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Brain drain or economic gain? Untangling the global migration-growth puzzle through causality and time-frequency lenses

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ABSTRACT

This study investigates the complex causal relationships between net migration and economic growth at the global, income group, and country levels, framing these dynamics within the evolving landscape of global economic integration and disparities, thereby addressing the enduring "brain drain or economic gain" debate. The analysis is conducted employing the latest available panel data from 1990 to 2023 for 154 countries. Additionally, several advance analytical techniques including Juodis, Karavias and Sarafidis non-causality test and Wavelet Transform Coherence is utilised to investigate relationships across multiple scales and time frequencies. To the best of the authors' knowledge, no prior research has examined these dynamics using these methods. Additionally, a novel visualisation technique called Lucius Jesper Chloe heatmap, was utilised to depict the Granger causalities. The findings confirm a relationship between migration and economic growth on a global scale. Further analysis reveals bidirectional and unidirectional relationships within income groups and countries. Finally, implications are made for policymakers to develop economic policies that leverage the economic potential of migration and vice versa.

Introduction

Migration and economic growth are some of the most potent forces shaping this world. Over the past 20 years, there has been a significant increase in the number of international migrants. As per the most recent statistics, there were approximately 304 million migrants residing out of their country of origin, making it nearly 3.8 % of total world population (United Nations, 2024). Compared to the 1990 statistics, it is nearly a one hundred percent increase in migrants.

These trends underscore the growing importance of understanding the relationship between migration and economic growth, raising questions about how these dynamics influence one another across different income levels. This intricate nexus lies at the heart of contemporary globalisation, reflecting the increasing interconnectedness of economies through human mobility. Income groups are an important classification to consider in terms of migration trends, as a primary motive of migration are usually due to higher income opportunities (Hicks, 1963). For instance, in High-income countries (HICs), nearly 16 % of total population consisted of migrants in 2024, whereas for Upper-middle-income countries (UMICs), Lower-middle-income countries (LMICs), and Low-income countries (LICs), it was 1.7 %, 1.3 % and 1.9 % respectively (United Nations, 2024). Moreover, migration is experienced differently by each income level; for instance, HICs tend to draw skilled migrants while LICs have more excellent emigration rates frequently resulting in brain drain (Docquier, 2014; Jennissen, 2003; Morley, 2006). Compared to a mere 31 % in UMICs and LMICs and 4 % in LICs, 65 % of all international migrants reside in HICs according to the United Nations (United Nations Department of Economic and Social Affairs, 2020). Therefore, an income-based analysis is essential when examining the relationship between migration and growth, as demonstrated by these differences in migration patterns.

Despite these upward trends in migration over the years, there is a certain level of uncertainty about the migration economic growth nexus across countries in different income groups. The existing studies often focus on examining a unidirectional relationship, and there are limited research on studies focusing on the plausible bidirectional relationship between migration and economic growth, focusing specifically on the four income groups established.

Therefore, this study aims to bridge these gaps by addressing the overarching research question: How do the causal relationships between

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international net migration and economic growth manifest across different income levels, and what do these dynamics reveal about the evolving nature of global economic integration and disparities? To answer this, it investigates the relationship between migration and economic growth globally, classifying countries into High-income countries (HICs), Upper-middle-income countries (UMICs), Lower-middle-income countries (LMICs), and Low-income countries (LICs) as per World Bank country classifications by income level (Hamadeh et al., 2022), making use of the latest available data.

This study contributions to the extant knowledge in this domain, primarily in six ways. Firstly, this research aims to analyse the relationship between migration and economic growth, at the global level and across four different income groups. This allows for an in-depth view of the complex ways human mobility shapes, and is shaped by, globalisation and divergence, thereby contributing to the broader discourse on globalisation's multi-faceted impacts. Secondly, to conduct a thorough and up-to-date examination, the research utilises the most recent data, from 1990 to 2023. Thirdly, using per capita net migration (PNM) as a measure of migration, which accounts for the overall net effect of immigration and emigration, offers a more inclusive perspective, by shifting the focus from limited types of migration. Moreover, the data analysis was conducted using one of the latest Granger causality analysis methodologies which has never previously been used in the migration domain, along with Wavelet Transform Coherence (WTC). These methods combined, offer insights into the different dimensions of the migration-economic growth relationship. Further, this paper utilises a novel visual representation method, the Lucius Jesper Chloe heatmap (LJC heatmap), to visualise Granger causality results. This method effectively allows comparisons of advanced statistics across different panels and different periods. Finally, the research offers practical economic policy implications based on the dynamics identified across income groups per the analytical results. These policy recommendations assist in formulating effective policies that enhance the positive contributions of migration and economic growth.

The following sections of the paper are structured to critically review extant literature and outline the data sources and methodologies. Next, the findings are presented, followed by policy recommendations and concluding remarks.

Literature review

The literature search was systematically conducted and is detailed in Fig. 1. The literature was obtained from a range of reputed sources following the PRISMA methodology.

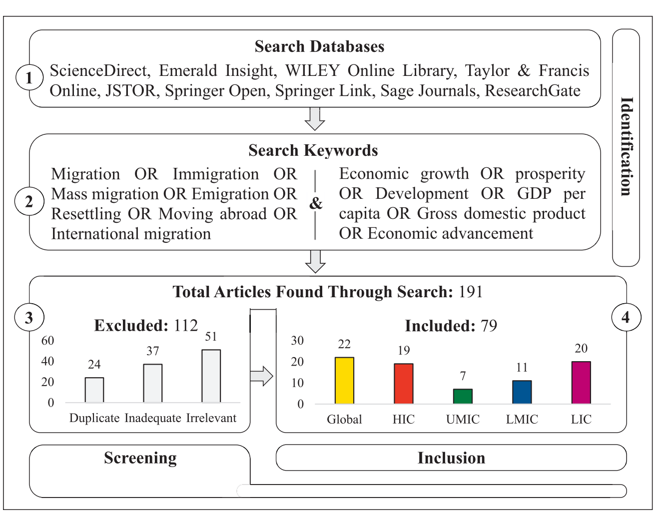

Fig. 1. Literature search.
Source: Authors' composition.

Many studies were excluded during the screening as their focus is towards internal migration or bird migration, rather than international migration. The remainder of the articles were then categorised according to the respective income groups.

Most of the literature focuses on specific types of migration, such as immigration, emigration, or return migration, and does not capture the net effect of migration. Further, the literature that considers global and income group-specific aspects is also limited. This gap is significant as the type of relationship is prospective to vary according to income levels and the type of migration.

Global

Numerous factors shape the global relationship between migration and economic growth. These include a variety of factors such as the skills of the migrants; the country's development level; broader socio-economic conditions like social globalisation (Sandanayaka et al., 2025); whether the government is primarily taking in or sending out migrants; and whether net migration is positive or negative.

Many studies show that skilled migration contributes positively to economic growth, especially in developed countries. As per global studies, developed countries frequently obtain advantages from the arrival of professional migrants, and they help boost PGDP growth and improve productivity (Alesina et al., 2016; De Pascale et al., 2020; Dritsaki & Dritsaki, 2024; Orefice, 2010). In contrast, other studies indicate a negative impact of immigration on economic growth due to the accumulation of low-skilled immigrants (Akanbi, 2017), in low income countries. However, there can be instances where least-developed countries also obtain benefits from immigrants as well (Kang & Kim, 2018). When people migrate from their birthplace while searching for better opportunities, host countries are more likely to experience an increase in PGDP, since different backgrounds of immigrants can stimulate economic dynamism and foster innovation (Andronova & Ryazantsev, 2023; Bove & Elia, 2017; Caballero et al., 2024; Dao, 2010; Sanderson, 2013; Strzelecki et al., 2022). Similarly, a study conducted on Belt and Road Initiative (BRI) countries emphasises that, improvement in Information Communication Technology (ICT), as a result of globalisation, have facilitated cross border knowledge sharing and development of diasporas, which in turn has positively improved migration and economic growth trends (Iqbal et al., 2020). However, the long-term impact on the host country depends on their ability to retain and utilise these immigrants' diverse skills.

Moreover, it is recognised that emigration occurs depending on the economy's development and income level. If the source countries' income level is low, the emigration rate is more likely to increase (Dao et al., 2018; Lanati & Thiele, 2024; Restelli, 2023). When considering the emigration of skilled workers from developing countries, studies also indicate a significant impact of emigration on economic growth. Some studies demonstrate that the "brain drain effect" is a critical concern since the outflow of skilled workers can negatively impact the source country's economic development, particularly in less developed countries (Afridi et al., 2020; Beine et al., 2011; Beine et al., 2001; Di Maria & Lazarova, 2012). Although the individuals and the host countries gain benefits through talent migration (Di Maria & Stryszowski, 2009), source countries may face difficulties maintaining economic growth (Di Maria & Lazarova, 2012). The decision to emigrate often depends on both the source and the host country's development levels.

However, these studies, have mainly focused on a unidirectional aspect of the nexus, only analysing the impact of migration on economic growth or vice versa. Only a limited number of studies have conducted Granger causalities in order to study the bidirectional nature of the relationship between migration and economic growth. Additionally, majority of the studies have not focused specifically on income groups and have mainly utilised data ranging from the time period 1990 to 2015. This would entail the possibility of changes in the nexus dynamics, considering the more recent changes in migratory and economic growth patterns.

High-income countries

In comparison, HICs are likely to have more immigrants than emigrants, indicating a positive net migration. Several studies reveal that in HICs, the immigrants' human capital makes a considerable contribution to PGDP (Boubtane et al., 2016; D'Albis et al., 2016; Peck, 2023), while some studies found a significant impact from economic growth on net immigration, wherein better economic growth conditions, attract more migrants (Boubtane et al., 2013; Jennissen, 2003; Morley, 2006; Vogler & Rotte, 2000). In terms of attracting migrants, education is found to be a pull factor, whereas labour market issues are push factors (Istudor et al., 2020). Despite successful economies attracting more immigrants, their eventual contribution to the economy may be delayed or limited.

