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Migration and Short-Run Macroeconomic Adjustment across Energy Environments

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Research Article

Keywords: net migration, energy intensity, macroeconomic adjustment, labor productivity, labor utilization

Posted Date: November 13th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11443875/v1

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Additional Declarations: No competing interests reported.

Migration and Short-Run Macroeconomic Adjustment across Energy Environments

Abstract

This paper examines whether short-run macroeconomic adjustment to net migration varies with predetermined energy intensity. Using annual data for 128 countries over 2005–2022, we estimate panel local projections and decompose GDP per capita into hourly productivity, working time, and employment relative to population. Higher net migration is associated with a temporary decline in GDP per capita at average energy intensity, with a significantly less negative association in more energy-intensive economies. This differential primarily reflects aggregate output, with working time providing a consistent adjustment margin. However, the interaction becomes small and insignificant after excluding migration observations outside the first–ninety-ninth percentiles and changes sign under wider trimming. Excluding Ukraine's 2022 observation also reduces precision. Differences across migration directions and development groups are insignificant. The estimates describe conditional associations sensitive to exceptional migration episodes, without establishing causal effects.

Keywords: net migration; energy intensity; macroeconomic adjustment; labor productivity; labor utilization
JEL codes: F22; J61; O47; Q43

1. Introduction

Large migration movements require economies to adjust employment, working time, capital, and production, often within relatively short periods. Their implications for income per capita depend on how rapidly additional workers enter productive employment, how firms adjust capacity, and whether productivity responds. These adjustment margins may be particularly important in emerging and developing economies, where migration flows can be substantial relative to the domestic population and productive constraints may limit the speed of adjustment.

Existing evidence points to heterogeneous economic responses to migration. Studies of major immigration episodes document substantial labour-market adjustment through occupational specialization, firm expansion, and technological change (Card, 1990; Friedberg, 2001; Beerli et al., 2021). Broader evidence also links immigration to productivity and income growth (Peri, 2012; Ortega and Peri, 2014; Boubtane et al., 2016). However, Engler et al. (2023) find more favourable macroeconomic responses in OECD economies than in emerging and developing countries experiencing refugee inflows. These findings suggest that the consequences of migration depend not only on migrant characteristics but also on the productive environment of receiving economies.

This paper investigates one potentially important source of heterogeneity: predetermined energy intensity. Energy is a complementary input to capital, infrastructure, transport, and many production activities, yet energy use per unit of output differs considerably across countries. These differences reflect industrial specialization, production technologies, installed capacity, infrastructure, climate, and energy efficiency. Economies with substantial energy-using capital may accommodate changes in labour supply through adjustments in operating hours and capacity utilization, whereas others may rely more heavily on employment reallocation or subsequent capital accumulation. Energy intensity is therefore interpreted as a broad indicator of inherited production structures, not as a direct measure of efficiency or an intrinsically desirable economic characteristic.

We address two questions. Does the short-run association between net migration and GDP per capita vary with initial energy intensity? If so, which productivity and labour-utilization margins account for this heterogeneity? We also examine aggregate output and population adjustment, alongside complementary evidence on capital intensity, total factor productivity (TFP), human capital, and investment.

Our analysis uses annual data for up to 128 countries over 2005–2022, combining the Penn World Table and World Development Indicators. Net migration is measured relative to lagged population, while energy intensity is averaged over 2000–2004, preceding the estimation period. We estimate panel local projections (Jordà, 2005) with country and year fixed effects and lagged controls. A central feature is an exact accounting decomposition of GDP per capita into output per hour, hours worked per employee, and employment relative to population. Common samples and regressors ensure that the estimated contributions sum to the aggregate association. An additional decomposition distinguishes aggregate GDP from population adjustment.

The paper makes three contributions. First, it introduces predetermined energy intensity as a conditioning characteristic in the analysis of dynamic macroeconomic adjustment to migration, complementing research emphasizing migrant composition and labour-market institutions. Second, it combines local projections with exact

productivity–hours–employment and GDP–population decompositions, revealing adjustment margins obscured by aggregate income measures. Third, it examines the importance of migration magnitude and direction, distinguishing ordinary fluctuations from unusually large population movements and assessing the sensitivity of the results to influential episodes.

The results indicate that higher net migration is associated with a temporary decline in GDP per capita at average initial energy intensity, but this association becomes significantly less negative in more energy-intensive economies. At horizon one, the migration–energy-intensity interaction is 0.475, implying a 0.475-percentage-point more favourable GDP-per-capita association for a one-standard-deviation increase in initial energy intensity, conditional on a one-percentage-point increase in the net migration rate. The decomposition identifies a relatively consistent contribution from hours worked, alongside a larger but less precisely estimated hourly-productivity component. Importantly, the differential GDP-per-capita association primarily reflects aggregate-output rather than population adjustment. Supplementary estimates provide some evidence of TFP adjustment but little systematic support for capital deepening or investment.

These findings are subject to important qualifications. The positive interaction survives several alternative specifications and regional exclusions but weakens when extreme migration observations are removed and becomes less precisely estimated following the exclusion of Ukraine's 2022 episode. Formal tests also fail to establish systematic differences between immigration and emigration or between advanced and developing economies. Moreover, migration is not externally identified, and predetermined energy intensity may capture correlated structural characteristics. The estimates therefore describe conditional associations rather than causal effects. Their principal implication is that inherited production environments contain information about how economies adjust to major population movements, without implying that greater energy intensity is desirable.

The analysis complements related work on natural population growth, land scarcity, and structural transformation, while focusing specifically on net migration and short-run adjustment across energy environments. Section 2 reviews the literature, Section 3 presents the empirical framework, Section 4 describes the data, Section 5 reports the results, and Section 6 concludes.

2. Literature review

The economic consequences of migration depend not only on the substitutability between migrants and incumbent workers but also on adjustments in labour demand, occupational specialization, capital accumulation, and technology. These general-equilibrium responses help explain why estimated labour-market effects vary across settings, time horizons, and identification strategies (Dustmann et al., 2016; Peri, 2016). Evidence from major migration episodes illustrates this heterogeneity. Card (1990) and Friedberg (2001) find limited adverse effects on native labour-market outcomes following large inflows into Miami and Israel, respectively. Using Denmark's refugee-dispersal policy, Foged and Peri (2016) show that less-skilled natives shifted towards less manual-intensive occupations, improving wages and employment. Beerli et al. (2021) document

increases in employment, firm size, productivity, and innovation following greater access to cross-border workers in Switzerland.

Migration can also alter production techniques and aggregate productivity. Lewis (2011) finds that US manufacturing plants exposed to larger inflows of less-skilled immigrants adopted less automation-intensive production methods. Peri (2012) links immigration to productivity growth and task specialization across US states, while Ortega and Peri (2014) associate immigration openness with higher long-run income per capita. Alesina et al. (2016) find that birthplace diversity is positively associated with economic prosperity, particularly where skilled migrants complement domestic workers. These studies suggest that migration adjustment involves changes in productive organization rather than simply movements along a fixed labour-demand curve.

Cross-country evidence provides a closer benchmark for the present analysis. Boubtane et al. (2016) find positive contributions of immigration and migrants' human capital to economic performance in OECD countries. Engler et al. (2023), using instrumental-variable local projections, identify increases in output and productivity following large immigration waves in OECD economies but obtain less conclusive results for refugee movements into emerging and developing economies. Our analysis complements this work by examining whether predetermined energy intensity helps explain cross-country differences in adjustment and by decomposing GDP per capita into productivity, working time, and employment components. Unlike Engler et al. (2023), however, migration is not instrumented, and our estimates are interpreted as conditional associations. Moreover, because net migration includes both immigration and emigration, we examine directional asymmetries and the importance of unusually large population movements. This distinction is relevant given the additional dynamics associated with temporary and return migration (Dustmann and Görlach, 2016).

