but instead characterised by alternating periods of positive and negative co-movements, varying across short- and medium-term horizons. These patterns suggest the coexistence of reactive and proactive policy responses, as well as the presence of lagged feedback mechanisms between migration pressures and expenditure adjustments. Furthermore, the robustness of these findings is assessed through alternative wavelet-based measures, confirming the stability of the core relationships while also highlighting the influence of external factors, such as pandemic and regulatory shocks, geopolitical risk, economic uncertainty and climate conditions.

This study makes three main contributions. First, it provides new empirical evidence on the dynamic relationship between irregular migration and border mission expenditures at the Serbian - Romanian border, using smoothed high-frequency data to uncover co-movement behaviour. Existing studies focus on theoretical frameworks (De Haas, 2015; Akkerman, 2023; Jones *et al.*, 2023), time-series analyses (Gathmann, 2008) or qualitative

approaches (Suber, 2025), but completely overlook time-frequency patterns. Although conventional time-series methods remain the dominant analytical approaches in migration research, they generally assume that relationships between variables are stable over time and are often examined at a single temporal scale (Mutascu *et al.*, 2026). However, migration processes are inherently dynamic, being shaped by short-term shocks (e.g., conflicts, policy changes, border closures) as well as long-term structural factors, including economic disparities and demographic trends. Wavelet analysis provides a non-parametric alternative that simultaneously captures both the time and frequency dimensions of these relationships, enabling the identification of transient, non-stationary and scale-dependent patterns that conventional time-series techniques may overlook. Consequently, wavelet methods are particularly well suited for analysing complex migration dynamics characterised by structural breaks, evolving interdependencies and heterogeneous temporal responses.

Second, it conceptualizes and tests two competing mechanisms - proactive (control) versus reactive (adaptive) - thereby offering a clearer theoretical framework to interpret the direction of interaction between policy effort and migration flows. The prevailing literature does not directly examine how border mission expenditures influence irregular migration flows through a proactive mechanism, but instead focuses on the immediate effects of regulatory measures (Angelucci, 2012; Helbling and Leblang, 2019). Similarly, no literature directly addresses the reactive mechanism in which migration flows drive border mission expenditures. Most studies instead focus on how overall immigrant inflows influence border enforcement (Massey *et al.*, 2016) or offer not conclusive results in terms of budget enforcement (Facchini and Testa, 2021).

Third, it situates the dynamics between immigration and border mission expenditures within the context of recent external shocks, geopolitical shifts, economic trends and climatic conditions, highlighting how these factors reshape migration pressures and enforcement responses across sub-periods and time-horizons through budgetary resources. The existing literature addresses these factors individually, such as pandemics (Benton *et al.*, 2021; Klein *et al.*, 2024; Chi *et al.*, 2025; González-Leonardo *et al.*, 2025), border regulation (Angelucci, 2012; Helbling and Leblang, 2019), geopolitical risk (Hyndman, 2012), economic uncertainty (Moridian *et al.*, 2024) and climate conditions (Benveniste *et al.*, 2025; Yang *et al.*, 2025), but does not examine them within an integrated framework that captures their dynamics across both time and frequency.

The remainder of the paper is structured as follows: Section 2 describes the methodology and dataset; Section 3 presents and discusses the findings; and Section 4 provides robustness checks. Section 5 concludes with a summary of the policy implications, while Section 6 outlines the study's limitations and directions for future research.

## 2. METHODOLOGY AND DATASET

### 2.1. Methodology

The interaction between irregular immigration and border mission expenditures at the Serbian-Romanian border from January 2018 to April 2025 is analysed using a time-domain approach.

Wavelet analysis offers several advantages over classical time-series methods. It effectively handles non-stationary data by allowing relationships to evolve over time. Compared with

Fourier-based approaches, it provides simultaneous time-frequency localization, enabling the identification of both short-term fluctuations and long-term cycles, as well as the timing of their occurrence. Additionally, wavelets capture multi-scale dynamics by decomposing series into different frequencies, distinguishing between short-run shocks and long-run trends. They are also well suited for detecting localized events and structural breaks, such as crises or policy changes. Finally, wavelet methods accommodate nonlinear and time-varying relationships, revealing dynamic correlations that conventional techniques may overlook.

Unlike conventional regression-based approaches, wavelet analysis does not estimate structural causal effects but instead characterizes the strength, timing and frequency of associations between variables across different time horizons. By simultaneously examining the time and frequency domains, it identifies localized co-movements and lead-lag relationships, revealing when and at which temporal scales variables move together. Consequently, wavelet analysis provides valuable insights into the dynamic evolution of relationships but should be interpreted as identifying temporal dependence rather than causal effects.

The methodology involves decomposing a time series into two components: one in time, and another in frequency. This procedure is facilitated by a wavelet function, which has zero mean and finite energy. This decomposition is performed using a wavelet function, which has zero mean and finite energy. Among various wavelet functions (e.g., Coiflet, Daubechies, Haar, Meyer, Mexican hat), the Morlet wavelet is often preferred in socio-economic applications, as it provides an optimal balance between time and frequency localization (Grinsted *et al.*, 2004, p. 563).

Compared with other wavelet functions, the Morlet wavelet offers a superior balance between time and frequency localization, enabling the simultaneous identification of localized co-movements and phase differences across multiple time scales. This feature makes it especially appropriate for examining dynamic associations and lead-lag relationships across multiple time horizons, which constitute the primary objective of the present study. Consequently, the Morlet wavelet has become the standard choice in economics and finance, where the emphasis is on understanding how relationships between variables vary over both time and frequency.

Let $\eta$ denote a dimensionless time parameter and $\omega_0 = 6$ the dimensionless central frequency, chosen to satisfy the admissibility condition outlined by Farge (1992), with $= \sqrt{-1}$. Moreover, setting the central frequency to 6 has become the standard specification in economic and financial wavelet applications, thereby enhancing the comparability of the results with the existing literature. Under these definitions, the Morlet wavelet $\psi_0(\eta)$ is given by:

$$\psi_0(\eta) = \pi^{-\frac{1}{4}} e^{i\omega_0\eta} e^{-\frac{1}{2}\eta^2} \tag{1}$$

Using the Morlet wavelet, the Continuous Wavelet Transform (CWT) of a time series $x_n$ can be derived by incorporating key parameters, including the time step $\delta t$, the translation parameter $\tau$ and the scale factor $s$, as follows:

$$w_n^x(s,\tau) = \frac{\delta t}{\sqrt{s}} \sum_{n=0}^{N-1} x_n \psi^* \left( (n-m) \frac{\delta t}{s} \right) \tag{2}$$

with $n = 0 \ldots N-1$,and $m = 0, 1, \ldots, N-1$ (Grinsted *et al.*, 2004).