Furthermore, studies focusing on United States concludes that areas with high immigration, often increase diversity, and have been more resistant to economic turbulence, and rather contribute better to economic development in comparison to areas with less diversity (Ager & Brueckner, 2018; Huang, 2021). This correlates with a recent study which unveiled bidirectional causalities between social globalisation and economic growth in high income countries (Sandanayaka et al., 2025), which entails that the spread of skills and cultures, resulting from migration, can cause improvements in economic growth. Additionally, immigrants in European regions often fill labour market gaps with diverse skills and fresh ideas (Anna et al., 2023; Noja et al., 2018). However, the benefits of immigration may not be evenly distributed among all the financial dimensions. Whereas skilled immigration generally boosts economic growth (Noja et al., 2018) and competitiveness in most contexts (Oliinyk et al., 2021), unskilled immigration has been observed to impact economic development in specific contexts, negatively (Serban et al., 2020). The disparity emphasises the importance of the skill composition of immigrant populations in determining their financial impacts.

Moreover, HICs in the Gulf countries show that an increase in migrant populations, incur reduction in economic growth (Wagle, 2024). Other studies conducted on wealthy nations of Bahrain, Kuwait, Qatar, Saudi Arabia and United Arab Emirates, also indicate a unidirectional Granger causality from economic growth to remittance outflow (Khan et al., 2019) which can be correlated to migration. The literature on HICs in the Gulf, show mixed relationships between migration and economic growth.

Another determinant in this context is unemployment. Portugal, as a HIC, shows a negative impact of the unemployment rate on immigration, although immigration did not influence unemployment (Boubtane et al., 2013). On the other hand, some studies have found that immigration can negatively impact unemployment, but with a minor effect on wage increase (Fromentin, 2013). Migrants are more likely to respond to negative economic situations, such as unemployment than favourable situations, indicating loss aversion among migrants (Czaika, 2015). This underlines the complex dynamics between immigration and economic growth, emphasising that while immigrants may heavily respond to economic downturns, their overall influence on the labour market, needs to be carefully controlled.

Therefore, existing studies have analysed aspects of impacts of migration and economic growth and vice versa, however, these studies have limited to a selected few high income countries, and may not be representative of the current nexus between migration and economic growth.

Upper-middle-income countries

UMICs are one of the common choices to migrate, as they provide comparatively more affordable migration and better economic opportunities than home countries. The existing literature reveals that there is a complex relationship between migration and economic growth in UMICs, demonstrating how different factors interact to shape this dynamic. In such countries, migration that is facilitated through means social and financial globalisation, often provide opportunities for overall economic improvement (Rapoport, 2016) through brain gain, remittance and trade flows and development of community networks.

In Thailand, one of the major factors that significantly contributes to economic growth is migration. People who come to the country to seek job opportunities often contribute to the advancement of the economy by enhancing labour force diversity and reducing the poverty level (Pholphirul, 2012). Additionally, emigrants in Thailand also play pivotal roles in augmenting Thailand's economic performance (Bhula-Or, 2021). While low-skilled foreign workers may provide short-term benefits that could be necessary for immediate gaps in labour shortages, long-term participation and contribution to economic growth are much more robust with highly skilled immigrants who can contribute to sustained economic growth (Tipayalai, 2020). However, only depending on migration without focusing on the other aspects, such as improvement of monetary policies, might tend to limit the long-term benefits, since actual growth requires more changes beyond just increasing the labour force.

However, in the case of China, the literature demonstrates that both permanent emigration and temporary migration have negative impacts on economic growth (Cui et al., 2025; Ha et al., 2016). Several reasons lead to the negative effects, such as loss of skilled workers and instability in the labour market due to temporary migration. This implies that even though migration can bring advantages, such as increased remittances and diversified skills, the overall impact on economic growth may be influenced by the type and duration of migration.

Furthermore, in the context of return migration, the returnees frequently bring advanced skills and resources obtained from their experiences in developing countries, which can help encourage entrepreneurial activities and contribute to economic growth in their home countries (Wassink, 2020). However, with little support and opportunities in the home countries, these skills and resources may become underutilised. This could lead to a decrease in return migration.

Lower-middle-income countries

In LMICs, the relationship between migration and economic growth is shaped by several factors, including remittances and domestic economic conditions. Several studies indicate that remittances sent by emigrants will boost economic growth in countries like Sri Lanka, India, Pakistan, Nepal, and Bangladesh, especially in cases where the level of financial development and education is high (Azam, 2015). As seen in Sri Lanka, emigrants have contributed to increased education and small-scale investment through remittances as a further result of globalisation. This has then allowed households to utilise income from remittances for capital expenditures and better education options (Ramanayake & Wijetunga, 2018; Siddique et al., 2012). However, a study conducted in Ghana, a well globalised low-income nation states that emigration and resulting migrant remittances can have a negative impact to endogenous growth (Adenutsi, 2011). However, the effect of remittances and outcomes may vary based on local economic conditions and policies.

As per another study carried out in Ghana, emigrants are critical drivers of economic growth since they send back plenty of remittances to the source country. Depending on the emigrants' knowledge and skill levels, the contribution of remittances to economic growth may vary, with high skill levels having a more significant potential to stimulate economic growth (Agbola, 2013). However, while skilled emigrants have a greater positive impact, the overall effect of remittances on economic growth will depend on how effectively the source country can manage and control them for productive uses.

A study conducted in Sri Lanka reveals a negative impact of economic growth on migration, meaning that economic growth reduces the emigration level (Kaluarachchi & Jayathilaka, 2024). In contrast, another study demonstrates that despite education success and high human development among people, many people tend to migrate due to economic and social changes caused by globalisation (Sriskandarajah, 2002). Even though economic growth reduces the emigration level, it is not sufficient to maintain it in the long run, due to persistent domestic economic challenges and a lack of job opportunities.

When it comes to return migration, it provides additional economic benefits. In Myanmar and Bolivia, the factors contributing to return migration include better job opportunities, political stability, and improved public services. These returning migrants not only invest locally but also use social remittances to contribute much to the economic development and success of their home communities. Which can be a further outcome of globalisation (Jones, 2011; Thet & Pholphirul, 2016). Furthermore, studies show that countries under LIC as a whole is more likely to experience emigration than the countries in UMIC as a result of neoliberal globalisation (Paudel, 2025; Peck, 2023). However, if the receiving communities are unable to utilise the resources and skills of returning migrants effectively, it will lead to adverse effects on the economy.

Low-income countries

The majority of LICs often belong to the African continent. Overall, existing literature emphasises the prevailing economic pressures and conflicts in such LICs, resulting in a significant migration outflow to other regions in the continent.

The vast outward movement of people from African countries impacts economic growth, both positively and negatively (Afridi et al., 2020; Lucas, 2006). Firstly, LICs that are already embroiled in poor economic conditions face risks of brain drain (Akanbi, 2017). The loss of skilled labour diminishes productivity and output, preventing the economy from expanding. While it also withdraws people from seeking better opportunities in globalised economies (Benček & Schneiderheinze, 2024; Okunade et al., 2025). Additionally, this can lead to fiscal drawbacks as there is a higher potential loss of tax revenue from skilled workers. However, whilst the brain drain in these countries leads to a loss of trained manpower, it also paves the way for foreign income through remittances as a result of globalisation (Coulibaly, 2015; Marwan et al., 2013; Oumarou, 2021). Which, if invested correctly, can lead to economic growth. However, it is to be noted that a significant proportion of remittances sent to LICs are informal, often going unrecorded. Therefore, its complete impact may not be realised.

A World Bank report that analyses the economic benefits and risks of migration in ten African countries, including LICs of Burkina Faso and Uganda, highlights that migration is mainly seasonal (Shaw, 2007). This fluctuation of migrants in specific sectors, like agriculture, could lead to short-term boosts or declines in economic activity. Furthermore, as a result of cross-broader linkages due to globalisation, the migration-induced remittances have increased significantly, contributing to the GDP. However, some researchers note that regions receiving such large remittances haven't developed self-sustaining economic growth and instead, cause a reduction in work effort and agricultural output. It is to be noted that the full effect of emigration and remittances on economic growth may not be realised due to a lack of information and much of the remittances being sent through informal channels.

Furthermore, when considering Sub-Saharan African countries, including Togo, Uganda, Ethiopia, Gambia, Malawi, and Madagascar, a positive relationship exists between migration outflow or emigration and economic growth (Adow, 2025; Ceesay, 2020; Gebbisa, 2017; Mago, 2018; Ofori & Grechyna, 2021; Thomas & Inkpen, 2013; Yadeta & Hunegnaw, 2022). While a negative correlation exists between emigration and poverty (Belloc, 2015; Usman et al., 2022). However, these findings oppose the conventional push and pull factor theory. As the economic development of a country improves, emigration rates can rise, as individuals are better able to afford the costs of migration, as opposed to getting better local opportunities in globalised economies. Emigration, in turn, leads to remittance inflows, which can contribute to sustainable economic growth. However, if the opposite occurs and the economy faces a decline, the benefits of migrating cannot be justified by its cost, leading to a reduction in emigration. In contrast, an increase in poverty levels, rather than forcing people to migrate for better opportunities, restricts costly movements and causes a decrease in emigration.

On the other hand, countries such as Uganda and Sierra Leone shows that even though people are more likely to emigrate, these countries are well known destination choices of refugees. This is because they are not able to afford migrating to well globalised economies (Cantore & Calì, 2015; Murahashi, 2021). However, these studies are based on remittances, which is one aspect of migration. Therefore, these studies cannot be considered as studies that show a direct analysis of net migration and economic growth.

Data and methodology

The latest panel data were collected from 1990 to 2023, resulting in 5,236 observations. The collected data consist of 154 countries, including 60 HICs, 40 UMICs, 39 LMICs, and 15 LICs. The data sources and primary variables of the study are depicted in Table 1.