A second literature examines energy as an input into production and a determinant of economic performance. Stern (2011) emphasizes the productive role of energy and the importance of substitution and technological change, while Stern and Enflo (2013) document long-run relationships between energy, energy quality, and output. However, energy intensity—the amount of energy required per unit of output—is not a pure indicator of technical efficiency. Csereklyei et al. (2016) document substantial international variation in energy intensity and its evolution with development. Sue Wing (2008) and Mulder and de Groot (2012) show that changes in sectoral composition and within-sector efficiency both contribute to energy-intensity dynamics. Consequently, inherited energy intensity reflects a combination of industrial specialization, technology, infrastructure, and other structural characteristics.

Production-function evidence provides a potential link between energy environments and migration adjustment. Van der Werf (2008) finds that substitution possibilities among capital, labour, and energy differ from restrictive assumptions commonly imposed in applied models, while Koetse et al. (2008) document substantial heterogeneity in capital–energy substitution elasticities. These findings suggest that the ability to reorganize production following changes in labour supply may depend on inherited input combinations and productive capacity. Economies with different energy intensities may therefore adjust through different combinations of employment, working hours, capital utilization, and productivity. This interpretation does not imply that greater energy intensity is desirable or that it independently causes more favourable adjustment.

Research directly connecting migration and energy remains relatively limited. Abbas et al. (2024) use a multiregional general-equilibrium framework to examine how skilled migration affects production, welfare, energy consumption, and emissions. Whereas their analysis focuses on the consequences of migration for energy demand, the present paper investigates whether the inherited energy environment is associated with subsequent macroeconomic adjustment to migration. In this respect, it also complements related work on natural population growth, land scarcity, and structural transformation, while focusing on short-run net migration rather than longer-run demographic pressure.

Taken together, these literatures motivate a dynamic empirical approach that distinguishes aggregate income from its productivity and labour-utilization components and treats predetermined energy intensity as a conditioning characteristic rather than an exogenous mechanism. The resulting framework examines whether inherited production environments help explain heterogeneous adjustment to migration, particularly during large population movements.

3. Conceptual and empirical framework

3.1. Macroeconomic Adjustment and Accounting Decomposition

Migration can influence income per capita through changes in employment, working time, capital utilization, and productivity. These margins need not adjust simultaneously: employment and hours may respond relatively quickly, while capital accumulation and technological adaptation generally take longer. The inherited production environment may influence both the speed and composition of adjustment. Energy intensity captures differences in industrial specialization, installed capital, infrastructure, and production technologies that may affect how economies accommodate population movements. It is treated as a broad structural characteristic rather than a direct measure of energy efficiency or productive capacity.

Let Y_{it} denote real output, P_{it} population, H_{it} total hours worked, and E_{it} employment. GDP per capita satisfies the accounting identity:

$$\frac{Y_{it}}{P_{it}} = \frac{Y_{it}}{H_{it}} \times \frac{H_{it}}{E_{it}} \times \frac{E_{it}}{P_{it}} \qquad (1)$$

The three components represent output per hour, hours worked per employee, and employment relative to population. Taking logarithms and cumulative changes gives:

$$\Delta_h \ln(Y/P)_{i,t+h} = \Delta_h \ln(Y/H)_{i,t+h} + \Delta_h \ln(H/E)_{i,t+h} + \Delta_h \ln(E/P)_{i,t+h} \qquad (2)$$

where, for any variable z,

$$\Delta_h \ln z_{i,t+h} = 100\left[\ln z_{i,t+h} - \ln z_{i,t-1}\right], \quad h \in \{0,1,2,3,5\}. \qquad (3)$$

This identity separates hourly productivity, intensive labour utilization, and the extensive employment margin. When estimated using identical samples and regressors, the coefficients for these components sum exactly to those for GDP per capita. We also exploit the complementary identity linking GDP per capita, aggregate GDP, and population to distinguish production adjustment from demographic changes.

3.2. Predetermined Energy Intensity and Empirical Specification

For each country, initial energy intensity is measured using the average energy intensity observed during 2000–2004, before the estimation period:

$$\widetilde{EI}_i^0 = \ln\left(\frac{1}{n_i}\sum_{s\in T_i}\text{EnergyIntensity}_{is}\right). \qquad (4)$$

where $\mathcal{T}_i$ denotes the available years during 2000–2004 and $n_i \geq 3$ is the number of observations. We standardize the resulting logarithmic measure across countries to have mean zero and unit standard deviation, denoting the standardized variable by EI_i^0. This is the measure used in all migration–energy-intensity interactions. Although predetermined, it may remain correlated with persistent structural characteristics.

Following Jordà (2005), we estimate panel local projections for each outcome z and horizon h:

$$\begin{aligned}\Delta_h \ln z_{i,t+h} = \quad & \alpha_{i,h} + \lambda_{t,h} + \beta_h m_{it} + \gamma_h (m_{it} \times EI_i^0) \\ & + \sum_{k=1}^{2} \theta_{h,k}\, m_{i,t-k} + \sum_{q=1}^{3}\sum_{k=1}^{2} \rho_{h,q,k}\, g_{q,i,t-k} + \varepsilon_{i,t+h}.\end{aligned} \qquad (5)$$

Here m_{it} is net migration as a percentage of population in $t-1$, $\alpha_{i,h}$ and $\lambda_{t,h}$ denote country and year fixed effects, and $g_{q,it}$ represents annual growth in each accounting component: output per hour, hours per employee, and employment relative to population. All baseline decomposition regressions include the same two lags of migration and of the three components, ensuring coefficient additivity. Supplementary mechanism regressions instead include two lags of migration and two lags of the corresponding outcome's growth rate.

Because initial energy intensity is time invariant, its level is absorbed by country fixed effects. The conditional association between migration and the cumulative outcome at standardized energy intensity e is:

$$\frac{\partial \Delta_h \ln z_{i,t+h}}{\partial m_{it}} = \beta_h + \gamma_h e. \qquad (6)$$

Thus, β_h measures the migration association at mean initial energy intensity, while γ_h captures how it varies with a one-standard-deviation increase in that characteristic. A positive interaction indicates a more favourable association at higher energy intensity, but does not necessarily imply a positive total response.

3.3. Decomposition, Inference, and Interpretation

Applying the same local-projection specification to the accounting components yields an exact decomposition of the interaction coefficient:

$$\gamma_h^{Y/P} = \gamma_h^{Y/H} + \gamma_h^{H/E} + \gamma_h^{E/P}. \qquad (7)$$

An equivalent relationship holds for the migration coefficient β_h. The complementary decomposition of GDP per capita into aggregate output and population follows the same principle:

$$\gamma_h^{Y/P} = \gamma_h^{Y} - \gamma_h^{P}. \qquad (8)$$

These identities describe the accounting composition of estimated associations, rather than separately identified causal mechanisms. All accounting equations use common estimation samples at each horizon. Statistical inference relies on standard errors clustered by country.

The local projections are interpreted as conditional dynamic associations, not causal impulse responses. Migration may respond to economic conditions, conflict, policy, and other developments that also affect macroeconomic outcomes. Country and year fixed effects, lagged controls, and predetermined energy intensity do not eliminate these concerns. Furthermore, energy intensity may proxy for income, industrial specialization, or energy-exporter status. We therefore examine alternative controls and energy measures, regional and country exclusions, development-group heterogeneity, and placebo specifications.

Finally, because net migration is highly unevenly distributed, the analysis distinguishes ordinary observations from exceptionally large inflows and outflows using winsorization, trimming, and regime-specific interactions. These exercises assess whether the estimated heterogeneity characterizes typical migration fluctuations or is concentrated in major demographic episodes.