In this framework, no assumption of stationarity is imposed on the time series (Aguiar-Conraria and Soares, 2011). More precisely, the wavelet analyses a time series locally, not globally. Instead of assuming that the entire series behaves the same way over time as classical methods do, wavelet breaks the series into small time segments and studies each segment at different frequencies.

The interaction between two decomposed time series $x_n$ (irregular immigration) and $y_n$ (border mission expenditures) is facilitated by the Wavelet Coherency (WTC) method. Unlike traditional correlation, it captures both the strength and timing of co-movements in the time-frequency domain, allowing identification of periods and frequencies where the series are strongly correlated. Additionally, it provides information on phase relationships, indicating which variable leads or lags the other, and is particularly suitable for non-stationary and nonlinear socio-economic data.

WTC is conducted through the following procedure (Aguiar-Conraria and Soares, 2011):

$$R_n(s) = \frac{\left|S\left(s^{-1}W_n^{xy}(s)\right)\right|}{S(s^{-1}|W_n^x|)^{\frac{1}{2}}\, S\left(s^{-1}\left|W_n^y\right|\right)^{\frac{1}{2}}} \tag{3}$$

with, $S$ representing the smoothing operator.

CWT enables the identification of the phase difference $\phi_{x,y}$ between the series $x_n$ and $y_n$, capturing not only the co-movement but also the lead-lag dynamics between the two series. It is computed as follows (Aguiar-Conraria and Soares, 2011):

$$\phi_{x,y} = tan^{-1}\left(\frac{\Im\{W_n^{xy}\}}{\Re\{W_n^{xy}\}}\right) \tag{4}$$

Here, $\phi_{x,y} \in [-\pi, \pi]$, with $\Re$ and $\Im$ denoting the real and imaginary parts of a complex number, respectively.

The phase difference $\phi_{x,y}$ indicates the synchronization and lead-lag relationship between the series at a given frequency. A phase difference of zero signifies in-phase movement and positive connection. When $\phi_{x,y}$ lies between $0$ and $\pi/2$, series $x$ leads $y$, whereas a value between $-\pi$ and $-\pi/2$ indicates that $y$ leads $x$. Conversely, a phase difference of $\pm\pi$ corresponds to anti-phase synchronization, reflecting negative connection. Accordingly, $x$ leads $y$ when $\phi_{x,y}$ lies between $-\pi$ and $-\pi/2$, while $y$ leads $x$ when $\phi_{x,y}$ lies between $\pi/2$ and $\pi$.

In all WTC plots, the thick black contour denotes the 5% significance level, while the shaded region marks the cone of influence (COI), where edge effects may affect the results. The colour scale represents power, ranging from intense blue for low coherence to intense yellow for high coherence. Arrows indicate the phase difference. Arrows pointing to the right show a positive (in-phase) relationship, with $x$ leading when they point upward and $y$ leading when they point downward. Arrows pointing to the left indicate a negative (out-of-phase) relationship, with $x$ leading when pointing downward and $y$ leading when pointing upward.

Strategically, the baseline WTC estimations include the interaction between immigration, alternatively captured through total irregular immigrants, irregular immigrants and smuggled immigrants, and border mission expenditures.

### 2.2. Dataset

The study focuses on the Serbian - Romanian border, covering the period from January 2018 to April 2025, data availability. Stretching 541.8 kilometres in total, the border comprises 230.5 kilometres along the Danube River and 311.3 kilometres of overland frontier.

*Border mission expenditures (expenditures)* is the dependent variable and measures the mission-related public expenditures, encompassing travel, accommodation and per diem for deployed officers, along with costs for fuel, vehicles, equipment, communications, surveillance and other specialized operational resources necessary for the mission. The variable is expressed in constant prices to eliminate the bias caused by inflation.

*Irregular immigration* is the variable of interest and is alternatively measured using *irregular immigrants (irregular)*, *smuggled immigrants (smuggled)* and *total immigrants (total). Irregular immigrants* are foreign citizens officially recorded as entering Romania without legal authorization, whereas *smuggled immigrants* are those irregular migrants documented as having used smugglers for a fee.

Finally, *total immigrants* is an aggregate variable and represents the sum of *irregular immigrants* and *smuggled immigrants.*

The dataset originates from the Territorial Inspectorate of the Border Police Timisoara (2025), a regional branch of the Romanian Border Police. Responsible for border security in South-Western Romania, including the counties of Timis, Caras-Severin and Mehedinti, it operates under the Ministry of Internal Affairs to enforce legal compliance and combat illicit cross-border activities.

An extended set of **control variables**, drawn from the literature, is also included for robustness checks. This set comprises pandemic, regulatory, geopolitical, economic, and climatic factors.

*Pandemic shock (pandemic)* is a dummy variable and controls for COVID-19 disease. For example, Chi *et al.* (2025) state that the global migration flows declined by 64% in 2020, partly due to the implementation of border controls. In the same vein, Klein *et al.* (2024) show that stricter domestic restrictions unrelated to international travel were linked to declines in migrant stocks in affected countries, suggesting that reduced inflows were the primary driver. In contrast, Benton *et al.* (2021) note that travel restrictions and border closures left many regular migrants and travellers stranded, confronting significant financial and logistical obstacles to returning home. (González-Leonardo *et al.*, 2025) partially corroborate this finding, documenting a general decline in immigration in 2020, followed by a rebound to expected levels in 2021, with the exception of Spain.

*Regulatory shock (regulatory)* also is a dummy and captures the effects of Schengen Borders Code. This code, which came into effect in July 2024, aims to enhance external-border management by clarifying operational procedures and strengthening coordination among EU member states. These changes are likely to affect enforcement practices and the allocation of border resources, making it essential to account for this institutional shift when analysing the link between irregular migration pressures and border mission expenditures. A

substantial body of literature examines the implications of immigration regulations (Angelucci, 2012; Helbling and Leblang, 2019).