The PGDP data were directly taken from the World Bank. Due to the unavailability of PNM data, PNM values were calculated by dividing the net migration values from the total population values which were collected from the World Bank. Countries with missing values were omitted during the data cleaning process to ensure data completeness and consistency. This approach avoids potential bias or artificial trends that may arise from imputation techniques. While World Bank is a widely accepted as a secondary data source, cross-country variations in reporting quality may still contribute to heterogeneity and potential bias in the dataset.

The final data set used in the analysis is included in the S1 Appendix. Further, Fig. 2 outlines the six-step process followed during the research.

The Granger causality and WTC have distinct approaches to analysing relationships. As each method, investigates different properties of the relationships, it could lead to potentially varied results. While the Granger causality analysis provides insight into overall predictability through lead-lag relationships, the WTC points to co-movements and phase shifts at different frequencies. Therefore, these complementary approaches contribute to a deeper understanding of complex, time-varying interactions between PNM and PGDP.

Granger causality

The Granger causality tests examine whether one variable can reveal predictive information about another variable in a time series context. When two variables are Granger-caused, it suggests that past values of the one variable can be utilised to predict the other variable the other variable. The Vector Autoregressive models are applied to each unit in determining the Granger causality. These methodologies have been frequently utilised across various disciplines, including economics

Table 1
Data sources and variables.

Variable	Measure	Measuring unit	Source
Economic growth	PGDP (Per capita gross domestic product)	United States Dollars ($)	World Bank: https://data.worldbank.org/indicator/NY.GDP.PCAP.CD?end = 2023&start = 1960
Migration	PNM (Per capita net migration)	Per person	World Bank: https://data.worldbank.org/indicator/SM.POP.NETM World Bank: https://data.worldbank.org/indicator/SP.POP.TOTL

Source: Authors' composition.

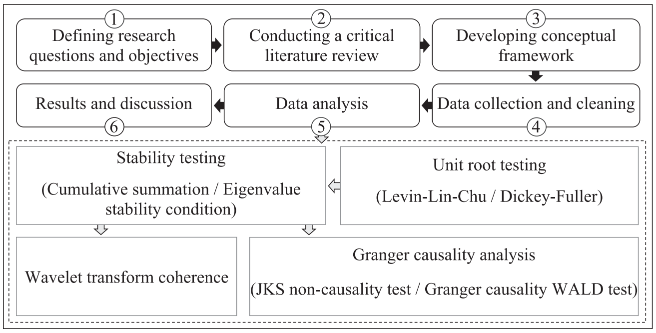

Fig. 2. Methodology flow diagram.
Source: Authors' composition.

(Jiang et al., 2022; Kaluarachchi & Jayathilaka, 2024; Marques & Lima, 2022; Wijesekara et al., 2022), finance (Cincinelli et al., 2022; Yilanci et al., 2021), engineering (Gunjal et al., 2023; Wang et al., 2024; Yuan & Qin, 2012), energy (Arogundade & Hassan, 2024; Raifu et al., 2025; Simionescu & Plopeanu, 2023), environmental science (Wang et al., 2024), healthcare (Akbar et al., 2021; Rana et al., 2020; Rosoł et al., 2022), and neuroscience (Barnett & Seth, 2017; Dong et al., 2019; Gao et al., 2020) to study causal relationships.

Granger causality was selected for this study due to its effectiveness in identifying temporal cause-and-effect relationships between time series variables. Unlike simple correlation analysis, which only reveals associations, Granger causality is particularly suitable for assessing the predictive power of economic indicators such as PGDP and PNM.

Accordingly, this study employed two distinct Granger causality techniques—one for panel data and another for time series data—to investigate the causal relationship between PGDP and PNM. To estimate the Granger causality of heterogeneous panel data, the Juodis, Karavias and Sarafidis (JKS) non-causality test (Juodis et al., 2021), was utilised. JKS non-causality test overcomes critical limitations of traditional Granger causality in several ways. Unlike traditional Granger tests, which assume uniform effects and independence across units, the JKS framework allows unit-specific coefficients, recognising divergent migration-growth dynamics (remittances in LICs vs. skilled migration in HICs). It corrects Nickell bias (common in panels with fixed effects) via a Half-Panel Jackknife estimator, ensuring robustness for moderate time spans. Further, JKS test evaluates average non-causality across panels, accommodating shared global shocks (shared growth or migration trends) without explicit spatial modelling. This suits the study dataset, where heterogeneity across income groups is critical. Additionally, this technique utilises a Wald test based on the bias-corrected estimator for causality calculations. Finite-sample evidence shows that the resulting approach performs well in a variety of settings and outperforms existing procedures (Juodis et al., 2021).

The authors followed a standard approach using the Half-Panel Jackknife (HPJ) estimator to control for the Nickell bias inherent in dynamic panels with fixed effects for the JKS non-causality test. The optimal lag length for the panel VAR was determined based on the Bayesian Information Criterion (BIC). The test was conducted by estimating a bias-corrected panel VAR model, then computing a Wald-type statistic for the null hypothesis of no Granger causality from the explanatory variable to the dependent variable across the panel units.

In addition, the standard Granger causality WALD test (Granger, 1969) was employed to uncover country-level Granger causalities as JKS non-causality is limited to panel data analysis.

Equation (1) and Equation (2) were used in both panel and country-level time series Granger causality analysis.

$$PGDP_{i,t} = \alpha_i + \sum_{l=1}^{p} \upsilon_i PGDP_{i,t-l} + \sum_{=1}^{p} \gamma_i PNM_{i,t-l} + \varepsilon_{i,t} \tag{1}$$

$$PNM_{i,t} = \rho_i + \sum_{l=1}^{p} o_i PGDP_{i,t-l} + \sum_{l=1}^{p} \chi_i PNM_{i,t-l} + \varepsilon_{i,t} \tag{2}$$

These models consider the two covariance-stationary variables (PGDP and PNM) in each unit (either panel or country) across t time periods. Here, $\varepsilon_{i,t}$ denotes the error term, while α_i and ρ_i represent unit-specific fixed effects. The terms $PGDP_{i,t-l}$ and $PNM_{i,t-l}$ are the lagged values of PGDP and PNM respectively, where l denotes the specific lag length, and p is the maximum lag order chosen for the VAR model. The coefficients, υ_i, γ_i, o_i, and χ_i represent the impacts of the lagged variables on the dependent variable.

In Granger causality, a non-significant result (p-value more than 0.1) implies a failure to reject the null, suggesting no Granger causality in the specified direction. Conversely, a significant result would indicate that past values of the explanatory variable improve the prediction of the dependent variable.

LJC heatmap

The LJC heatmap is an innovative visualisation tool for visualising Granger causality test results through which direction of causality, the significance levels, z values, tested and selected lag lengths can be visualised. As an advanced visualisation method, the LJC heatmap provides a novel way of visualising complex causal relationships and makes it easier for researchers to identify causal relationships between different variables and allows easy comparison of entities.

The LJC heatmaps website (Chloe, 2024) was utilised to illustrate the LJC heatmap used in the study. It provides a straightforward way of inputting the Granger causality results to generate LJC heatmaps.

The sizes of circles were generated based on z values. Equation (3) represents the formula used to calculate circle sizes.

$$r = \frac{(s - smn)}{smx - smn} x\left(\left(\frac{n}{w*0.9}\right) - \left(\frac{n}{w*0.3}\right)\right) + \left(\frac{n}{w*0.3}\right) \tag{3}$$

In this equation, r represents the radius of the circle, s represents the z statistic of the specific unit, n represents the number of entities displayed in the heatmap, w represents the width of the heatmap canvas, and smx and smn represents maximum and minimum z statistic values across all units visualised in the heatmap respectively.

Further, the Equation (4) represents the formula used for calculating the length of the arrows.

$$a = \left(\frac{(l - lmn)}{(lmx - lmn + 1)*h*0.9}\right) + \frac{h*0.9}{lmx - lmn + 1} \tag{4}$$

Here, a is the length of the arrow, l is the optimal lag length selected for the respective entity, h is the height of the heatmap canvas, and lmx and lmn are the maximum and minimum lag length tested across all entities, respectively.

Majority of the existing literature utilise tabular formats in visualising Granger causality results (Perera et al., 2024); Yiwei (Wang et al., 2025); Yunong (Wang et al., 2023), often neglecting the importance of factors such as optimal lag lengths and is comparatively difficult in quick comparison between analysed units (panels or time series). Further, multivariate Granger Causality results has been visualised by methods that merge the notion of Granger causality with network diagrams (Eichler, 2007). However, these types of techniques are limited in simultaneously displaying multiple statistics. LJC heatmaps overcome these limitations by provide a comprehensive overview of the critical statistics across analysed units allowing quick comparison.

Wavelet transform coherence

WTC can be used to analyse two variables throughout a time series. Over time, it has been used in various domains, from Neuroscience (Haresign et al., 2024; Nguyen et al., 2020; Reddy et al., 2023) to

Economics and Finance (Galappaththi et al., 2023; Saeed et al., 2023; Wijesekara et al., 2022), starting with its initial application in 1998 (Torrence & Compo, 1998). This study has employed the WTC method to analyse the time–frequency relationship between net migration and economic growth, providing a nuanced understanding of their dynamics.

The decision to use WTC is grounded in its ability to localise relationships in both time and frequency, which is particularly valuable when investigating phenomena influenced by long-term trends as well as short-term shocks such as migration patterns responding to economic cycles. WTC surpasses other methods in several aspects. It overcomes the limitations of the Fourier analysis, such as its inability to depict rapid fluctuations in economic data accurately. Wavelets, being localised, enable the examination of the relationship between PNM and PGDP at various frequencies by dividing the time series into segments that reflect distinct time scales. Additionally, it goes beyond fundamental causality by revealing the intensity and direction of the relationship over time.

Given the growing recognition of migration as both a cause and consequence of economic development, a methodology that can reveal when, at what frequency, and in which direction migration and economic growth interact is essential. WTC provides precisely this type of insight, which justifies its adoption in this study.