4. Data and stylized facts

4.1 Data and measurement

The analysis combines annual data from the Penn World Table (Feenstra et al., 2015) and the World Development Indicators (WDI), covering 128 countries over 2005–2022. The descriptive sample contains 2,303 country-year observations, while the common annual-growth decomposition sample comprises 2,242 observations. Coverage varies across projection horizons and supplementary outcomes. Variable definitions and summary statistics are reported in Appendix Table A1, while horizon-specific estimation samples, including the corresponding migration and outcome years, are documented in Appendix Table A5.

Real GDP, population, employment, hours worked, capital, total factor productivity, human capital, and investment are obtained from the Penn World Table. GDP per capita is decomposed into output per hour, hours worked per employee, and employment relative to population. Net migration, obtained from WDI, is expressed as a percentage of lagged population.

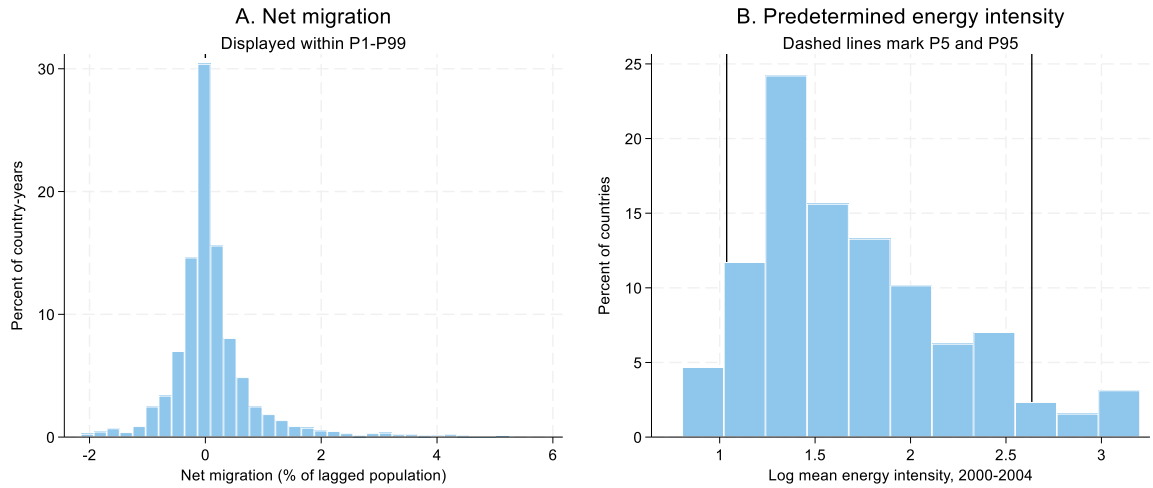
Predetermined energy intensity is measured as primary-energy use in megajoules per 2017 PPP dollar of GDP. For each country, we average at least three available observations over 2000–2004, take the logarithm, and standardize the resulting measure across countries. This predetermination limits contemporaneous mechanical feedback from migration and output, although energy intensity remains a broad indicator of inherited production structures rather than an exogenous measure of productive capacity.

4.2 Stylized facts

Figure 1 illustrates the distributions of net migration and predetermined energy intensity. Annual net migration averages 0.197% of lagged population, with a median close to zero (−0.005%) and a standard deviation of 1.474 percentage points. Its distribution exhibits pronounced tails: the first and ninety-ninth percentiles are −2.152% and 5.242%, respectively, while the full range extends from −12.866% to 25.256%. The baseline analysis retains these extreme observations, with their influence assessed separately in Section 5.

Migration also varies substantially within countries. Its within-country standard deviation is 1.141 percentage points, compared with 0.936 between countries, and 58.6% of countries record both positive and negative net migration during the sample period. These features provide variation for estimating interactions between migration and predetermined country characteristics.

Figure 1. Support of net migration and predetermined energy intensity



Notes: Panel A shows net migration as a percentage of lagged population, excluding observations outside the first and ninety-ninth percentiles from the display only. Panel B shows the distribution of country-level log average energy intensity over 2000–2004. Dashed lines indicate the fifth and ninety-fifth percentiles. All observations remain eligible for the baseline regressions.

Initial energy intensity also exhibits substantial cross-country variation, ranging from 2.234 to 24.590 megajoules per 2017 PPP dollar of GDP, with a median of 5.030. In the common annual-growth sample, average GDP-per-capita growth is 2.079%, comprising growth of 1.777% in output per hour, −0.149% in hours per worker, and 0.450% in employment relative to population. These components satisfy the accounting identity up to rounding.

5. Empirical results

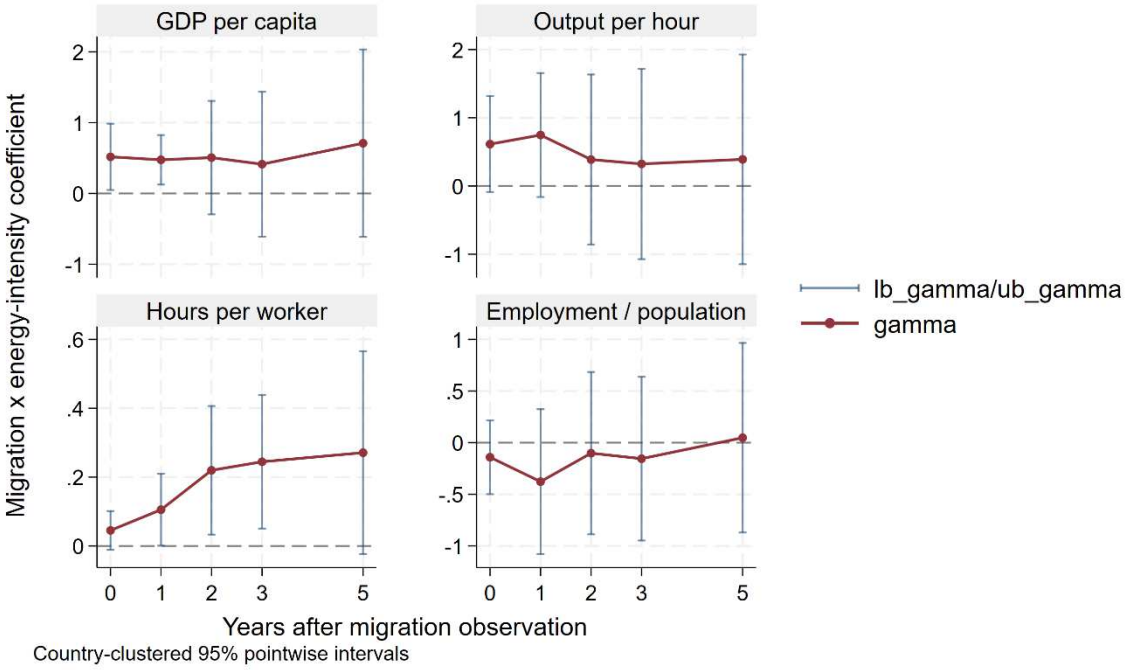
5.1. Baseline Dynamic Responses and Accounting Decomposition

Figure 2 and Table 1 report the dynamic associations between net migration and GDP per capita across predetermined energy environments, together with the accounting decomposition into output per hour, hours worked per employee, and employment relative to population. At average initial energy intensity, a one-percentage-point increase in net migration is associated with a decline in GDP per capita of 0.372 percentage points after one year ($p = 0.036$). The coefficient remains negative at horizon two (−0.467) but is not statistically significant, and the estimates provide little evidence of a persistent negative association at longer horizons.

The central finding is a positive migration–energy-intensity interaction, statistically significant on impact (0.518, $p = 0.031$) and after one year (0.475, $p = 0.008$). The latter implies that a one-standard-deviation increase in initial log energy intensity is associated with a 0.475-percentage-point more favourable GDP-per-capita response to a one-percentage-point increase in net migration. Although the interaction remains positive at longer horizons, its confidence intervals include zero. The evidence for heterogeneous adjustment is therefore strongest in the short run.