*Geopolitical risk (GPR)* is measured using the GPR Index developed by Caldara and Iacoviello (2022) and captures uncertainty arising from political instability, policy shifts, military conflicts, terrorism or diplomatic tensions that can influence countries, regions or global markets. There is a large body of literature linking the geopolitical risk to migration. For instance, Hyndman (2012, p. 243) observes that 'migration has long been a barometer of geopolitics,' underscoring the importance of understanding regional political processes that shape migration patterns.

*Economic status (EPU)* is captured via Economic Policy Uncertainty (EPU) proposed by Baker *et al.* (2016). This index quantifies economic policy uncertainty, reflecting how businesses, investors, and the public perceive ambiguity about future government policies and their potential economic effects. Immigration flows are strongly shaped by the economic conditions of both origin and destination countries, typically rising during periods of economic growth and declining during recessions (Moridian *et al.*, 2024).

Finally, climatic conditions on border is captured through *temperature (temp)* and *precipitations (precip)* as main climatic variables to account for seasonal or extreme weather effects that could affect migration flows, border enforcement or human mobility. Climate conditions, particularly the temperature and precipitations, act as a physical constraint along migration routes, shaping the timing, scale and location of irregular border crossings (Benveniste *et al.*, 2025). Temperature and precipitations are reliable, continuous and globally comparable metrics that capture both direct human impacts and indirect livelihood pressures, making it ideal indicators of climate conditions in socio-economic and migration research (Yang *et al.*, 2025).

All variables are seasonally adjusted using the additive moving-average method, which assumes that seasonal fluctuations are roughly constant in absolute terms. This approach allows for clear separation of seasonal effects from the underlying trend and it is particularly suitable for socio-economic series, such as irregular migration and public expenditures, where seasonal variations do not scale with the level of series. After adjustment, the variables appear in their natural logarithms for all estimations, facilitating variance stabilization and interpretation as elasticities. Negative deseasonalized variables (i.e., *irregular* and *smuggled*) have been rescaled by adding the absolute value of their minimum plus one, ensuring strictly positive values suitable for logarithmic transformation.

Table no. A1 (Annex) summarizes the variable descriptions, units of measurement and corresponding data sources. Their descriptive statistics are shown in Table no. A2.

## 3. RESULTS

The baseline WTC plots are illustrated in Figures no. 2-4 and reveal the interaction between irregular immigrants, smuggled immigrants and total irregular immigrants, and border mission expenditures, at the Serbian - Romanian frontier, over January 2018 - April 2025.

Figure no. 2 shows the WTC of *log(irregular)* and *log(expenditures)* pair. All significant co-movements are registered in the short-run, until 12 months band of scale (The classification of time horizons follows conventional practice in economics: the short-run spans up to 12 months, the medium-run covers 12 to 60 months, and the long-run extends beyond 60 months).

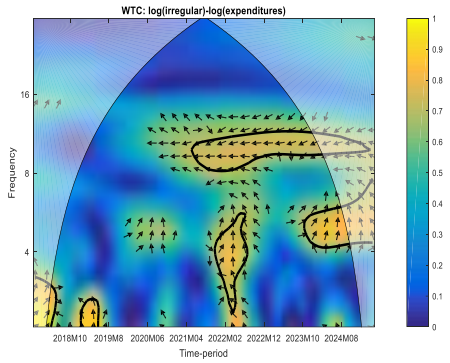



**Figure no. 2 – WTC of pair log(irregular) vs log(expenditures)**

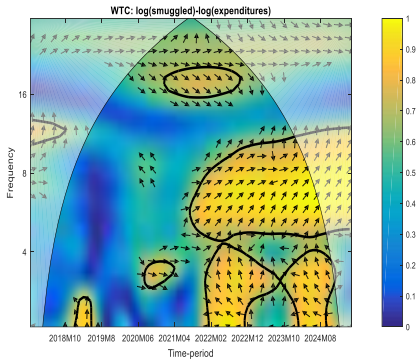



**Figure no. 3 – WTC of pair log(smuggled) vs log(expenditures)**

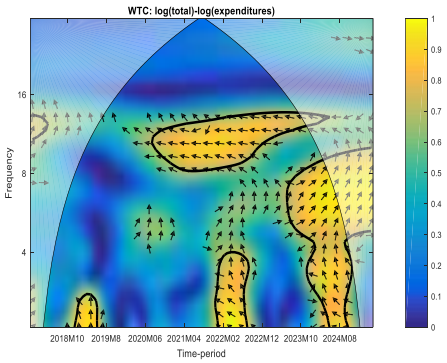



**Figure no. 4 – WTC of pair log(total) vs log(expenditures)**

There are four zones exhibiting significant and strong co-movements. The first zone corresponds to the period from 2019M1 to 2019M5, within a scale band of up to 2 months, indicating high frequency dynamics (i.e., short-run). As the arrows are nearly perpendicular to the OX axis, the results are conclusive. Similar patterns are observed over the period 2021M11-2022M8, within a scale band of up to 4 months, reflecting high-frequency dynamics (i.e., short-run), with the arrows predominantly oriented perpendicular to the OX axis.

The third zone spans 2023M11-2024M9, within 5-7 months scale band, at high frequency (i.e., short-run), with arrows oriented to the right and upward, indicating a positive co-movement between *irregular* and *expenditures*, with the *irregular* leading. Importantly, the phase direction suggests that short-term shocks or fluctuations captured by the irregular component tend to precede and potentially drive changes in expenditures during this period, coinciding with a peak in irregular inflows, as shown in Figure no. 1. Such behaviour may be associated with heightened uncertainty, adjustment processes or external shocks, where border authorities adjust their spending decisions after observing irregular movements. The leading role of the irregular component therefore indicates a

transmission mechanism in which temporary shocks are not immediately absorbed but instead propagate into expenditure dynamics with a short delay.

In the fourth zone, the *irregular* negatively leads e*xpenditures* over 2021M6-2024M2, also at high frequency, within 8-12 months scale band, in the short-run. This indicates an inverse short-run transmission mechanism, possibly reflecting adjustment effects, delayed responses or corrective behaviour in border mission expenditures following the downward trend in irregular immigration starting in 2021M11, as shown in Figure no. 1.

Figure no. 3 reveals the WTC plot of *log(smuggled)* and *log(expenditures)* pair, with six zones of significant co-movements, at high and medium frequencies (i.e., short- and medium-run). The first and second zones are inconclusive, as the arrows are either nearly perpendicular to the OX axis (i.e., 2019M1-2019M5, within a scale band of up to 2 months) or nearly horizontal (2020M8-2021M4, within 2-4 months scale band).