The implementation of WTC involves decomposing both PNM and PGDP using appropriate wavelet functions. The general wavelet function is defined in Equation (5).

$$\psi^{a,b}(x) = |a|^{-\frac{1}{2}}\psi\left(\frac{x-b}{a}\right) \quad (5)$$

In this model, the x time index or continuous time variable, index a denotes the scale (controls frequency), index b represents the translation (controls position in time) and ψ is the mother wavelet function. In wavelet coherence, the direction and specifics of which variable precedes the other can be obtained by examining two-time series (PNM, PGDP). Equation (6) presents the equation for wavelet coherence, which accounts for the smoothing factor(s).

$$Coherance = \frac{|sWave.PNMPGDP|^2}{sPower.PNM \bullet sPower.PGDP} \quad (6)$$

Here, the *sWave* is the smoothed cross-wavelet transform and the *sPower* smoothed wavelet power spectrum of each variable.

Wavelet Transform Coherence (WTC) analysis was conducted using the biwavelet package in Posit (RStudio) Software (Posit RStudio, 2024). Morlet wavelet ($\omega_0 = 6$) with scales of 2–16 years to capture short-term (2–4 years), medium-term (5–10 years), and long-term (11–16 years) dynamics were used during the analysis. Significance thresholds (black contours) were determined via 1,000 Monte Carlo simulations. Phase arrows (length = 0.05, width = 0.03) denote lead-lag relationships, and edge effects were mitigated using the cone-of-influence (grey).

Results

The following section details the descriptive statistics, historical trends, and Granger causality and WTC analysis results. Fig. 3 illustrates the distribution of the variables using violin plots. The plots have been appropriately squished to focus on the central distribution. At the same time, extreme values outside the specified range have been compressed to maintain clarity and interpretability without compromising the overall analysis. The comprehensive summary of the panel descriptive statistics data utilised in creating the violin plots, along with the time series descriptive statistics, are detailed in the S2 Appendix.

As per Fig. 3(A), PNM shows less variability in its mean across groups

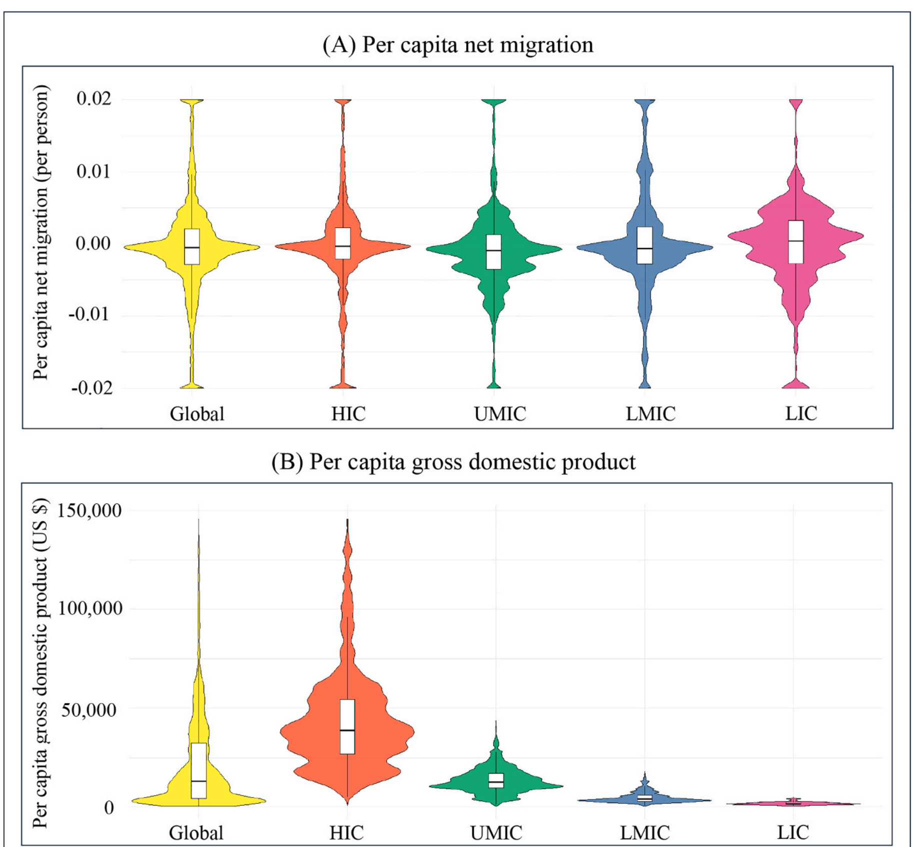

Fig. 3. Distribution of the variables.
Source: Authors' composition using Posit RStudio (2024).

but has a notable range in UMICs. The range of PNM is most extensive in UMICs, suggesting more variability in the economic or migration dynamics within this group. Further, as per Fig. 3(B), PGDP trends vary significantly across income groups, with HICs having the highest mean and standard deviation.

Further, the historical migration and economic growth trends from 1990 to 2023 are demonstrated in Fig. 4. For a clear representation of the trends, the total period (1990——2023) was divided into two time periods (1990 – 2006, and 2007——2023). Each x-axis represents the time in years, and the y-axis represents the mean PGDP and mean PNM in Fig. 4(A) and Fig. 4(B), respectively. Additionally, the average mean values of each variable are included at the top of each chart for the respective periods.

From 1990 to 2006, during the early period, global economic patterns exhibited modest dynamics across all income groups, whilst migratory patterns exhibited some moderate fluctuations, with average net migration being negative (80 net emigrants per 100,000 persons). As illustrated in Fig. 4(B), the mean PGDP growth rates were comparatively low, with HICs improving steadily reflecting increased globalisation and technological progress during this period. The end of the Cold War and the formation of the European Union might also have played a crucial role in shaping these patterns (Schulz & Kurtz, 2008; Union, 2022). Additionally, the UMICs demonstrate gradual economic growth, whereas LMICs and LICs make minimal growth. Additionally, Fig. 4(B) reveals that, during this period, average PNM levels across all income levels were comparatively more negative, suggesting that net emigration was more common in the considered countries, and thus, a net outflow of people. Notably, UMICs displays significant fluctuations between net immigration and emigration from 1990 to 1996 indicating that these countries were transitional zones between sending and receiving areas. Further, all income groups have experienced periodic spikes, often correlated with regional conflicts and economic distress.

The disparities in the income groups are more evident during the recent period from 2007 to 2023, wherein the HICs had increasingly higher mean PGDP growth, establishing them as centres of global economic activity (OECD., 2023). This lead to increases in average PNM, having a record high of 16,471 and 19,044 net immigrants per 100,000 persons in 2018 and 2022 respectively. The UMICs sustained incremental improvements in the economy, whilst migratory trends stabilised and were overall negative PNM. However, the LMICs, despite making minimal economic improvements, showed a comparatively higher level of positive PNM. The same concept is observed for LICs, which remained challenged by stagnating economic growth, but displayed comparative positive PNM, indicating a higher rate of return migrants, coupled with less emigrants. Conversely, compared to the period of 1990 – 2006, all income groups indicate more positive PNM trends, with a reduction in net emigrants from 80 net emigrants to 10 net emigrants per 100,000 persons, even though the overall mean PNM for the whole period indicates a negative value. The effect the COVID-19 pandemic had can be observed as all the income groups indicate a drop in mean PNM, and

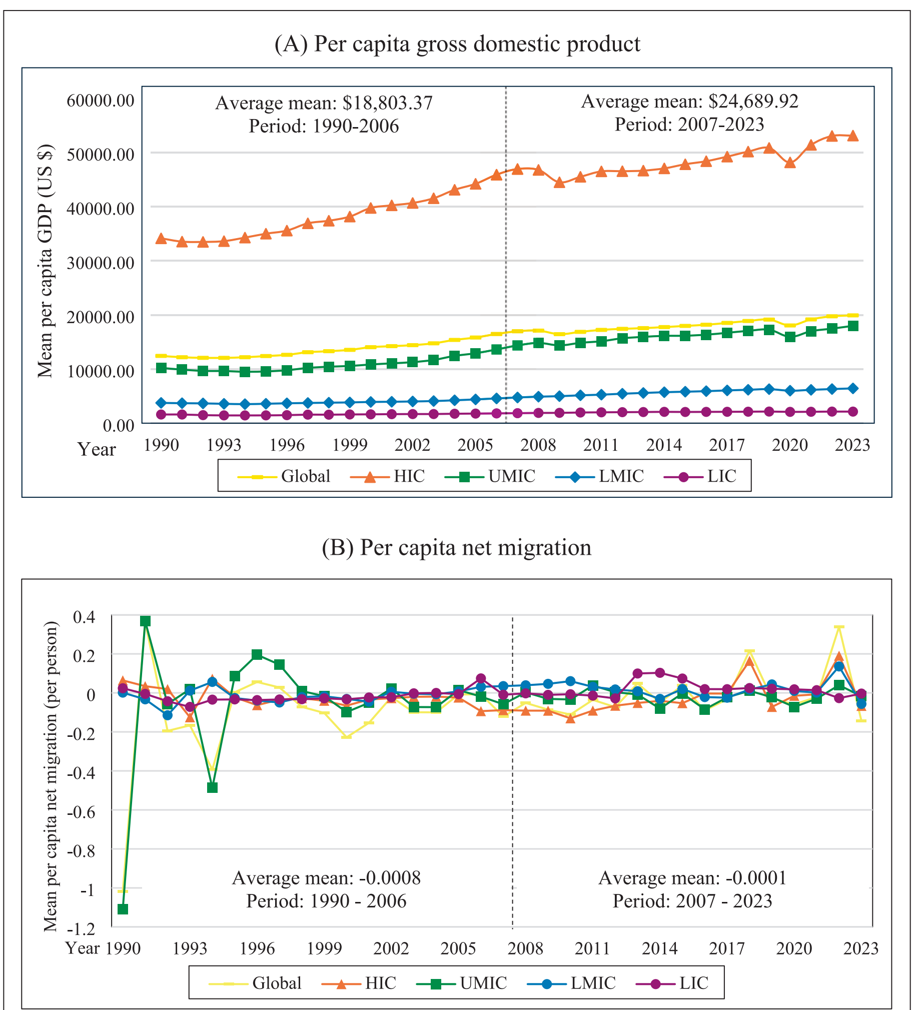

Fig. 4. Historical trend of mean PGDP and PNM.
Source: Authors' composition based on data from the World Bank (2024).

mean PGDP during 2019 and 2020.