The implied marginal associations vary considerably across the energy-intensity distribution (Appendix Figure A1). At horizon one, a one-percentage-point increase in net migration is associated with a GDP-per-capita decline of 0.708 percentage points at the twenty-fifth percentile of initial energy intensity, compared with 0.129 percentage points at the seventy-fifth percentile. The former estimate is statistically significant, whereas the latter is not. The positive interaction therefore primarily reflects an attenuation of the negative short-run association rather than evidence of a positive GDP-per-capita response in more energy-intensive economies.

Figure 2. Dynamic interaction between migration and initial energy intensity



Notes: Estimated migration–energy-intensity interaction at horizons 0, 1, 2, 3 and 5. Outcomes are cumulative log changes multiplied by 100. The vertical bars show pointwise 95% confidence intervals based on country-clustered standard errors. All regressions include country and year fixed effects and identical lagged controls across the four accounting outcomes.

The accounting decomposition in Table 1, Panel B, indicates that the horizon-one interaction of 0.475 comprises contributions of 0.747 from output per hour, 0.105 from hours worked per employee, and −0.378 from employment relative to population. Although the hourly-productivity component is economically larger, it is imprecisely estimated ($p = 0.106$). By contrast, the interaction involving hours worked per employee is statistically significant at horizons one through three. The employment-to-population component is negative at shorter horizons but statistically insignificant. Thus, working time emerges as the most consistently estimated margin of differential adjustment, while hourly productivity may also contribute substantially.

Together, these findings indicate that predetermined energy intensity is associated with heterogeneous short-run GDP-per-capita adjustment, particularly through labour utilization and potentially hourly productivity. The next subsection distinguishes aggregate-output from population adjustment and examines additional macroeconomic mechanisms.

Table 1. Dynamic migration associations and accounting decomposition

Panel A. Migration coefficient at average predetermined energy intensity

Outcome	*h = 0*	*h = 1*	*h = 2*	*h = 3*	*h = 5*
GDP per capita	0.043	−0.372**	−0.467	−0.391	0.113
Standard error	(0.178)	(0.175)	(0.374)	(0.439)	(0.467)
Output per hour	−0.165	−0.862*	−1.579**	−1.442*	−0.695
Standard error	(0.307)	(0.496)	(0.652)	(0.739)	(0.749)
Hours per worker	−0.025	−0.004	0.120*	0.099	0.164
Standard error	(0.031)	(0.047)	(0.069)	(0.068)	(0.099)
Employment/population	0.233	0.494	0.992**	0.951*	0.645
Standard error	(0.202)	(0.431)	(0.484)	(0.497)	(0.504)

Panel B. Migration × predetermined energy-intensity coefficient

Outcome	*h = 0*	*h = 1*	*h = 2*	*h = 3*	*h = 5*
GDP per capita	0.518**	0.475***	0.506	0.413	0.709
Standard error	(0.237)	(0.177)	(0.405)	(0.517)	(0.669)
Output per hour	0.613*	0.747	0.388	0.324	0.391
Standard error	(0.355)	(0.459)	(0.630)	(0.705)	(0.777)
Hours per worker	0.045	0.105**	0.220**	0.245**	0.271*
Standard error	(0.028)	(0.053)	(0.094)	(0.098)	(0.149)
Employment/population	−0.141	−0.378	−0.102	−0.155	0.048
Standard error	(0.181)	(0.355)	(0.397)	(0.401)	(0.464)
Component sum	0.518	0.475	0.506	0.413	0.709
Observations	2,120	2,119	1,991	1,863	1,607
Countries	128	128	128	128	128

Notes: Dependent variables are cumulative changes between \(t-1\) and \(t+h\), multiplied by 100. Panel A reports the migration coefficient at mean initial energy intensity. Panel B reports the interaction coefficient. All regressions include country and year fixed effects, two lags of migration and two lags of growth in each of the three accounting components. Each horizon uses a common sample across outcomes. Country-clustered standard errors underpin the significance indicators. ***, ** and * denote significance at the 1%, 5% and 10% levels, respectively.

5.2. Aggregate Output, Population, and Adjustment Mechanisms

The baseline results raise the question of whether heterogeneity in GDP-per-capita adjustment primarily reflects aggregate production or population changes. Table 2 addresses this distinction by decomposing cumulative GDP-per-capita growth into aggregate GDP and population growth at horizon one. Estimating identical specifications on a common sample ensures that the coefficients satisfy the underlying accounting identity.

At average initial energy intensity, higher net migration is associated with increases in both aggregate GDP (0.867, $p < 0.001$) and population (1.239, $p < 0.001$). The larger population response accounts for the negative GDP-per-capita coefficient (−0.372, $p = 0.036$). More importantly, the migration–energy-intensity interaction is positive and statistically significant for aggregate GDP (0.455, $p = 0.010$), but small and insignificant for population (−0.020, $p = 0.519$). Their difference reproduces the GDP-per-capita interaction of 0.475 ($p = 0.008$). Thus, the more favourable adjustment associated with higher initial energy intensity primarily reflects differences in aggregate-output responses rather than population adjustment. This decomposition locates the estimated interaction primarily in aggregate output rather than population, but does not identify the underlying mechanisms or exclude confounding shocks and measurement effects.

Table 2. Migration, Initial Energy Intensity, and the Decomposition of GDP-per-Capita Adjustment

Outcome	*Net migration*	*Net migration × initial energy intensity*
Aggregate real GDP	0.867***	0.455**
	(0.181)	(0.174)
Population	1.239***	−0.020
	(0.029)	(0.030)
Real GDP per capita	−0.372**	0.475***
	(0.175)	(0.177)
Observations	2,120	2,120
Countries	128	128

Notes: Dependent variables are cumulative log changes multiplied by 100. Net migration is measured as a percentage of lagged population. Initial energy intensity is the standardized log of the 2000–2004 country average. All specifications include country and year fixed effects, two lags of net migration, and two lags of growth in output per hour, hours per worker, and employment relative to population. Standard errors, clustered by country, are shown in parentheses. The same observations and explanatory variables are used across equations, ensuring exact coefficient additivity: GDP per capita = aggregate GDP − population. ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 3 examines potential adjustment mechanisms through capital per hour worked, total factor productivity (TFP), human capital, and investment. The interaction for capital per hour is positive at horizon one (0.368) but statistically insignificant (p = 0.278), with no consistent pattern at longer horizons. TFP provides more suggestive evidence: its interaction is positive at horizon one (0.512, p = 0.060) and statistically significant at horizon five (0.934, p = 0.024), although intermediate estimates are imprecise and the TFP sample is smaller. The human-capital interaction remains insignificant throughout, while the investment-share interaction becomes negative at horizon five (−0.472, p = 0.073) without establishing a systematic response.

Table 3. Migration, Initial Energy Intensity, and Potential Macroeconomic Adjustment Mechanisms

Outcome	*h = 0*	*h = 1*	*h = 2*	*h = 3*	*h = 5*
Capital per hour worked	0.165	0.368	0.138	0.146	−0.115
Total factor productivity	0.370	0.512*	0.317	0.358	0.934**
Human capital	0.010	−0.001	−0.006	−0.018	0.023
Investment share	0.091	−0.009	−0.006	−0.187	−0.472*

Notes: Entries report coefficients on the interaction between net migration and predetermined standardized log energy intensity. Dependent variables are cumulative log changes multiplied by 100, except the investment share, which is measured in percentage-point changes. All specifications include country and year fixed effects, two lags of net migration, and two lags of the corresponding dependent-variable change. Standard errors are clustered by country. Sample sizes vary by outcome and horizon. ** and * indicate significance at the 5% and 10% levels, respectively.

