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Article

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Analysis of the long-run relationship between public capital, economic growth, and (non-)renewable energy consumption: a pooled mean group approach

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Abstract

This study examines the long-run interplay between public capital, economic growth, and energy consumption (renewable and non-renewable) across 48 countries over the period 1981 to 2019. Based on the PMG-ARDL approach, we contribute dual insights. First, a 1% increase in public capital boosts income growth by 0.34% and raises renewable and fossil-based energy consumption by 0.46% and 0.23%, respectively, highlighting the potential of public investments to facilitate a shift towards more sustainable energy usage; and a 1% rise in renewable energy use leads to a 0.39% decrease in fossil-based energy. Second, heterogenous panel causality tests indicate bidirectional causality between public capital and output, private capital, and employment. Importantly, income influences both forms of energy consumption, but the reverse is not statistically significant. These empirics underscore the significant role of public infrastructure investments in promoting economic development and steering the energy sector towards sustainability, offering vital policy insights for accelerating the transition to a low-carbon economy, thereby supporting the achievement of SDGs 7, 8, 9, and 13.

Keywords: public capital, renewable energy, fossil-based energy, panel cointegration, pooled mean group
JEL Classification Codes: Q40, Q43, Q50, O13

1. Introduction

Infrastructure capital, economic growth, and energy consumption—both fossil-based and renewable—are interconnected elements that significantly influence the sustainability and development of economies. The interplay among these variables has received considerable

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attention in economic literature, supported by a wealth of theoretical and empirical studies that explore their dynamics and implications (Mensah *et al.*, 2019; Sikder *et al.*, 2022; Ansari, 2022, among others).

One salient dimension of this multifaceted relationship is the influence of public capital on economic growth. National infrastructure, encompassing transportation networks, communication systems, and public utilities, serves as a vital catalyst for economic development. It enables the efficient flow of goods, services, and people (Nourzad *et al.*, 2014; Han *et al.*, 2021). Research has consistently demonstrated that public investment in infrastructure can augment productivity, enhance efficiency, and bolster competitiveness, thereby stimulating economic growth (Barro & Sala-i-Martin, 1992; Romp & De Haan, 2007). The quality and availability of infrastructure are pivotal in attracting investment, promoting trade, and fostering innovation and entrepreneurship. Consequently, nations with robust infrastructure are more likely to experience elevated economic growth rates (Bennett, 2019).

Another noteworthy dimension is the relationship between economic growth and energy consumption. Nonrenewable energy sources have historically driven economic activity, but environmental concerns have increased interest in renewable substitutions (Scheffran *et al.*, 2020). Studies show a positive link between renewable energy consumption and economic growth (Shahbaz *et al.*, 2012; Bhattacharya *et al.*, 2016). Advancements in renewable energy technology enhance cost-effectiveness, making renewables viable energy sources (Ponce & Khan, 2021). However, there is evidence that renewable energy consumption in developing countries must exceed a certain threshold to realize the positive growth effect (Chen *et al*. 2020). Therefore, the extent to which renewables can replace fossil fuels is a subject of ongoing debate.

This paper examines the complex nexus between public capital, economic growth, and energy consumption in the long run. We aim to uncover the nuanced impacts of public capital across 48 countries from 1981 to 2019. The study offers two significant contributions. Firstly, by utilizing the PMG-ARDL approach, we robustly demonstrate that public infrastructure investments can boost economic growth and influence the sustainability of energy sector. Secondly, heterogeneous panel causality tests reveal bidirectional relationships among output, public capital, private capital, and employment. Real income Granger causes both energy consumption types, but the reverse is not statistically supported. In simpler terms, public infrastructure investments can concurrently positively impact economic growth and shape the energy sector's sustainability. To the best of our knowledge, this paper is the first to explore the influence of public capital on private growth and the use of fossil and renewable energy sources.

The paper proceeds as follows: Section 2 reviews existing literature, while Section 3 details data and methodology. Sections 4 and 5 discuss empirical findings and conclude the study, respectively.

2. A short literature review

The relationship between infrastructure capital, economic growth, and energy consumption—both fossil-based and renewable—is complex. Existing literature contributes to our understanding from two distinct angles.

The first strand of research focuses on public capital's role in fostering economic growth. Romp & De Haan (2007) and Agénor & Neanidis (2015) emphasize public capital as essential for economic activities, a view supported by numerous studies. For instance, Gupta *et al.* (2014) stress its criticality for development in low-income nations, while Bom & Lighart (2014) and Sun et al. (2021) assert its broader positive economic impacts. However, there is also a caveat: such state investments might induce energy demand (Waheed *et al.*, 2019), potentially worsening energy poverty (Dimnwobi *et al.*, 2023).

The second strand of research extensively explores the economic growth-energy nexus, positing that economic growth could lead to increased energy consumption across various types (Omri, 2014; Pala, 2020). As a country becomes more affluent, a transition tends to occur from nonrenewable energy sources, such as fossil fuels, to more renewable alternatives. Research by Asiedu *et al.* (2021) and Ivanovski *et al.* (2021) support this notion, showing a positive correlation between renewable energy consumption and economic growth in both OECD and non-OECD countries. Remarkably, only non-OECD nations showed a positive correlation between nonrenewable energy consumption and economic growth. These studies identified a bidirectional Granger causality between economic growth and renewable energy consumption, as well as a unidirectional one between renewable and nonrenewable energy use.