Fig. 5 depicts a choropleth map visualising the changes in the mean values of PGDP and PNM, providing a more in-depth view of the individual countries within their respective income groups.

The HICs contain the highest percentage of countries which report positive PNM values in both periods. Certain countries like Nauru, Panama and Poland have experienced economic growth over 200 %. Contrastingly, Greece and Czechia faced reduction in economic growth in the latter period. In terms of recent migratory trends, the majority of HICs have faced an increase in PNM in the latter period. The HICs such as Kuwait, Singapore and Luxembourg exhibit strong increases in average PNM. However, countries like Qatar and United Arab Emirates

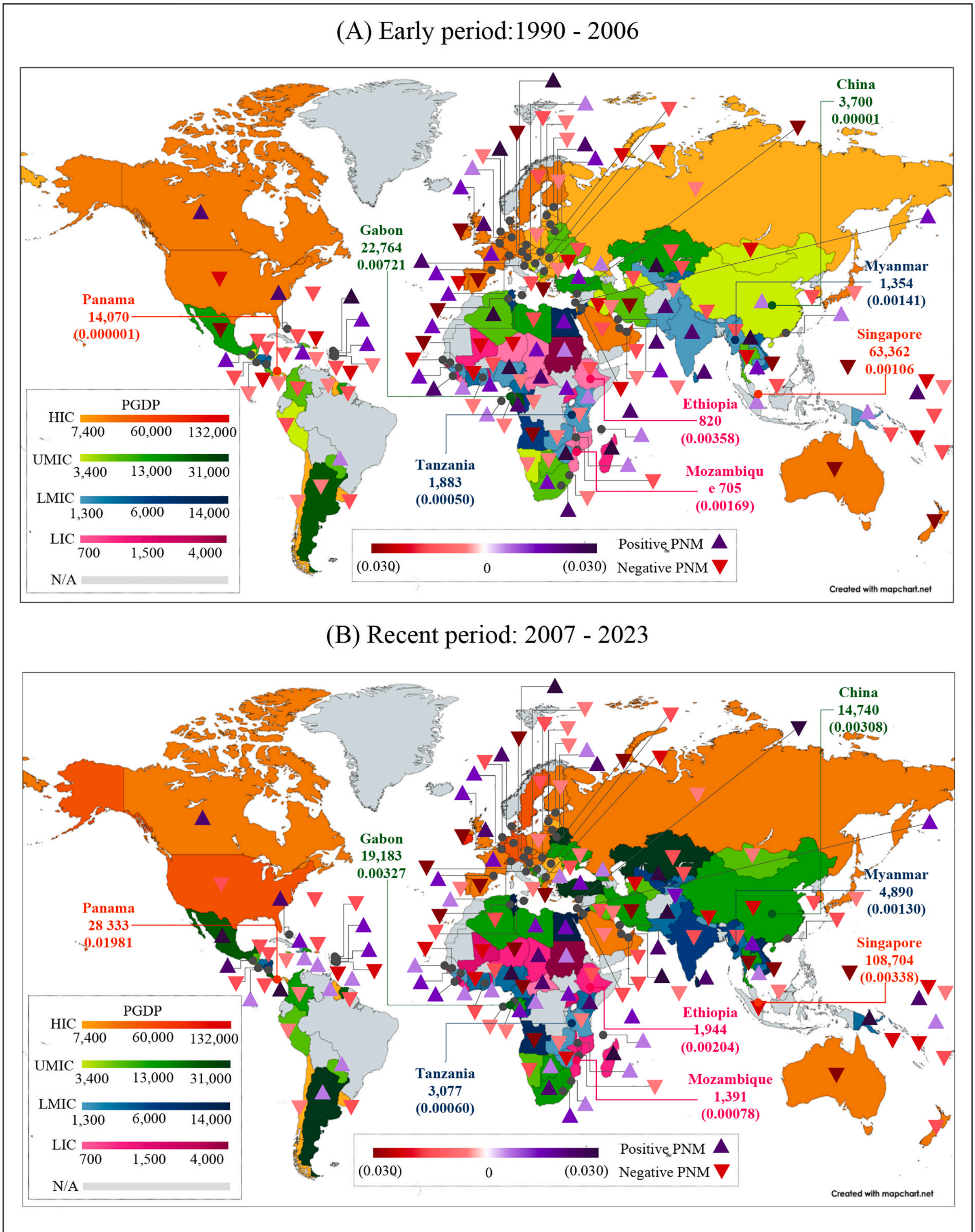

Fig. 5. Country level changes in mean PGDP and PNM based on World Bank data.
Source: Authors' composition using MapChart website (MapChart, 2024) based on World Bank (2024).

depict stark reductions in PNM, indicating a comparative outflow of migrants.

UMICs display an overall steady increase in PGDP for all countries. China faced significant growth, with PGDP increasing by approximately US$9800 in the second period. Migration on the other hand has slightly reduced by 20 to 30 % for almost all UMIC countries, except for Gabon, which displayed a 29 % increase in comparative inflow of migrants.

Similar to UMICs, majority of LMICs have trends of increases in PGDP, with notable increases for Tanzania and Myanmar. The LMICs also report an increase in the number of countries that showed negative mean PNM during the late period. Countries such as Benin and Cambodia have reported over a 100 % reduction in mean PNM during the late period, wherein migratory trends have changed from negative PNM to positive PNM.

The LICs, despite being characterised by lower PGDP, have demonstrated slight growth over the years. In particular, Ethiopia and Mozambique, have nearly doubled their income in the latter time period. with many countries suffering from economic stagnation. Simultaneously, despite maintaining negative PNM, migration outflows have steadily decreased, by approximately 40 % for majority of the LICs.

Overall, the maps demonstrate that economic strength in a country tends to have a big impact on migration patterns. Whereas most HICs and numerous UMICs recorded net positive migration, exceptions such as the United Arab Emirates and Qatar recorded declines, which demonstrate that policy or labor market forces were reversing. Some of the LMICs such as Cambodia and Benin transitioned from emigration to immigration, meaning people are immigrating into the country rather than out of it. In LICs, reduced out-migration alongside minimal PGDP growth is a sign of reversing socio-economic forces. The findings emphasise that while economic growth plays a crucial role, country-specific situations also shape migration responses. Consequently, the maps offer more precise details about how migration and growth are related in terms of both spatial and temporal aspects among income groups.

Stationarity, stability and lag selection

The stationarity results obtained using the Levin-Lin-Chu and Dickey-Fuller unit-root tests are detailed in the S3 Appendix and S4 Appendix. The nonstationary unit variables were differenced with a maximum of two difference limits to achieve stationarity while ensuring the clarity of result interpretation.

The cumulative summation (CUSUM) test was carried out using RStudio software to test the structural stability of the panel data. The

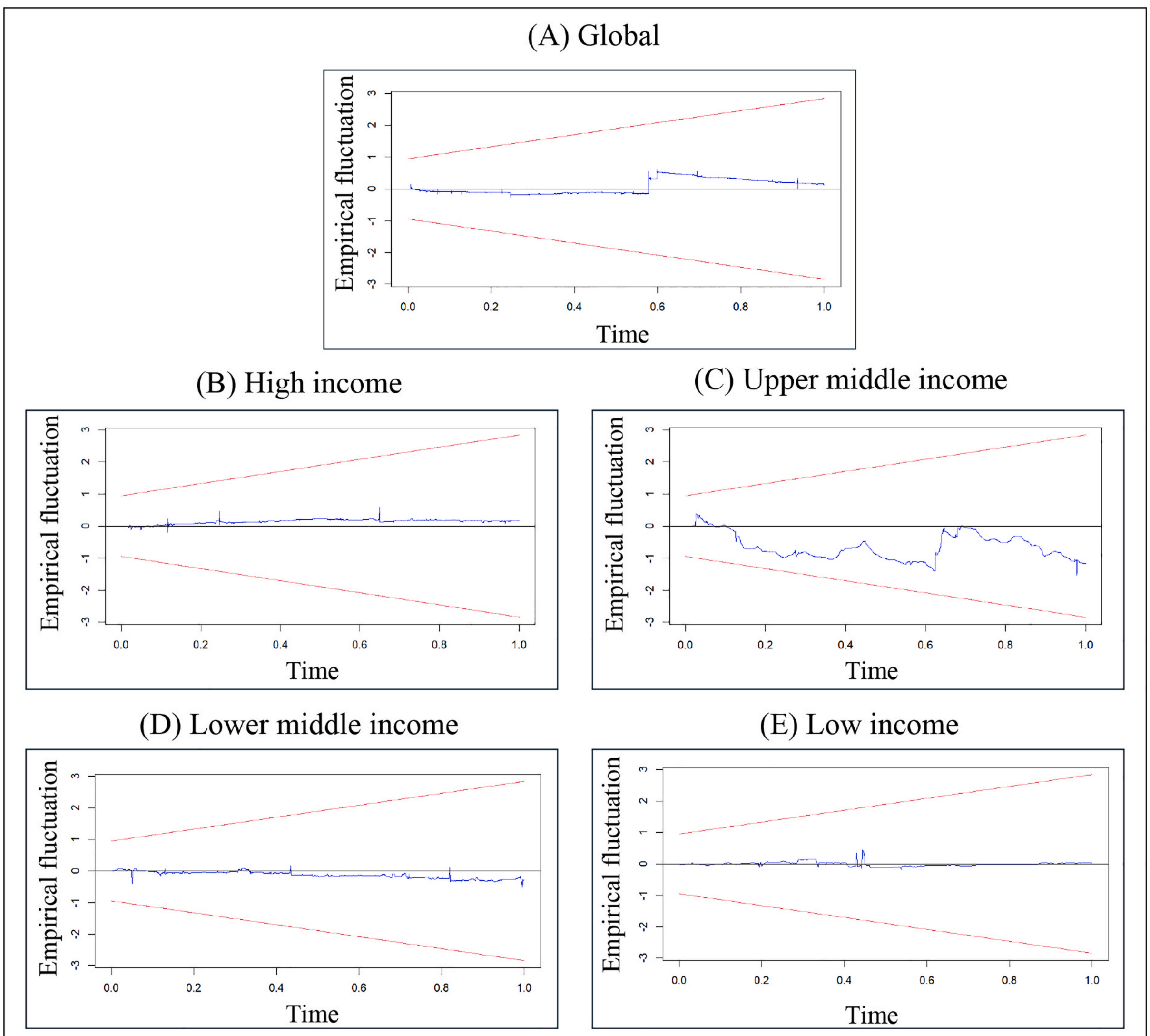

Fig. 6. Recursive CUSUM plots for the total period.
Source: Authors' composition using Posit Rstudio (2024).

recursive CUSUM plots for the total period are illustrated in Fig. 6.