Taken together, these estimates suggest that the differential aggregate-output association may involve labour utilization and, less conclusively, productivity-related adjustment, rather than systematic short-run changes in capital deepening or investment. However, the mechanism regressions are not an exact decomposition, use different samples, and cannot identify independent causal channels. The next

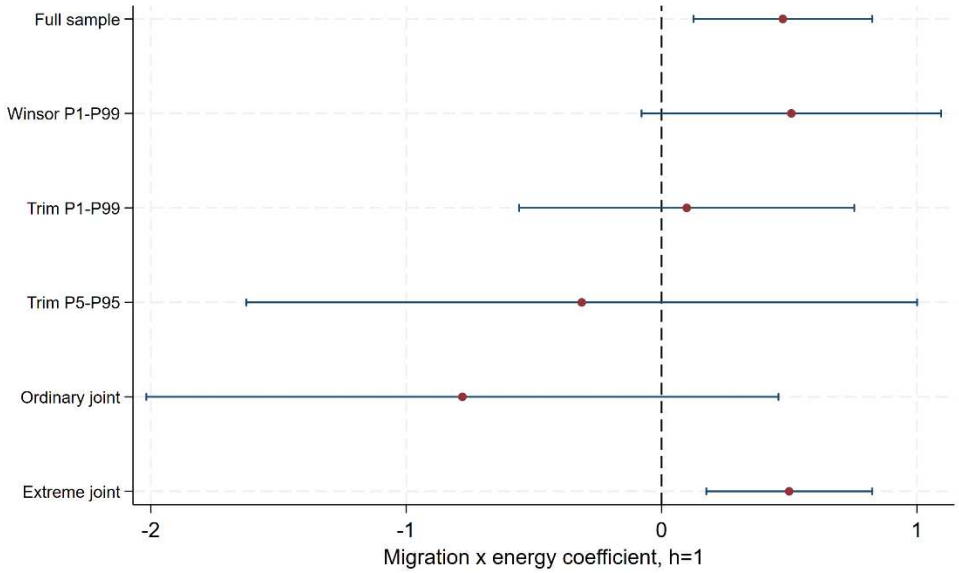
subsection examines whether the baseline interaction is driven by unusually large migration episodes.

5.3. Large Migration Episodes and Directional Asymmetries

The distribution of net migration is highly skewed, raising the possibility that exceptionally large inflows and outflows disproportionately influence the baseline interaction. Figure 3 examines this possibility by comparing the horizon-one migration–energy-intensity coefficient under winsorization, alternative trimming thresholds, and a specification distinguishing ordinary from extreme migration episodes.

The baseline interaction is positive and statistically significant (0.475, p = 0.008). Winsorizing migration at the first and ninety-ninth percentiles yields a similar coefficient (0.508), although significance weakens (p = 0.089). Excluding observations outside these percentiles reduces the estimate to 0.099 (p = 0.767), while trimming at the fifth and ninety-fifth percentiles produces an imprecisely estimated negative coefficient (−0.312, p = 0.639). Thus, the positive baseline interaction is sensitive to unusually large migration movements and cannot be established statistically within the central part of the migration distribution.

Figure 3. Sensitivity of the Migration–Energy-Intensity Interaction to Large Migration Episodes



Notes: The figure presents horizon-one coefficients on the interaction between net migration and predetermined energy intensity across alternative treatments of the migration distribution. The baseline includes all available observations; winsorized and trimmed specifications use the first and ninety-ninth percentiles or the fifth and ninety-fifth percentiles, respectively. The final two estimates distinguish ordinary observations from episodes outside the fifth–ninety-fifth percentile interval within a joint regression that permits the migration slope and its interaction with energy intensity to differ across regimes. Horizontal bars represent 95% confidence intervals based on country-clustered standard errors. The regressions include country and year fixed effects and the baseline lagged controls. The horizontal axis reports the interaction coefficient, and the dashed vertical line indicates zero.

Allowing separate interactions for ordinary and extreme observations reinforces this finding. The estimated coefficient for ordinary migration is negative and statistically

insignificant (−0.780, p = 0.215), whereas the coefficient for extreme episodes is positive and significant (0.500, p = 0.003). These estimates indicate that the positive interaction is more precisely identified among large migration movements, although differences in individual significance levels do not establish a statistically significant difference between regimes. Such episodes include major inflows into Gulf economies and Lebanon and Jordan, as well as substantial outflows from Ukraine and Venezuela. Their different economic and political circumstances caution against interpreting them as manifestations of a common structural mechanism.

Appendix Table A2 examines whether the interaction differs between immigration and emigration. Separate estimates for positive net migration (0.295, p = 0.202) and the absolute magnitude of negative net migration (−0.067, p = 0.863) are statistically insignificant, and a formal symmetry test cannot reject equality of the corresponding signed-flow responses (p = 0.631). Further distinguishing ordinary and extreme movements yields positive but imprecise interactions for ordinary inflows (0.895, p = 0.287), extreme inflows (0.433, p = 0.057), ordinary outflows (3.835, p = 0.074), and extreme outflows (1.118, p = 0.203), with outflows expressed in absolute magnitude. Formal tests fail to reject equality between ordinary and extreme inflows (p = 0.623) or outflows (p = 0.283). Evidence of directional differences among extreme episodes is only suggestive (p = 0.078).

Overall, the results indicate that unusually large migration movements contribute importantly to the baseline interaction, but do not establish systematic differences between immigration and emigration or between ordinary and extreme episodes within each direction. Because major migration movements may coincide with conflict, policy changes, and other economic disturbances, these associations should not be interpreted causally. Section 5.4 therefore assesses their sensitivity to influential countries, alternative specifications, and development-group heterogeneity.

5.4. Development Heterogeneity, Influential Observations, and Robustness

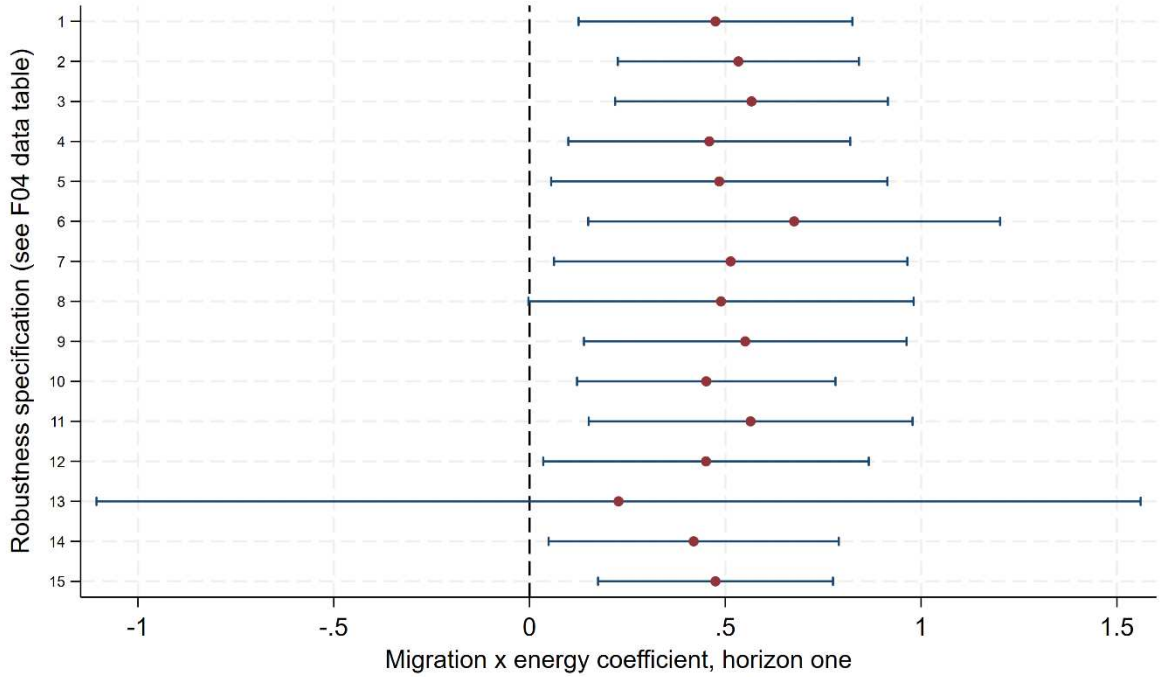
Figure 4 summarizes the sensitivity of the horizon-one migration–energy-intensity interaction to alternative specifications and sample restrictions. The baseline estimate remains positive and statistically significant when energy intensity is measured in standardized levels rather than logs (0.533, p < 0.001), when countries outside the fifth–ninety-fifth percentile range of initial energy intensity are excluded (0.567, p = 0.002), and when restricting the sample to economies with at least one million inhabitants (0.459, p = 0.013) or excluding energy exporters (0.485, p = 0.027). The interaction also persists with country-specific linear trends (0.551, p = 0.009), terms-of-trade controls (0.451, p = 0.008), and additional migration interactions with initial income (0.565, p = 0.008) or energy-exporter status (0.451, p = 0.034). These findings suggest that the baseline relationship is not solely explained by the functional form of energy intensity or several observable structural characteristics.