The third and fourth zones exhibit strong negative co-movements within a 2-4 months scale band, at high frequency (i.e., short-run), over 2022M1-2024M12, with arrows oriented to the left and upward, indicating that *expenditures* are leading. The increase in expenditures corresponds to later decreases in irregular flows, reflecting a possible quick corrective mechanism.

Consistent positive co-movements are observed in the fifth zone, over 2021M8-2024M6, with arrows pointing to the right and upward, indicating that *smuggled* leading, within 5-10 months scale band, at high frequency (i.e., short-run). This suggests that sudden surges in immigrant flows, peaking around late 2020 and likely facilitated by smugglers (Figure no. 1), may have driven subsequent adjustments in expenditures.

Positive co-movements are also reported in the sixth zone, over 2021M03-2022M02, within 16-18 months scale band, at medium frequency i.e., medium-run), with arrows pointed to the right and downward. Here, *expenditures* leads *smuggled*. This indicates delayed responses in irregular migration to policy or resource adjustments. Therefore, the medium-run adjustments indicate that expenditure policies may anticipate changes in irregular flows but also reflect delayed feedback effects, likely due to temporary constraints in financial resources.

Finally, Figure no. 3 illustrates the WTC plot of *log(total)* and *log(expenditures)* pair. Herein, four zones indicate intensive and significant co-movements, all at high frequency (i.e., short-run).

As in the previous cases, the first zone shows no conclusive co-movements from 2019M1 to 2019M5, at high frequency, within a scale band of up to 2 months (i.e., short-run), as the arrows are largely perpendicular to the OX axis.

Second zone covering 2022M1-2022M8, with 2-4 months scale band, at high frequency (i.e., short-run), partially coincides with that from Figure no. 3. Here, the arrows are pointed to the left and upward, indicating a negative co-movement, with *expenditures* leading. When expenditures increase slightly, migrant numbers tend to decline shortly after (within a few months). Hence, short-run spending may be reactive or deterrent, reducing flows with a lag. Similar negative co-movements are observed over 2023M12-2024M11, with *expenditures* leading, with 2-4 months scale band, at high frequency (i.e., short-run). Furthermore, as the frequency increases within the 4-8 month scale band, at high frequency (i.e., short-run), from 2023M6 to 2024M7, the arrows shift to the right and upward, indicating a positive lead-lag relationship with *total* leading. In this case, the changes in

migrant flows are followed by similar-direction adjustments in expenditures, the authorities responding to migration pressure, rather than preempt it.

In contrast, a consistent negative interaction between *total* and *expenditures* characterizes the fourth zone, within the 8-12 month scale band, at high frequency (i.e., short-run), from 2020M8 to 2023M11. Here, the arrows point to the left and upward, indicating that *expenditures* are leading. Higher (or increasing) expenditures are associated with subsequent reductions in migrant flows, consistent with Figure no. 1, where the sharp decline in spending precedes the surge in migration. Conversely, later adjustments in expenditures tend to precede subsequent declines in migrant flows.

Overall, the findings suggest that financial border management is neither purely preventive nor purely reactive but instead adjusts continuously in response to evolving migration pressures over the short and medium-run, with the direction and strength of this relationship varying across time and frequency. No long-run co-movements are reported.

## 4. ROBUSTNESS CHECKS

Robustness checks are conducted by: (1) applying an alternative method to wavelet coherence and (2) isolating the effects of the variables of interest using a partial wavelet approach with an extended set of controls.

(1) Wavelet Cohesion (WC) from Rua (2010) is computed to replicate all three-baseline WTC scenarios. WC provides a coherence measure $\rho_{x_n y_n}$ ranging from $-1$ to $1$, calculated as follows:

$$\rho_{x_n y_n} = \frac{\Re(W_n^x W_n^y)}{\sqrt{|W_n^x|^2 |W_n^y|^2}} \tag{5}$$

Positive co-movement between the variables is signalled when $\rho_{x_n y_n}$nears +1, while values approaching −1 indicate negative co-movement. In all WC computed plots, blue and yellow colours denote negative and positive co-movement, respectively.

The WC results across all three scenarios are presented in Figures no. 5-7 (Annex). The WC results fully reinforce the WTC findings in both terms of significance and sign of co-movement, indicating that the relationship between migration flows and border mission expenditures is primarily short-run and time-varying, with most significant co-movements occurring at high frequencies (up to 12 months). A dominant negative relationship is observed mainly over 2022-2024 (2-4 months scale band) and 2020M8-2023M11 (8-12 months scale band), where expenditures lead and are followed by reductions in migration, suggesting a corrective effect. In contrast, positive co-movements emerge during 2021-2024 (5-10 months scale band) and 2023M6-2024M7 (4-8 months scale band), where migration flows lead expenditures, indicating reactive policy responses. The positive co-movements observed between 2021M03 and 2022M02, within 16-18 months scale band, at medium frequency (i.e., medium-run), remain also robust under the WC method in the case of 'smuggled - expenditures' nexus. Overall, the findings are not sensitive to WC tool and highlight a dual dynamic of proactive control and reactive adjustment in border management.

(2) Partial Wavelet Coherency (PWC) developed by Mihanović *et al.* (2009) is employed for each of three-baseline scenarios by alternatively considering as controls pandemic shock, regulatory shock, geopolitical risk, economic status, temperature and precipitations. By controlling for selected observable confounding factors, this approach helps reduce the potential influence of omitted-variable bias, complementing the baseline wavelet coherence analysis and strengthening the assessment of the relationships of interest. Specifically, PWC estimates the association between the primary variables after accounting for the effects of the selected control variables, thereby revealing their conditional co-movement across time and frequency.

Concretely, PWC allows isolating the relationship between two time series while controlling for the influence of one additional variable. In fact, the tool removes the effect of confounding variables, revealing the "pure" association between the two primary series. PWC has this form:

$$\left(RP_n^{yx_1x_2}\right)^2 = \frac{\left|RP_n^{yx_1} - RP_n^{yx_2}RP_n^{yx_{1*}}\right|^2}{\left[1-\left(RP_n^{yx_2}\right)^2\right]\left[1-\left(RP_n^{x_1x_2}\right)^2\right]} \quad (6)$$

where, $x_2$ represents the control variable being removed, which in this study is alternately one of the following: pandemic shock, regulatory shock, geopolitical risk, economic status or temperature. In all PWC plots, the colour scale for power ranges from deep blue (low coherence) to deep yellow (high coherence).