Every single blue line running inside two red lines in Fig. 6(A), Fig. 6(B), Fig. 6(C), Fig. 6(D) and Fig. 6(E) imply the structural stability of the data of each respective panel. Further, the lag selection results of time series data are detailed in the S5 Appendix.

JKS non-causality analysis

The JKS non-causality test was carried out after the confirmation of the stability and stationarity of the panel data. The LJC heatmaps were used to depict the obtained JKS non-causality test results. Table 2 outlines interpretation guidance for LJC heatmaps for Granger causality.

The panel JKS non-causality results used in creating the LJC heatmaps are detailed in the S6 Appendix. Accordingly, Fig. 7 reveals long-term Granger causality patterns for the total period. The heatmap is horizontally, separated into two sections to clearly represent the respective covariance stationary and stable variables used to calculate the results.

The JKS non-causality tests revealed mostly similar causalities across the tested panels. The same length arrows across all panels indicate that aggregated optimal lag lengths are consistent. The global panel and all income group panels indicate statistically significant Granger causality from migration to economic growth, as indicated by the downward arrows and warm-coloured top circles. The LMIC panel indicates significant Granger causality between economic growth and migration making LMIC the only panel with a bidirectional causality. Notably, the LIC indicates comparatively the greatest effect on the causal relationship between net migration to economic growth. The heterogeneous nature of the observed results may reflect the unique push pull factors each panel contains and variances of migrant contributions.

Further, based on the country-level Granger causality results in the S7 Appendix, the proportions of the types of Granger causality across income groups are presented in Table 3. 14 countries were omitted during the Granger causality WALD test analysis as they did not meet the stationarity and stability requirements and are listed in S8 Appendix.

The relatively high proportion of countries that indicate no significant Granger causality in HICs and UMICs suggests that, at least within the timeframe and using this methodology, economic growth and migration are relatively independent, or that the relationship is more complex than captured by simple Granger causality.

Further, the increasing proportion of unidirectional causality from net migration to economic growth as income levels decrease potentially suggests that migration plays a more significant role in driving economic growth in countries with lower income levels. This could be due to remittances, brain gain effects, or the contribution of migrant labour to specific sectors.

The causal relationship from economic growth to net migration implies different levels of influence across income groups. In LICs, only 7.1 % have this causality, thereby suggesting that economic growth alone would not significantly impact the process of migration in low-income environments. In HICs and UMICs, 8.9 % and 8.6 % of the countries, respectively, had this causality, which suggests a modest effect of economic performance on migrant attraction or retention. LMICs experienced the largest percentage, with 13.9 % experiencing growth-oriented migration patterns, which ties in with the belief that high-end economies are able to pull in migrants with improved prospects and infrastructure.

On the other hand, 50 % figure for LICs indicating net migration leading economic growth is particularly significant. This highlights the potential vulnerability of these economies to changes in migration patterns. LMICs also show a relatively stronger trend, at 19.4 % in the same direction. In contrast to this, UMICs and HICs showed lesser percentages, at 8.6 % and 8.9 % respectively, indicating that in wealthier countries, migration could be less immediate or more complex in accelerating growth.

The relatively low proportion of bidirectional Granger causality across all income groups suggests that the relationship between economic growth and net migration is not strongly mutually reinforcing, at least not in a way that is consistently detectable by the Granger causality WALD test.

Table 2
Interpretation of LJC heatmap.

Axis		Interpretation / Description
X-axis	↔	Entity names
Y-axis	↕	Variable names (Name on the top – first variable, name on the bottom – second variable)
Arrows		**Interpretation / Description**
Downward arrows	↓	Unidirectional Granger causality from first variable to second variable.
Upward arrows	↑	Unidirectional Granger causality from second variable to first variable.
Bidirectional arrows	↕	Bidirectional Granger causality between variables.
Bidirectional arrows cut in the middle	⇞	No Granger causality between the variables.
Arrow length		The longer the arrow, the higher the number of lags used in the model.
Circles		**Interpretation / Description**
Top circle		Granger causality from first variable to second variable.
Bottom circle		Granger causality from second variable to first variable.
Warm colours		Results are statistically significant. (Red – 1 % significance, Orange – 5 % significance, Yellow – 10 % significance)
Cold colours		The results are not statistically significant. (Significance more than 10 %)
Circle size		The higher the circle size, the higher the z-bar tilde statistic value.

Source: Authors' composition.

Wavelet transform coherence analysis

The coherence and phase relationship between migration and economic growth were investigated using the WTC. To facilitate the analysis of different frequencies of panel data in multiple time domains, WTC analysis entailed creating WTC heatmaps. A detailed guide for interpreting WTC maps is given in Table 4.

Fig. 8 reveals the WTC between migration and economic growth of each panel under varying frequencies. It reveals time frequency nature of the economic growth and net migration variables.

An extensive understanding of the dynamic relationship between migration and economic growth can be obtained through WTC as it reveals insights in different periods under different frequencies.

Globally, varying degrees of coherence between changes in economic growth and net migration across different time scales can be observed. While short-term anti-phase. relationships appear sporadic, medium-term relationships are evident in the early 2000 s and from 2016 to 2019. Specifically in 2015, in-phase high frequency coherence can be observed. Significant anti-phase long-term coherences are also present where the PNM drives PGDP, indicating that global economic growth and net migration might be strongly connected over extended periods. However, as majority of the observed long-term coherences reside outside the COI, the results might be unreliable to confirm the long term the relationships.

In the HIC panel, short-term in-phase coherences are intermittent, while medium term relationships are evident in the early 2000 s and 2010–2021. The observed short-term coherence observations are consistent with the JKS Granger causality results. Similar to the global panel, in-phase coherences can be observed in medium term in HICs as well. However, the observed moderate long-term coherences are statistically insignificant for HICs indicating that the long-term coherences are not strong enough to rule out random variation as a plausible explanation for the findings.

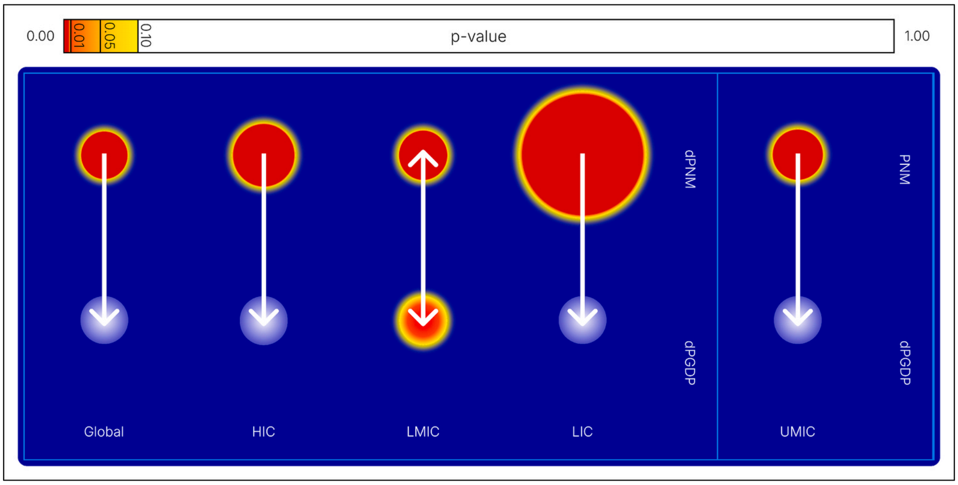

Fig. 7. LJC heatmap for JKS non-causality results.
Source: Authors' composition using the ljcheatmap website (Chloe, 2024).

Table 3
Granger causality income group-wise country proportions.

Category	No Granger causality		Unidirectional Granger causality				Bidirectional Granger causality		Total	
			Economic growth ↓ Net Migration		Net Migration ↓ Economic growth					
HIC	76.8 % 43.4 %	43	8.9 % 35.7 %	5	10.7 % 26.2 %	6	3.6 % 40.0 %	2	**100 %**	**56**
UMIC	77.1 % 27.3 %	27	8.6 % 21.4 %	3	8.6 % 13.0 %	3	5.7 % 40.0 %	2	**100 %**	**35**
LMIC	63.9 % 23.2 %	23	13.9 % 35.7 %	5	19.4 % 30.4 %	7	2.8 % 20.0 %	1	**100 %**	**36**
LIC	42.9 % 6.1 %	6	7.1 % 7.2 %	1	50.0 % 30.4 %	7	0.0 % 0.0 %	0	**100 %**	**14**
Total	**100 %**	**99**	**100 %**	**14**	**100 %**	**23**	**100 %**	**5**	**141**	

Note: The underlined percentages represent the proportion of the total countries in the income group, and non-underlined percentages represent the proportion of the countries that indicate the specific type of Granger causality. The number of countries is represented by the whole numbers.
Source: Authors' composition based on Granger causality WALD test results.