Regional exclusions provide further evidence of stability. The interaction remains positive when excluding the Gulf economies (0.676, p = 0.012) or Lebanon and Jordan (0.528, p = 0.002), and when removing the principal Levant inflow episodes (0.423, p = 0.034). Excluding both the Gulf economies and Lebanon and Jordan yields a positive but

less precisely estimated coefficient (0.601, p = 0.081). The baseline relationship is therefore not confined to any single regional group, although these episodes contribute to its identification.

Development-group estimates suggest a positive interaction among emerging market and developing economies (EMDEs; 0.419, p = 0.027), compared with an imprecisely estimated coefficient among advanced economies (0.227, p = 0.731). However, the pooled triple-interaction test in Appendix Table A3 finds no statistically significant difference between the groups (0.152, p = 0.813). Thus, the data do not establish that the association differs systematically by development status.

Figure 4. Robustness of the Migration–Energy-Intensity Interaction



Notes: The figure reports horizon-one coefficients on the interaction between net migration and predetermined energy intensity across 15 baseline and alternative specifications. Horizontal bars show 95% confidence intervals based on country-clustered standard errors, except for the two-way-clustering specification. All regressions include country and year fixed effects and the baseline lagged controls unless otherwise indicated. The two-way-clustered variance–covariance matrix is not positive semidefinite; corresponding inference should be interpreted cautiously.

Influential-observation checks provide an important qualification. The leave-one-country-out estimates in Appendix Figure A2 generally remain close to the baseline, but excluding Ukraine reduces the interaction to 0.359 (p = 0.152). Removing only Ukraine's 2022 observation produces a similar result (0.361, p = 0.151), while restricting migration observations to 2005–2021 yields a coefficient of 0.457 (p = 0.095). Thus, the interaction remains positive but loses statistical significance at the 5% level under these restrictions, reinforcing the importance of the extreme migration episodes examined in Section 5.3.

Additional diagnostics in Appendix Table A4 reveal no statistically significant interactions with future migration at t+1 (0.079, p = 0.476) or t+2 (−0.224, p = 0.131), nor evidence of a quadratic interaction with initial energy intensity (0.043, p = 0.916). Two-way clustering by country and year also yields a significant coefficient, although the non-

positive-semidefinite covariance matrix limits the reliability of this inference. These checks do not resolve concerns about migration endogeneity.

Overall, the positive migration–energy-intensity interaction survives several conventional robustness checks and regional exclusions but remains sensitive to exceptionally large migration observations, particularly Ukraine in 2022. The evidence therefore supports a conditional relationship between inherited energy environments and short-run macroeconomic adjustment, rather than a universal association independent of major demographic episodes.

6. Conclusion

This paper examines whether short-run macroeconomic adjustment to migration varies across predetermined energy environments. Using annual data for 128 countries over 2005–2022, it combines panel local projections with an exact decomposition of GDP per capita into output per hour, hours worked per employee, and employment relative to population. Initial energy intensity, measured before the estimation period, serves as a broad indicator of inherited production structures.

The results reveal a positive interaction between net migration and predetermined energy intensity. At average initial energy intensity, higher net migration is associated with a temporary decline in GDP per capita, but this association becomes substantially less negative in more energy-intensive economies. The interaction is statistically significant on impact and after one year, with weaker evidence at longer horizons. The accounting decomposition points to hours worked as a relatively consistent adjustment margin, alongside a larger but less precisely estimated contribution from hourly productivity. A complementary decomposition shows that the energy-dependent response primarily reflects differences in aggregate output rather than population adjustment. Additional estimates provide suggestive evidence of TFP responses, but limited support for systematic adjustments in capital intensity, human capital, or investment.

These findings nevertheless require important qualifications. The baseline interaction is sensitive to unusually large migration movements and loses statistical significance when the tails of the migration distribution are excluded. Although the association remains positive across several alternative specifications and regional exclusions, its precision also weakens when influential observations, particularly Ukraine in 2022, are removed. Moreover, separate analyses of immigration and emigration, ordinary and extreme episodes, and advanced and developing economies do not establish statistically significant differences between these groups. The evidence therefore supports a conditional relationship between inherited energy environments and macroeconomic adjustment, rather than a universal or clearly differentiated response across migration regimes.

The findings do not support promoting energy-intensive production. Initial energy intensity captures several structural characteristics, and the analysis does not identify which account for the estimated association. The policy relevance therefore lies in considering existing production structures when assessing migration-related adjustment, while recognising that the estimates do not establish the effectiveness of particular policy interventions.

Future research should establish whether these conditional associations have a causal interpretation, particularly through plausibly exogenous migration episodes or policy changes. More detailed information on migrants' characteristics, firm-level production, capital utilization, sectoral reallocation, and energy infrastructure could help identify the mechanisms underlying heterogeneous adjustment. Greater attention to exceptional migration episodes would also clarify the distinct economic implications of large inflows and outflows.

Overall, the findings indicate that inherited production environments contain useful information about the short-run macroeconomic adjustment associated with migration, particularly during major population movements. By distinguishing aggregate output from population changes and decomposing labour adjustment into productivity, working time, and employment, the analysis highlights dimensions of economic adaptation that aggregate GDP-per-capita regressions alone would obscure. The results remain conditional associations rather than causal estimates, but underscore the importance of productive capacity and structural flexibility in understanding how economies respond to demographic change.