The PWC estimations across all three scenarios are presented in Figures no. 8-25 (Annex). In this case, the PWC plots in Figures no. 8-13, related to '*irregular* - *expenditures*' nexus, reveal that the negative co-movements running from *irregular* disappear over 2021M6-2024M2, within 8-12 months scale band, in the short-run, under *GPR*, *EPU*, *temp* and *precip* impact. This indicates that the results are sensitive to geopolitical, economic and weather-related factors. High geopolitical risk induces stricter border controls, while economic uncertainty drives policy shifts and particular changes in spending patterns. These findings are consistent with Hyndman (2012) and Moridian *et al.* (2024), highlighting the crucial role of these factors in shaping irregular migration. Extreme weather conditions also generate disruptions, affecting both irregular flows and border enforcement, thereby confirming the influential role of climate conditions in migration dynamics, as emphasized by Benveniste *et al.* (2025) and Yang *et al.* (2025).

Notably, the positive co-movements observed between 2023M11 and 2024M9, within the 5-7 month scale band at high frequency, with *irregular* leading, appear highly sensitive to *regulatory* control. The effect disappears once the *regulatory* variable is removed, coinciding with the implementation of the Schengen Borders Code in July 2024.

PWC plots in Figures no. 15-20 refer to the '*smuggled* - *expenditures*' nexus. The co-movements remain robust when the control variables are removed, with the exception of *precip*, in the medium-run, as shown in Figure no. 19. Heavy rainfall conditions can reduce mission expenditures as such weather disrupts smuggling routes and operations, thereby affecting irregular flows.

Finally, PWC plots in Figures no. 20-25 reflect the '*total* - *expenditures*' nexus. As in the previous case, the co-movements remain robust across various controls. Only the *regulatory* variable appears to have a distinct effect, exerting a notable influence on the relationship

between 2023M11 and 2024M9, coinciding with the implementation of the Schengen Borders Code. This highlights the particular role of this code in shaping smuggling activities.

Overall, the robustness checks confirm that the main findings are stable across alternative methods and model specifications. While the WC results validate the sign, timing and frequency of co-movements, the PWC analysis highlights that these relationships are partly shaped by geopolitical, economic, weather and regulatory factors. Together, these results underscore both the robustness of the core dynamics and the importance of controlling for external shocks in explaining migration - border mission expenditures linkages.

## 5. CONCLUSIONS AND POLICY IMPLICATIONS

Overall, the study reveals a predominantly short-run and time-varying interaction between irregular migration (irregular, smuggled and total) and border mission expenditures along the Serbian - Romanian frontier over January 2018 - April 2025. Most significant co-movements occur within the high-frequency domain, indicating that the relationship is largely driven by short-term dynamics rather than persistent long-run linkages.

At very short-run (≈ 2 months), the co-movements are often either inconclusive or dominated by rapid adjustments. This horizon reflects operational responses by border authorities (e.g., patrol deployment, surveillance adjustments), immediate detection of migration spikes, especially in smuggled flows, and limited time for strategic planning. Here, the system behaves almost like a real-time monitoring mechanism, where authorities react to observable inflows with minimal delay and smuggling networks also respond quickly to enforcement pressure.

The short-run dynamics (≈ 2-4 months) is one of the most prominent and consistent bands in the results. In this case, increased spending (e.g., enforcement, patrols) is followed by a decline in irregular or total flows, while sudden surges in irregular or smuggled migration trigger subsequent increases in spending. The mechanism is characterised by strategic interaction between authorities and migrants/smugglers. At 4-8 months scale, the relationship becomes more complex, with authorities adjust their spending after observing sustained migration pressure, but with smoothed or delayed responses, rather than immediate reactions. This is a transition from tactical response to resource reallocation**.** At superior band (≈ 5–10 months), smuggled migration leading expenditures (positive co-movement), indicating that migration pressures drive budgetary expansion with a lag. Here, authorities learn from repeated migration surges, recognizing the structural migration pressure, especially through smuggling networks. At 10-12 months scale, spending today is followed by reduced migration later, while migration spikes eventually induce budgetary increases. This horizon reflects administrative inertia, with enforcement begins to have measurable deterrent effects, but also reflects post-crisis adjustments (e.g., scaling up after migration surges).

Finally, at medium-run (16-18 month scale), there is a particular smuggled - expenditure relationship, indicating that policy interventions eventually influence migration patterns, but with a long delay. This horizon captures structural policy impacts**,** not just tactical responses.

The findings suggest that border management at the Serbian - Romanian frontier may benefit from a multi-horizon policy approach that reflects the temporal dynamics identified in the analysis. First, the predominance of short-run interactions, at high-frequency, indicates that migration flows and border mission expenditures respond rapidly to one

another. This pattern is consistent with the need for timely monitoring, early detection systems, rapid response capabilities, and flexible operational resource allocation. National border authorities and interior ministries, with operational and analytical support from EU agencies, including Frontex, could coordinate such measures.

Second, the observed lead-lag relationships, whereby migration surges are followed by subsequent adjustments in border expenditures, suggest that greater budgetary flexibility and adaptive planning may improve the responsiveness of border management. Rolling risk assessments, contingency funding mechanisms, and flexible staffing and procurement arrangements could help align operational resources with evolving migration pressures rather than relying solely on fixed annual planning cycles.

Third, the medium-run associations identified for smuggled migration indicate that structural policy measures may influence migration dynamics over longer time horizons. Although the present analysis does not establish causality, these patterns are consistent with the importance of sustained cross-border cooperation, intelligence sharing and coordinated action against migrant smuggling networks. Strengthening collaboration among national border authorities, judicial institutions, EU agencies such as Europol, Eurojust and Frontex, together with international organizations including the International Organization for Migration (IOM) and the United Nations High Commissioner for Refugees (UNHCR), may therefore contribute to addressing the structural dimensions of irregular migration.