Further, UMICs show varying relationships between changes in economic growth and net migration across different time scales. Similar to HICs, in-phase short-term connections are frequent, while medium-term links appear in the late 1990 s and 2018 to 2021. Specifically in 2019, the observed medium-term coherences indicate an anti-phase relationship where PNM drives PGDP. Further, significant long-term relationship suggests that economic growth and net migration are likely to be closely related in upper-middle-income countries over the long term. However, in UMICs also, the observed long-term coherences reside outside the COI.

The WTC map for LMICs shows varied relationships between economic growth changes and net migration across different time scales. While short-term coherences are less frequent compared to the other panels, both upward and downward arrows appear in the medium-term indicates a bidirectional nature between economic growth and net migration in the medium-term.

Among the analysed panels, LICs exhibit the strongest coherence, with significant and recurrent medium-term relationships between economic growth and net migration. Moreover, the WTC heatmap reveals both in-phase and anti-phase upward and downward arrow patterns, suggesting bidirectional causality in the medium term. This bidirectional nature, however, was not detected by the JKS non-causality analysis.

Discussion

The findings from both JKS non-causality and WTC analyses underscore the intricate relationship between net migration and economic growth globally, offering critical insights into the dynamics of globalisation. Granger causality suggests that migration contributes to economic dynamism, possibly through means such as innovation, as immigrants bring human capital that enhances productivity and GDP growth (Alesina et al., 2016; Andronova & Ryazantsev, 2023). WTC analysis further reveals a significant long-term coherence between migration and economic growth, reflecting the delayed but substantial impact of migration on economies. This aligns with prior studies indicating that the integration of migrants into labour markets and their contributions to innovation take time to materialise (Sanderson, 2013).

While some areas of WTC heatmaps indicate statistically significant coherence, other relationships, such as certain long-term coherences globally and in HICs, reside outside the Cone of Influence or are statistically insignificant. The presence of intermittent or moderately significant short and medium-term relationships in across panels suggests that economic cycles and policy fluctuations can temporarily align migration flows with economic performance. The potential for long-term relationships (even if statistically weak in the WTC test or outside the COI in specific panels) remains economically important, reflecting structural factors like labour market integration or brain drain effects.

The finding that a relatively high proportion of countries show no

Table 4
Interpretation of WTC.

Axis		Interpretation / Description
X-axis	↔	Time
Y-axis	↕	The frequency of the oscillations
Arrows		**Interpretation / Description**
Rightward	→	In-phase
Leftward	←	Anti-phase
Rightward and up	↗	The second variable drives the first variable.
Rightward and down	↘	The first variable drives the second variable.
Leftward and up	↖	The second variable drives the first variable.
Leftward and down	↙	The first variable drives the second variable.
Colours		**Interpretation / Description**
0.7—1.0		High frequency. Stronger relationships.
0.3—0.7		Moderate frequency. Moderately stronger relationships
0.0—0.3		Low frequency. Weak or no relationship.
Scale		**Interpretation / Description**
Time scale (x axis)	<16	Correspond to short-term trends
	16—64	Correspond to medium-term trends
	>64	Correspond to long-term trends
Other		**Interpretation / Description**
White curve		The white curve around the edges of the plot is called the COI. Inside COI, the results are more reliable.
Black contour lines		The black contour lines indicate regions where the coherence is statistically significant based on the Monte Carlo simulations.

Source: Authors' composition is based on the interpretation table by Adebayo et al. (2020).

significant Granger causality warrants closer economic interpretation. While simple statistical predictability may be limited by this methodology within the study's timeframe, this does not diminish the fundamental economic significance of migration flows in these contexts.

In HICs, a high proportion of countries show no significant Granger causality (76.8 %), suggesting that the relationship between economic growth and migration is either more complex or less consistently a simple lead-lag predictability within the timeframe and methodology used. Among those with causality, 10.7 % show net migration leading economic growth. This generally positive association in HICs is supported by the observation that several countries in country-level analysis as countries such as Australia, Denmark, and the United States, exhibit a causal link from net migration to economic growth. This may reflect the attraction of skilled migrants to these economies, contributing to innovation and productivity gains (Noja et al., 2018). However, the presence of reverse causality in countries like Austria and Greece warrants further investigation. It could be indicative of return migration patterns responding to economic downturns, or the influence of other factors such as ageing populations. The low proportion of bidirectional causality (3.6 %) in HICs suggests the mutual reinforcement is not consistently strong across this group. Overall, these patterns in HICs exemplifies how developed economies leverage human capital flows to maintain their competitive edge in the globalised economy, though with varying degrees of mutual reinforcement depending on specific national contexts.

Further, WTC analysis corroborates these findings, indicating strong long-term coherence between migration and economic growth in HICs. However, short-term and medium-term relationships are intermittent, likely influenced by fluctuations in migration policies and economic cycles. As skilled immigration is particularly impactful in HICs, while unskilled immigration may have mixed effects depending on the context (Serban et al., 2020), these findings emphasise the importance of policies that attract skilled migrants while addressing challenges posed by unskilled labour inflows.

UMICs also show a high proportion of no significant causality (77.1 %), similar to HICs, suggesting complexity beyond simple Granger predictability for many countries in this group. Where causality is present, 8.6 % show net migration leading economic growth. WTC analysis supports these findings by revealing frequent short-term connections alongside strong long-term coherence. Further, deeper analysis conducted at the country level, into investigating causal relationships reveals some complexities. For instance, while the causality analysis indicates China, Jamaica, and Peru exhibit net migration leading to economic growth, aligning with the broader positive trend, countries such as North Macedonia, Paraguay and Ukraine demonstrate the reverse relationship where economic growth drives net migration, which might mean that skilled migration is drawn to bigger economic growth in these countries. This divergence underscores the need to consider country-specific factors like economic structure, policy environment, and integration strategies when assessing the impact of migration on economic growth in UMICs.

LMICs show a lower proportion of no significant causality (63.9 %) compared to higher-income groups, with higher proportions of unidirectional and bidirectional relationships. Net migration leads economic growth in 19.4 % of LMICs. This suggests a dynamic interplay between migration and economic growth. Economic growth attracts migrants seeking better opportunities, while migration can contribute to further growth through remittances, increased labour supply, and the transfer of skills and knowledge (Azam, 2015). This creates a reinforcing cycle that can drive economic development in these countries. The significant role of remittances and the interplay with brain drain in LMICs highlight the challenges and opportunities for these economies to achieve deeper integration into the global economy. Further, WTC analysis reveals a strong long-term relationship between migration and growth in LMICs. However, local conditions such as governance quality and policy frameworks influence the extent of these benefits. For instance, while remittances have spurred growth in some LMICs like Sri Lanka, they have had adverse effects in others like Ghana due to poor resource allocation (Adenutsi, 2011). Crucially, while remittances provide an economic gain, this must be weighed against the potential negative effects of brain drain, a critical concern in many LICs where skilled workers emigrate.

LICs exhibit the lowest proportion of no significant Granger causality (42.9 %) and the highest proportion of net migration leading economic growth (50.0 %) among the income groups. As LMICs, as these countries also highly depend on remittances, expose these economies to vulnerabilities such as informal transfer channels and underutilised funds (Shaw, 2007). WTC analysis also shows frequent short-term relationships between net migration and economic growth. Additionally, the mixed results observed in LICs underscore the complexity of the migration-growth nexus in these contexts. While the Granger causality WALD test results reveal a pattern of net migration leading to economic growth in countries like Ethiopia, Liberia, and Uganda, this does not necessarily imply a uniformly positive outcome. In these settings, brain drain may offset any potential benefits from remittances or increased labour supply (Lucas, 2006). Furthermore, factors such as political instability and weak institutional capacity could limit the ability of these countries to effectively leverage migration for economic development. Further, the finding that Sierra Leone exhibits PGDP leading to PNM might reflect the impact of economic hardship driving emigration. Policies aimed at retaining skilled workers while maximising remittance utilisation could mitigate these challenges.

Conclusion

This study explored the complex relationship between net migration and economic growth using Granger causality and WTC analysis at the global level, by income group, and for individual countries, thereby addressing the overarching research question and providing novel insights into the complex role of migration in shaping global economic integration. While both methods suggest a relationship between net migration and economic growth, they differ in their approach and the