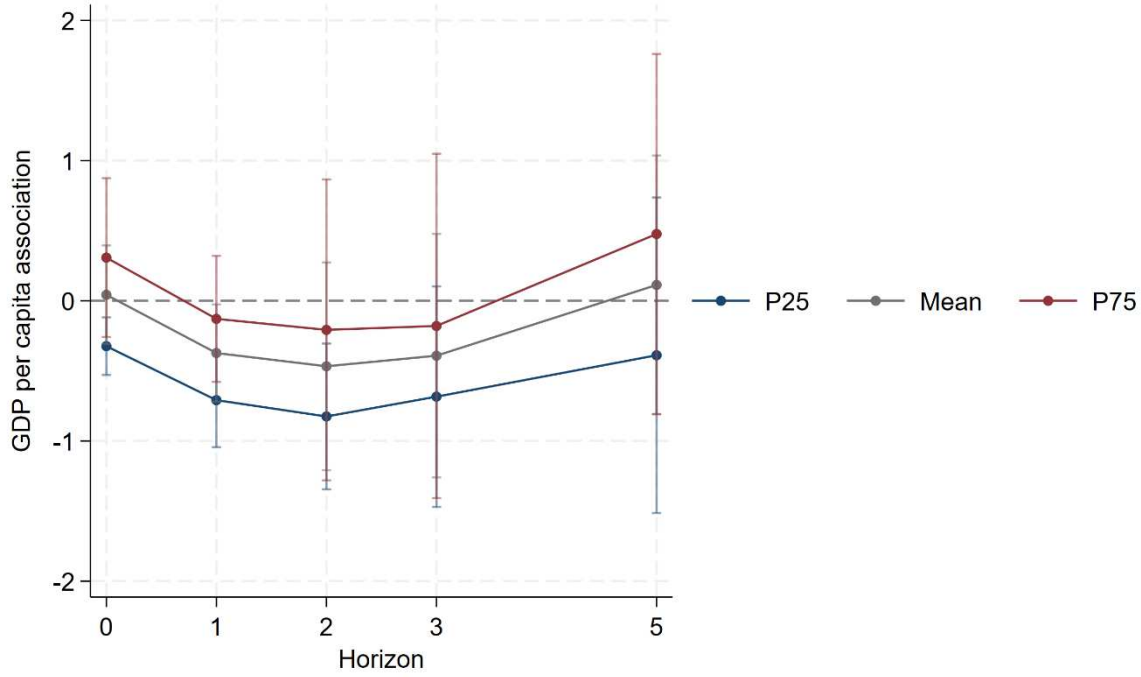
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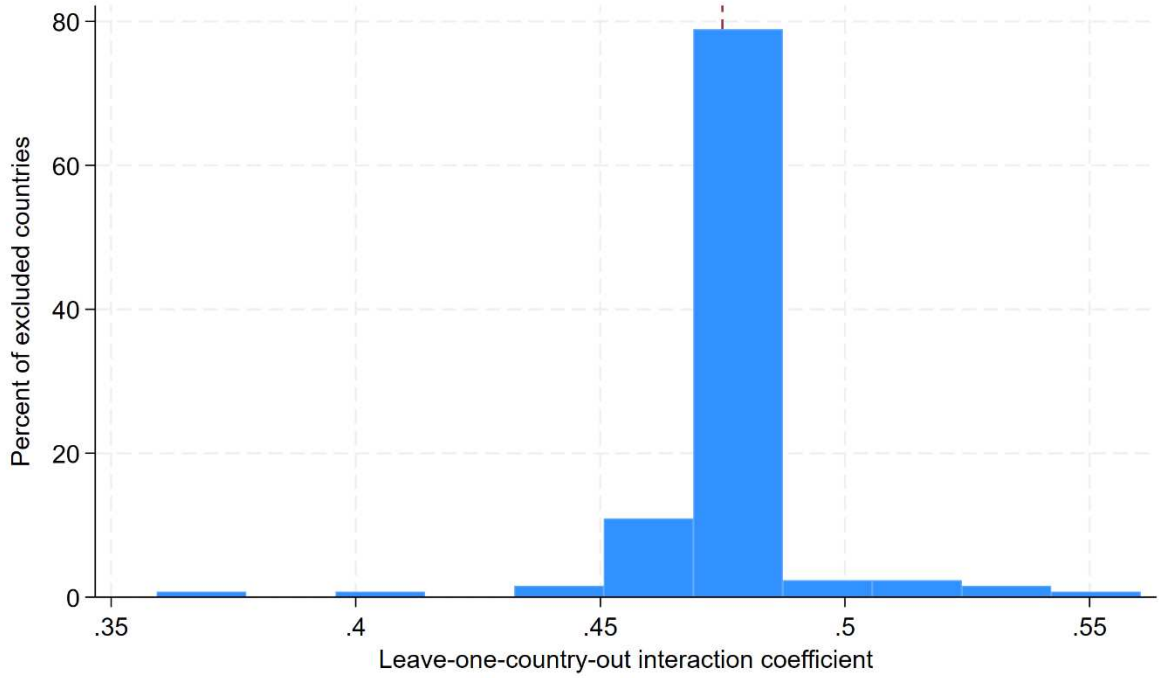
APPENDIX

Appendix Figure A1. Marginal Association Between Net Migration and GDP per Capita across Initial Energy-Intensity Environments



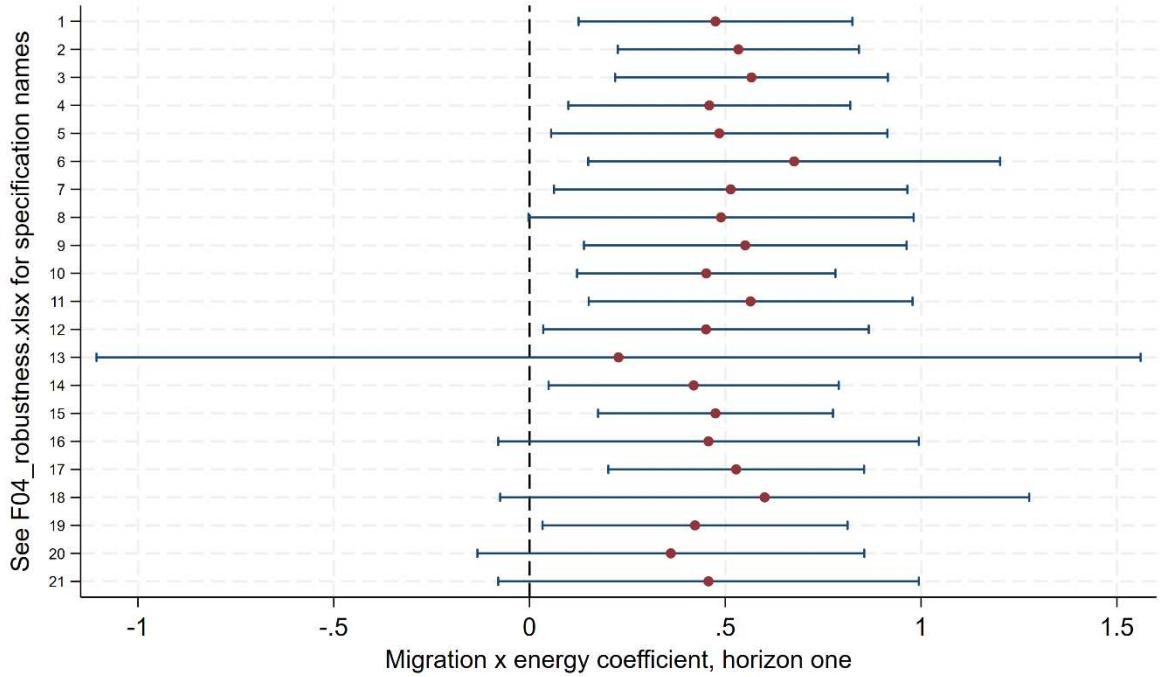
Notes: The figure reports the estimated marginal association between net migration (as a percentage of lagged population) and cumulative real GDP per capita at horizons 0, 1, 2, 3, and 5, evaluated at the 25th percentile (P25), mean, and 75th percentile (P75) of predetermined log energy intensity. Energy intensity is measured as the 2000–2004 country average and standardized across countries. The estimates are obtained from panel local projections controlling for country and year fixed effects, two lags of net migration, and two lags of growth in output per hour, hours per worker, and the employment-to-population ratio. Vertical bars indicate pointwise 95% confidence intervals based on country-clustered standard errors. The coefficients represent conditional associations rather than causal effects.

Appendix Figure A2. Leave-One-Country-Out Sensitivity of the Migration–Energy-Intensity Interaction



Notes: The figure displays the distribution of horizon-one coefficients on the interaction between net migration and predetermined energy intensity, obtained by re-estimating the baseline specification after excluding one country at a time. The vertical dashed line indicates the full-sample interaction coefficient (0.475). Each regression includes country and year fixed effects, two lags of net migration, and two lags of growth in output per hour, hours per worker, and the employment-to-population ratio. Standard errors are clustered by country. The analysis covers 128 countries and assesses the sensitivity of the baseline estimate to individual-country exclusions. The distribution indicates that most exclusions leave the coefficient relatively close to its baseline value, although Ukraine is particularly influential for statistical significance.