## 6. LIMITS AND FUTURE DIRECTIONS OF RESEARCH

The study has several limitations. First, the analysis focuses solely on the Serbian - Romanian frontier, which may limit the generalizability of the findings to other migration corridors characterised by different institutional settings, enforcement capacities or geopolitical conditions. Second, although wavelet coherence and partial wavelet coherency identify dynamic associations, lead-lag relationships, and co-movements across time and frequency, they do not establish structural causal mechanisms. While partial wavelet coherency controls for selected observable confounders, other unobserved factors may still influence the estimated relationships. Third, the analysis relies on administrative data on irregular and smuggled migration flows and border mission expenditures, which may be subject to measurement error arising from underreporting, detection biases and changes in enforcement intensity. In particular, smuggled migration is inherently difficult to observe, as detected cases represent only a fraction of total smuggling activity. Finally, the use of aggregate indicators may mask heterogeneity across migrant groups, smuggling networks, border sectors, and categories of operational expenditure, potentially overlooking important micro-level dynamics.

Future studies could extend the framework to multiple border regions or migration routes to assess whether the identified time-horizon dynamics are consistent across different institutional and geopolitical contexts. Moreover, incorporating individual-level migration data, differentiated expenditure categories or detailed smuggling network information would allow for a more granular understanding of mechanisms driving the observed relationships. Not least, future research could combine wavelet-based approaches with causal identification strategies (e.g., instrumental variables, natural experiments or structural models) to better isolate the direction and magnitude of causal effects between migration flows and border expenditures.

## ORCID

Mihai Mutascu https://orcid.org/0000-0003-3837-3243

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## ANNEX

**Table no. A1 – Dataset description**

| Variable | Explanation | U.M. | Source |
|---|---|---|---|
| Border mission expenditures *(expenditures)* | Captures all mission-related public expenditures, encompassing travel, accommodation and per diem for officers deployed away from their regular posts. It also covers the costs for fuel, vehicles, equipment, communication, surveillance and other specialized operational tools necessary for the mission. | lei (constant prices) | TIBPT (2025) |
| Irregular immigrants *(irregular)* | Count of foreign nationals officially recorded as entering Romania without legal authorization. | persons | TIBPT (2025) |
| Smuggled immigrants *(smuggled)* | Measures the irregular immigrants officially recorded as having used paid smuggling services. | persons | TIBPT (2025) |
| Total irregular immigrants *(total)* | Calculated as the sum between number of officially identified irregular immigrants and smuggled immigrants. | persons | TIBPT (2025) |
| Pandemic *(pandemic)* | Dummy variable controlling for COVID-19 disease, coded 1 for March 2020 - May 2023 and 0 otherwise (the dates are officially declared pandemic period in Romania). | dummy | Constructed |
| New border code *(code)* | Dummy variable controlling for the new Schengen Borders Code, coded 1 for July 2024 - April 2025 and 0 otherwise. | dummy | Constructed |
| Geo-political risk *(GPR)* | Measures the intensity of global geopolitical tension at a given time, with values above 100 signalling elevated risk relative to the historical average. | index | Caldara and Iacoviello (2022) |
| Economic Policy Uncertainty *(EPU)* | Captures the level of economic policy uncertainty over time, calculated as the average for selected Western European countries (France, Germany, Greece, Ireland, Italy, Spain, the UK, and Sweden). Values above 100 signify elevated uncertainty, whereas values below 100 indicate reduced uncertainty. | index | Baker *et al.* (2016) |
| Temperature *(temp)* | Captures the monthly average temperature, in the Romania's Vest Region, comprising the counties Timis, Caras-Severin and Mehedinti. | C° | INSSE. (2026a) |
| Precipitations *(precip)* | Captures the monthly average of precipitations, in the Romania's Vest Region, comprising the counties Timis, Caras-Severin and Mehedinti. | millimetres | INSSE. (2026b) |

**Table no. A2 – Descriptive statistics**

| Variable | Mean | Median | Maximum | Minimum | Std. Dev. | Sum | Obs. |
|---|---|---|---|---|---|---|---|
| *expenditures* | 97539.24 | 32485.12 | 406315.3 | 7675.766 | 108757.9 | 8583453 | 88 |
| *irregular* | 200.6932 | 107 | 986 | 0 | 218.1244 | 17661 | 88 |
| *smuggled* | 70.07955 | 28 | 637 | 0 | 107.148 | 6167 | 88 |
| *total* | 270.7727 | 152.5 | 1338 | 0 | 287.2543 | 23828 | 88 |
| *GPR* | 110.3448 | 105.365 | 318.95 | 58.42 | 39.19345 | 9710.34 | 88 |
| *EPU* | 230.8927 | 219.8548 | 581.7749 | 135.1105 | 73.97973 | 20318.56 | 88 |
| *temp* | 11.38125 | 11.415 | 23.9 | -1.47 | 7.399371 | 1001.55 | 88 |
| *precip* | 56.51523 | 49.94 | 157.6 | 10.59 | 32.57673 | 4973.34 | 88 |