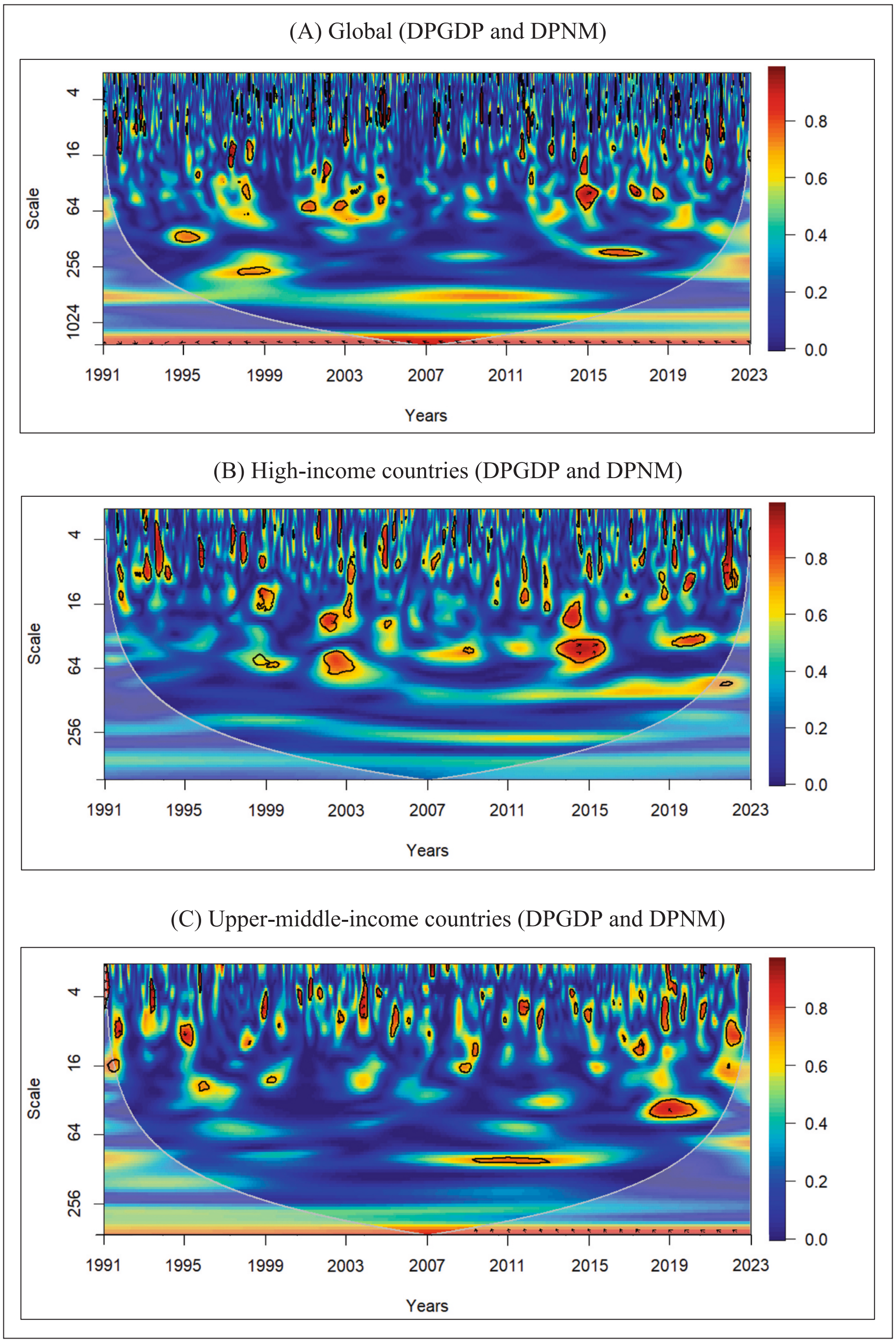

Fig. 8. Wavelet coherence: Net migration and economic growth.
Source: Authors' composition using Posit RStudio (2024).

specifics of what they measure. WTC heatmaps provide a visual representation of coherence across different time–frequency scales, while the JKS non-causality test offers a statistical framework for assessing Granger causality.

The similarity lies in the general direction of influence from migration to economic growth; however, the methods differ in their ability to capture bidirectional relationships and the explicit testing of causality. Combining Granger causality and WTC discussions provides a comprehensive understanding regarding to what extent net migration influences economic growth and vice versa.

The results revealed a unidirectional Granger causality from net migration to economic growth at the global level. This dynamic indicated similarities and variations across income groups, from bidirectional Granger causality in LMICs and unidirectional causality in HICs, UMICs, and LICs. Additionally, the WTC analysis further revealed time–frequency dynamics, gaining insight into when and how migration and economic growth relationships changed over time. Combined, the analysis reveals that migration's impact is multifaceted as it varies across income groups, depends on migrant skill composition, and evolves in response to global events such as crises or policy shifts. These varied dynamics highlight the differential impacts of globalisation on national economies, underscoring how human capital flows contribute to or mitigate global economic disparities, thus deepening the understanding of the effects of globalisation. Further, the results underscore

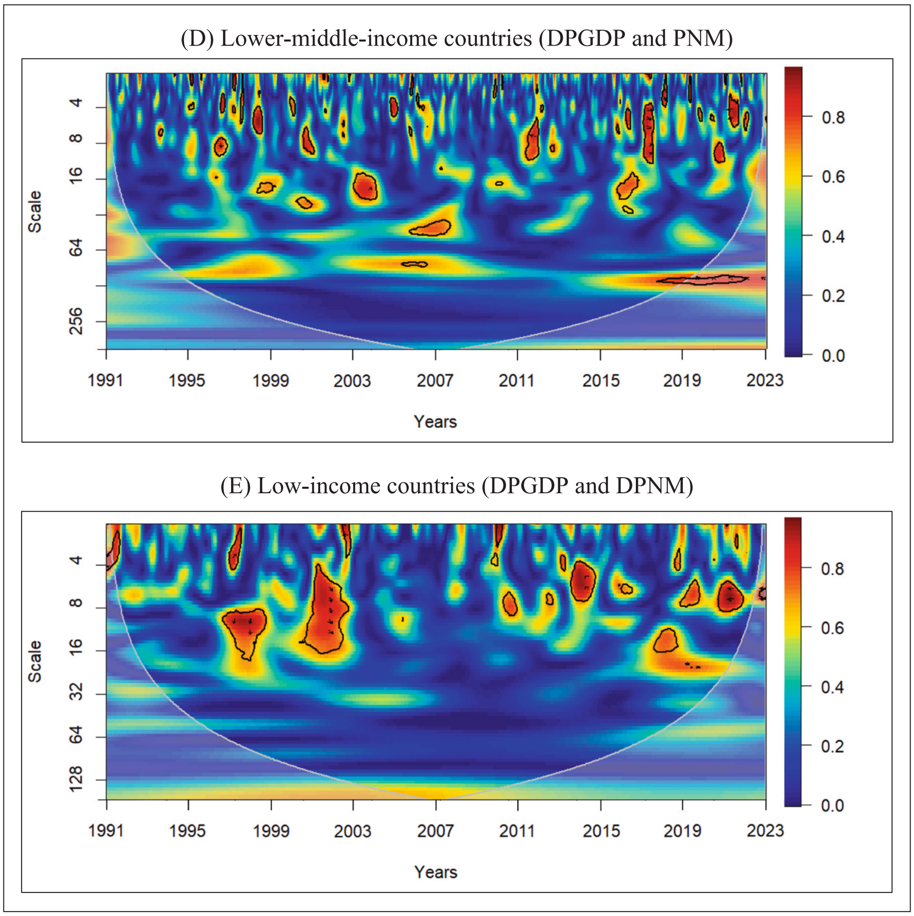

Fig. 8. (*continued*).

the need for policies tailored to each country's developmental stage.

While this study offers valuable insights in terms of the relationship between net migration and economic growth, potential endogeneity concerns, where migration and economic growth might simultaneously influence each other or be driven by unobserved factors, are not explicitly addressed by the methodologies as applied in this study. Future research could employ methods specifically designed to address potential endogeneity in panel data analysis of migration and economic growth along with robustness checks to ensure the consistency of the findings under different specifications or data subsets. Additionally, since a nation's placement in a particular income group fluctuates over time, the latest data from 2023 was used to make the classification. Further, analytical model-specific limitations such as assumptions of stationarity, requirements for balanced panels, and restrictions on the relationship between N and T are present in this study. Therefore, future research should explore the complex impacts of specific migration policies on economic growth across different income groups, considering factors like migrant integration, remittance utilisation, and brain drain mitigation. Further investigation into the causal mechanisms and long-term effects is also needed.

Policy recommendations

The analysis results suggest considering the income and time–frequency-dependent nature of the relationship between migration and economic growth when designing policies.

Global

Both Granger causality and WTC analysis results emphasise the need for coordinated migration policies between countries. Initiatives such as bilateral agreements for skill matching or multilateral frameworks for managing refugee movements can bring mutual benefits.

Further, policymakers are advised to adopt differentiated strategies based on income levels focusing on attracting talent in HICs while addressing the brain drain in LICs to optimise migration's developmental impact globally.

High-income countries

Based on the Granger causality results showing that net migration drives economic growth, HICs should implement targeted immigration policies to attract high-skilled workers. This includes streamlining visa processes, recognising foreign qualifications, and offering incentives like tax breaks or permanent residency for skilled migrants.

Additionally, WTC results highlight the importance of long-term coherence between net migration and economic growth. HICs should focus on integration policies such as language training, cultural orientation, and job placement programs to ensure migrants' contributions are maximised over time.

To leverage the intermittent short and medium-term relationships observed in WTC analysis, HICs should match migrant skills with labour market needs dynamically. This can be achieved through regular skills assessments and partnerships with origin countries to align workforce supply and demand.

Upper-middle-income countries

As Granger causality indicates net migration's positive impact on economic growth in UMICs, policies should encourage the inflow of skilled workers and facilitate the return of emigrants. Returnees should be incentivised through tax benefits or grants to invest their skills and resources locally.

Additionally, WTC results indicate frequent short-term coherences between net migration and growth. UMICs should capitalise on this by promoting policies that integrate migrants into diverse sectors of the economy, reducing poverty while boosting productivity.

The countries facing negative impacts from emigration, policies should focus on retaining skilled workers through competitive wages and career development opportunities while fostering diaspora engagement for knowledge and technology transfer.

Lower-middle-income countries

LMIC Governments should reduce remittance transfer costs and channel these funds into productive investments like education, infrastructure, and small businesses as Granger causality results highlight the critical role of net migration in those countries' economic growth.

Further, implementing skill-building programs aligned with global labour market demands to ensure that emigrants secure higher-paying jobs abroad while contributing to remittance flows.

In addition, in order to maximise the benefits of returnees, LMICs should create reintegration programs that help returnees utilise their skills effectively through entrepreneurship grants or preferential access to loans.

Low-income countries

As LICs rely heavily on remittances for economic growth, governments should formalise remittance channels to increase their impact on development outcomes such as education and healthcare.

WTC results highlight the detrimental effects of brain drain in LICs. Policies should focus on retaining skilled workers through improved working conditions and wages while fostering international partnerships to upskill workers for global markets without losing domestic capacity.

Given the short-term relationships observed in WTC analysis for LICs, governments should formalise seasonal migration programs with destination countries to ensure predictable income flows while minimising long-term skill loss.

By aligning these recommendations with empirical findings from Granger causality and WTC analyses, policymakers can design evidence-based strategies that maximise migration's potential as a driver of economic growth across diverse contexts.

CRediT authorship contribution statement

Pramoda Dissanayake: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Lucius Chloe:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation. **Yusra Azmi:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Formal analysis. **Shamen Landersz:** Writing – review & editing, Writing – original draft, Visualization, Validation, Data curation. **Ruwan Jayathilaka:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resglo.2025.100305.

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