Appendix Figure A3. Robustness of the Migration–Energy-Intensity Interaction across Alternative Specifications



Notes: The figure reports horizon-one coefficients on the interaction between net migration and predetermined energy intensity across 21 alternative specifications and sample restrictions. These include alternative energy-intensity measures, restrictions on initial energy intensity and population size, exclusions of energy exporters and selected countries or regions, crisis-year exclusions, country-specific trends, additional macroeconomic controls, advanced-economy and EMDE subsamples, alternative clustering, and restrictions involving the 2022 migration observations. Horizontal bars indicate 95% confidence intervals, generally based on country-clustered standard errors. The vertical dashed line denotes zero. The baseline specification includes country and year fixed effects and two lags of net migration and the three GDP-per-capita accounting components. The two-way-clustered variance–covariance matrix is not positive semidefinite, so inference from that specification should be interpreted cautiously. The results indicate broad stability across several conventional robustness checks, but reduced precision when influential migration episodes—particularly Ukraine in 2022—are excluded.

Appendix Table A1. Variable Definitions, Data Sources, and Summary Statistics

Annual panel, 2005–2022. Descriptive sample: up to 128 countries and 2,303 country-year observations.

Panel A. Summary statistics

Variable	*N*	*Mean*	*SD*	*P5*	*Median*	*P95*
Net migration	2,303	0.197	1.474	−0.896	−0.005	1.727
Initial energy intensity	128	0.000	1.000	−1.260	−0.155	1.792
GDP per capita growth	2,303	2.128	4.675	−5.488	2.385	8.387
Output per worker growth	2,303	1.673	4.659	−5.150	1.651	8.137
Output per hour growth	2,242	1.777	4.772	−5.343	1.732	8.277
Hours per worker growth	2,242	−0.149	2.412	−3.698	−0.044	2.879
Employment-to-population growth	2,303	0.455	2.695	−3.520	0.491	4.420
Capital per hour growth	2,242	2.672	4.985	−4.269	2.069	11.192
TFP growth	1,835	0.045	3.709	−5.562	0.188	5.038
Human-capital growth	2,123	0.812	0.758	−0.113	0.697	2.051
Investment share of GDP	2,303	23.480	7.918	11.107	23.442	36.282

Panel B. Definitions, units, and sources

Variable	***Definition and unit***	***Source***
Net migration	Net international migration divided by previous-year population (%)	WDI
Initial energy intensity	Standardized log of mean energy intensity, 2000–2004 (SD units)	WDI
GDP per capita growth	Annual log change in real GDP per capita (%)	PWT
Output per worker growth	Annual log change in real GDP per employed worker (%)	PWT
Output per hour growth	Annual log change in real GDP per hour worked (%)	PWT
Hours per worker growth	Annual log change in average hours per worker (%)	PWT
Employment-to-population growth	Annual log change in employment/population (%)	PWT
Capital per hour growth	Annual log change in capital stock per hour worked (%)	PWT
TFP growth	Annual log change in total factor productivity (%)	PWT
Human-capital growth	Annual log change in the human-capital index (%)	PWT
Investment share of GDP	Investment share of real GDP (%)	PWT

Notes: Statistics are calculated from the descriptive sample, with coverage varying across variables. Initial energy intensity is based on the World Development Indicators series Energy intensity level of primary energy (MJ per 2017 PPP dollar of GDP), averaged over 2000–2004, log-transformed and standardized across the 128 countries. Growth rates are annual log differences multiplied by 100. SD denotes standard deviation; P5 and P95 denote the fifth and ninety-fifth percentiles. WDI denotes World Development Indicators; PWT denotes Penn World Table. Initial energy intensity is a country-level variable, so its reported sample size is 128 rather than the number of country-year observations.

Appendix Table A2. Direction and Magnitude of Net Migration: Energy-Intensity Interactions

Panel A. Positive versus negative migration

Migration measure	*Coefficient*	*Standard error*	*p-value*
Positive net migration	0.295	0.230	0.202
Negative net migration, absolute magnitude	−0.067	0.388	0.863

Panel B. Four migration regimes

Migration regime	*Coefficient*	*Standard error*	*p-value*
Ordinary inflows	0.895	0.836	0.287
Extreme inflows	0.433*	0.225	0.057
Ordinary outflows, absolute magnitude	3.835*	2.128	0.074
Extreme outflows, absolute magnitude	1.118	0.874	0.203

Panel C. Formal hypothesis tests

Null hypothesis	*F-statistic*	*p-value*
Symmetric signed-flow responses	0.232	0.631
Equal ordinary and extreme inflow interactions	0.243	0.623
Equal ordinary and extreme outflow interactions	1.164	0.283
Symmetric signed responses in extreme episodes	3.157	0.078

Notes: All specifications use the horizon-one baseline estimation sample of 2,120 country-year observations covering 128 countries. Coefficients refer to interactions with standardized predetermined log energy intensity. Negative migration is expressed as a positive absolute magnitude, so its coefficient must be interpreted accordingly. Extreme migration is defined using the fifth and ninety-fifth percentiles of the pooled core-sample net migration distribution. Standard errors are clustered by country. The four-regime regression includes separate migration and energy-interaction slopes, as well as regime-specific intercept and energy-intensity adjustments. Formal tests use the associated clustered variance–covariance matrix. * indicates significance at the 10% level.

Appendix Table A3. Heterogeneity by Development Group

Specification	*Coefficient*	*Standard error*	*p-value*	*Observations*	*Countries*
Advanced economies	0.227	0.656	0.731	630	35
EMDEs	0.419**	0.187	0.027	1,490	93
EMDE–advanced-economy difference	0.152	0.639	0.813	2,120	128

Notes: The first two rows report coefficients on net migration interacted with standardized predetermined log energy intensity from separate country-fixed-effects regressions. The third row reports the triple-interaction coefficient from a pooled specification allowing development-group-specific year effects. All specifications include the baseline lagged controls, with standard errors clustered by country. ** indicates significance at the 5% level. The pooled coefficient is not the arithmetic difference between the two separately estimated subgroup coefficients because the specifications differ in their treatment of controls and year effects.

Appendix Table A4. Placebo and Functional-Form Tests

Test	*Coefficient*	*Standard error*	*p-value*	*Observations*
Migration lead \(t+1\) × energy intensity	0.079	0.111	0.476	2,120
Migration lead \(t+2\) × energy intensity	−0.224	0.147	0.131	2,120
Quadratic energy-intensity interaction	0.043	0.403	0.916	2,120

Notes: The first two rows report the interaction of future net migration with predetermined energy intensity in specifications explaining earlier GDP-per-capita growth. The third row reports the additional interaction between net migration and squared standardized initial log energy intensity, conditional on the linear interaction. All regressions include country and year fixed effects and the baseline lagged controls. Country-clustered standard errors are reported. The estimates should be interpreted as specification diagnostics, not formal tests of causal identification.

Appendix Table A5. Estimation-Sample Coverage across Local-Projection Horizons

Horizon (h)	*Observations*	*Countries*	*Migration years*	*Outcome years*
0	2,120	128	2005–2022	2005–2022
1	2,119	128	2005–2022	2006–2023
2	1,991	128	2005–2021	2007–2023
3	1,863	128	2005–2020	2008–2023
5	1,607	128	2005–2018	2010–2023

Notes: The table reports the estimation-sample coverage for the common-sample GDP-per-capita accounting decomposition. The projection outcome at horizon h is defined as the cumulative log change from t−1 to t+h. Migration years identify the dates of the explanatory migration observations, whereas outcome years identify the terminal dates of the corresponding cumulative responses. The declining number of observations at longer horizons reflects the availability of future outcome data and other sample restrictions. All horizons retain 128 countries.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- appendix.docx