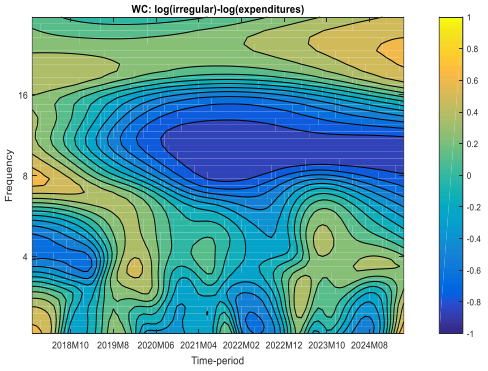



**Figure no. 5 – WC of pair log(irregular) vs log(expenditures)**

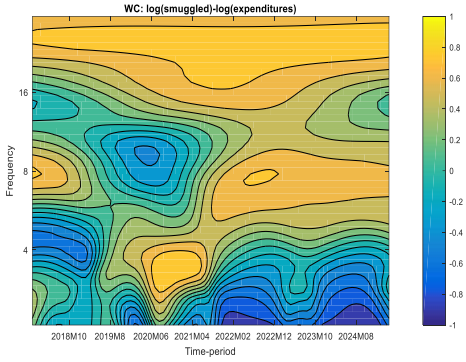



**Figure no. 6 – WC of pair log(smuggled) vs log(expenditures)**

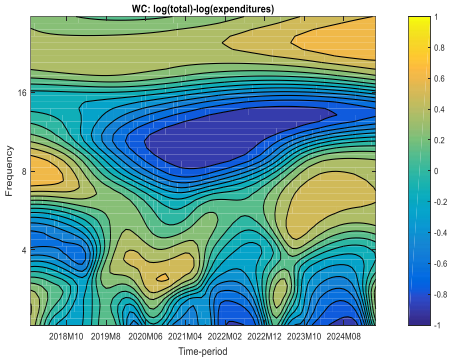



**Figure no. 7 – WC of pair log(total) vs log(expenditures)**

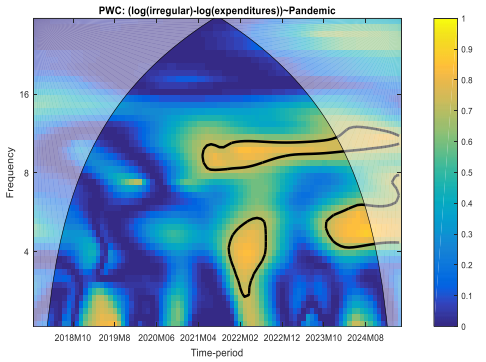



**Figure no. 8 – PWC of pair log(irregular) vs log(expenditures), removing log(pandemic)**

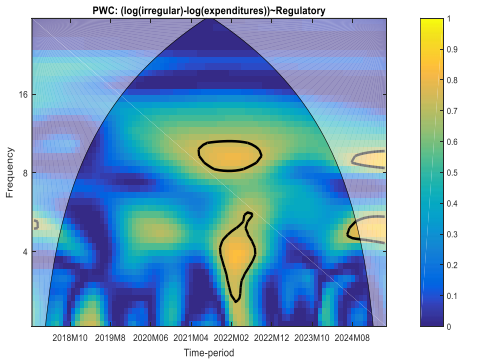



**Figure no. 9 – PWC of pair log(irregular) vs log(expenditures), removing log(regulatory)**

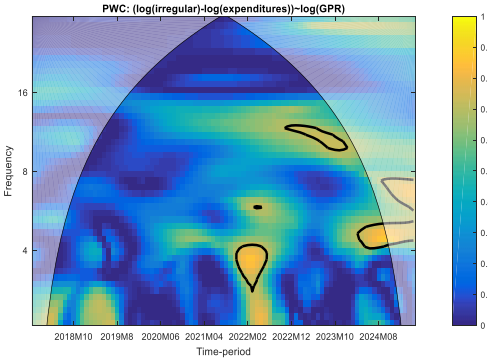



**Figure no. 10 – PWC of pair log(irregular) vs log(expenditures), removing log(GPR)**

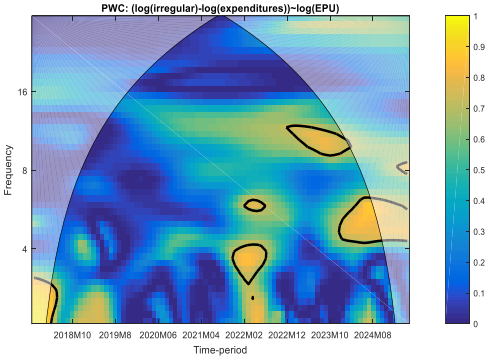



**Figure no. 11 – PWC of pair log(irregular) vs log(expenditures), removing log(EPU)**

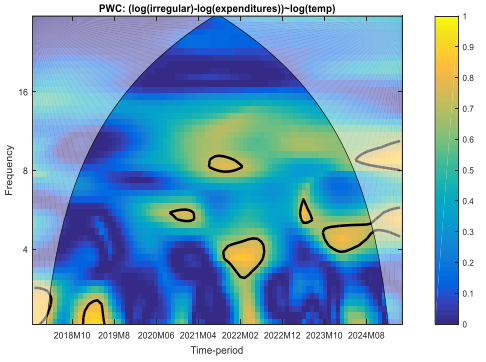



**Figure no. 12 – PWC of pair log(irregular) vs log(expenditures), removing log(temp)**

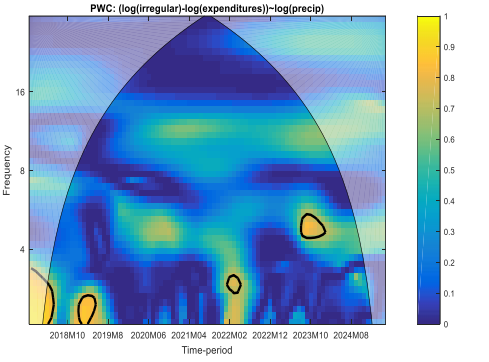



**Figure no. 13 – PWC of pair log(irregular) vs log(expenditures), removing log(precip)**

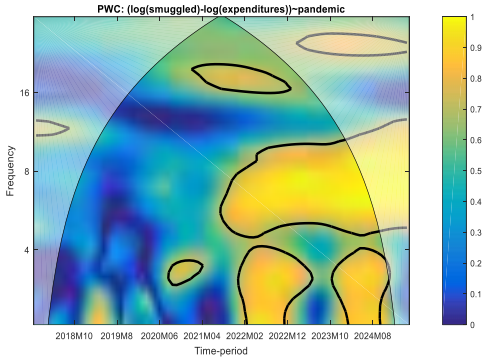



**Figure no. 14 – PWC of pair log(smuggled) vs log(expenditures), removing log(pandemic)**

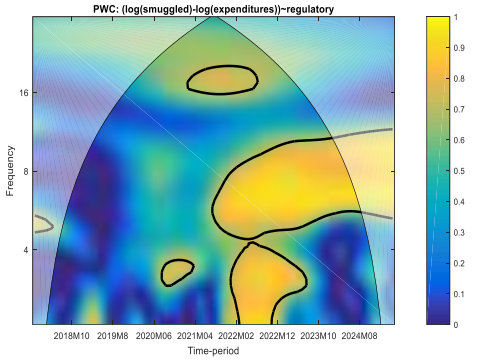



**Figure no. 15 – PWC of pair log(smuggled) vs log(expenditures), removing log(regulatory)**

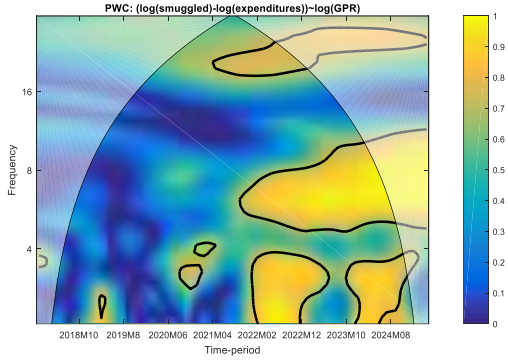



**Figure no. 16 – PWC of pair log(smuggled) vs log(expenditures), removing log(GPR)**

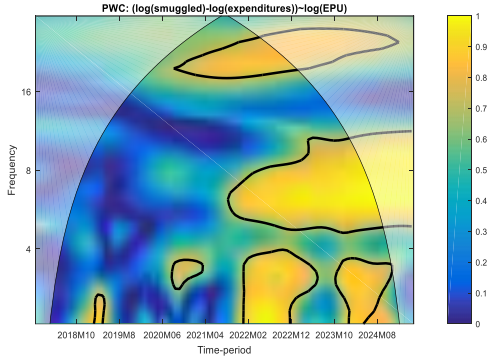



**Figure no. 17 – PWC of pair log(smuggled) vs log(expenditures), removing log(EPU)**

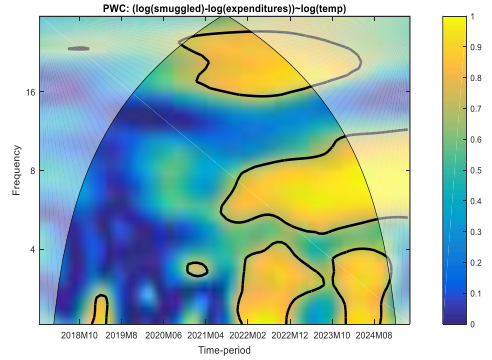



**Figure no. 18 – PWC of pair log(smuggled) vs log(expenditures), removing log(temp)**

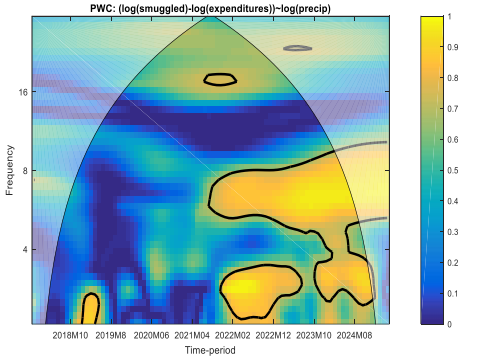



**Figure no. 19 – PWC of pair log(smuggled) vs log(expenditures), removing log(precip)**

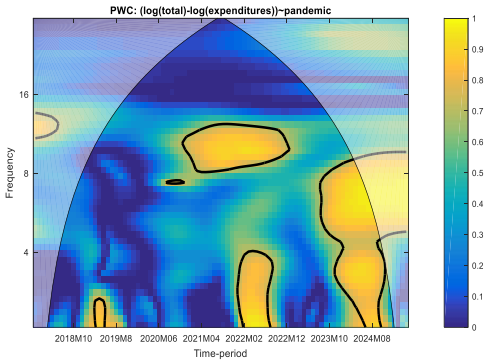



**Figure no. 20 – PWC of pair log(total) vs log(expenditures), removing log(pandemic)**

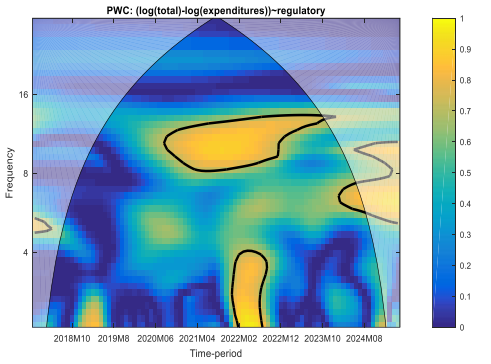



**Figure no. 21 – PWC of pair log(total) vs log(expenditures), removing log(regulatory)**

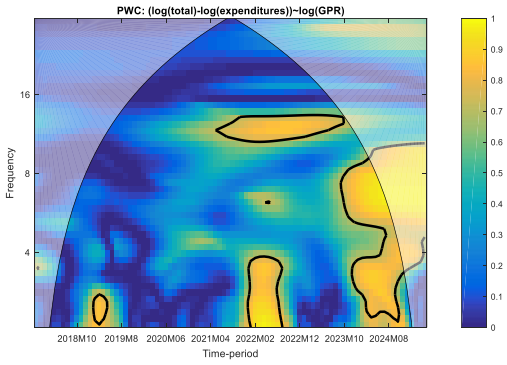



**Figure no. 22 – PWC of pair log(total) vs log(expenditures), removing log(GPR)**

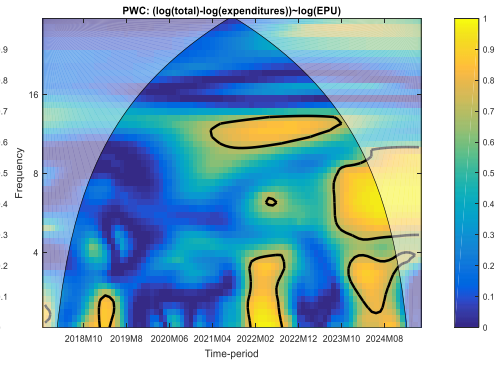



**Figure no. 23 – PWC of pair log(total) vs log(expenditures), removing log(EPU)**

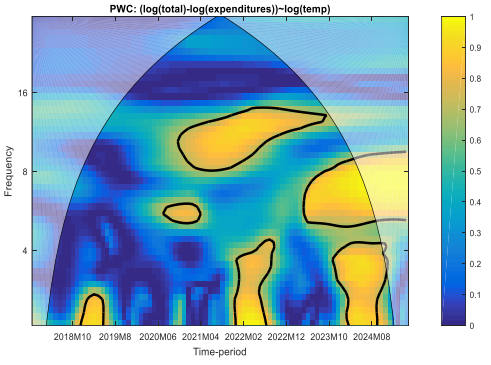



**Figure no. 24 – PWC of pair log(total) vs log(expenditures), removing log(temp)**

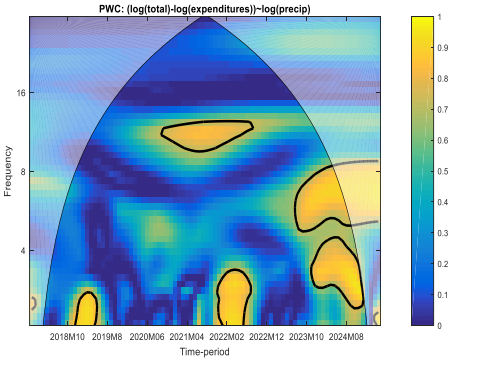



**Figure no. 25 – PWC of pair log(total) vs log(expenditures), removing log(precip)**