Similar findings emerged from Asafu-Adjaye *et al.* (2016), who investigated 53 countries. Their results align with conclusions from Apergis & Payne (2010), Omri & Nguyen (2014), and Opeyami (2021), suggesting mixed causality directions between energy consumption (both fossil and non-fossil) and economic growth across different country groups. Further validation of the positive effect of energy consumption on economic expansion, including a bidirectional feedback mechanism, comes from Azam *et al.* (2023) in the panel of 30 developing countries. However, Chen *et al.* (2020) found mixed evidence regarding the economic effects of renewable energy consumption, suggesting that consumption levels in developing countries need to exceed a certain threshold to realize a positive impact on growth.

The complexity arises when these strands intersect. Bhattacharya et al. (2016) and Asafu-Adjaye *et al.* (2016) argued that public capital investment in renewable energy can bridge economic growth and sustainable energy use. Conversely, investments in fossil-based infrastructure can lock economies into unsustainable paths (Unruh, 2000). The latter argument is deemed a focal point as Binh & Nguyen (2024) showed an inverted U-shape relationship between state investment and energy consumption but a U-shape relationship between that investment and CO_2 emissions in ASEAN.

In summary, the literature on the triadic relationship between public capital, economic growth, and mixed energy use is still underdeveloped. Therefore, two hypotheses are proposed:

H1a: There exists a long-run relationship between public capital, income growth, fossil-based energy consumption, and renewable energy consumption.

H2: Public capital accumulation positively influences the transition toward more sustainable energy consumption.

3. Methodology and data

3.1. Model development

Aiming to investigate a long-term theoretical relationship, we recruit the Cobb-Douglas-type production framework of Kahia *et al.* (2016), Oryani *et al.* (2021), and recently Binh & Nguyen (2024). The proposed production function can be written as follows

$$Y_{it} = f\left(K_{g,it}, K_{p,it}, A_{it}EM_{it}, FEC_{it}, REC_{it}\right) = K_{g,it}^{\alpha_{1i}} K_{p,it}^{\alpha_{2i}} (A_{it}EM_{it})^{\alpha_{3i}} FEC_{it}^{\alpha_{4i}} REC_{it}^{\alpha_{5i}} \quad (1)$$

where *Y*, K_g, K_p, *EM*, *FEC*, and *REC* denote real GDP, public capital, private capital, labor, fossil-based energy consumption, and renewable energy consumption, respectively; $\alpha_{j\in[1,5]i}$ are individual long-run elasticity coefficients but $\alpha_{\{j=1,4,5\}i}$ are the main coefficients of interest; subscript *it* represents an observation for country i^{th} in year *t*; and ϵ_{it} is a stochastic process. The presence of A_{it} term alongside with EM_{it} implies the labor efficiency improvement such that $A_{it} = A_{o,it}e^{\delta_i t + \epsilon_t}$. Log-linearizing the production function yields:

$$\log Y_{it} = \alpha_{3i}\log A_{o,it} + \alpha_{3i}\delta_{it}t + \alpha_{1i}\log K_{g,it} + \alpha_{2i}\log K_{p,it} + \alpha_{3i}\log EM_{it} + \alpha_{4i}\log FEC_{it} + \alpha_{5i}\log REC_{it} + \epsilon_{it}$$

or, it can be rewritten in terms of an estimable long-run panel model as,

$$LY_{it} = \alpha_{0i}^* + \delta_i^* t + \alpha_{1i}LK_{g,it} + \alpha_{2i}LK_{p,it} + \alpha_{3i}LEM_{it} + \alpha_{4i}LFEC_{it} + \alpha_{5i}LREC_{it} + \epsilon_{it} \quad (2)$$

Two parameters $\alpha_{0i}^* \equiv \alpha_{3i}\log A_{o,it}$ and $\delta_i^* \equiv \alpha_{3i}\delta_{it}$ represent country-specific heterogeneity capturing fixed effects and deterministic trends in human capital development, respectively. Model (2) can thus be estimated within the autoregressive distributive lag (ARDL) dynamic panel framework of Pesaran *et al.* (1999) as in Mensah *et al.* (2019). However, a Hausman test must be performed to verify the long-run heterogeneity assumption.

Let us define two vectors as $y_{it} \equiv LY_{it}$ and $X_{it} \equiv (LK_{g,it}, LK_{p,it}, LEM_{it}, LFEC_{it}, LREC_{it})$, the ARDL(*p*, *q*) specification is of the form,

$$\Delta y_{it} = \phi_i(y_{it-1} - \theta_i' X_{it}) + \sum_{j=1}^{p-1}\lambda_{ij}^*\Delta y_{it-j} + \sum_{j=0}^{q-1}\delta_{ij}'^*\Delta X_{it-j} + \mu_i + \epsilon_{it} \quad (3)$$

The adjustment speed term, $\phi_i = -(1 - \sum_{j=1..p}\lambda_{ij})$, is expected to be statistically negative, expressing the long-run equilibrium, whereas the error correction term $ECT_{it} = y_{it-1} - \theta_i' X_{it}$. In the ARDL setting, Eq. 3 restricts cross-country long-run parameters but allows for variations in short-term and intercept coefficients. Therefore, the vector θ_i' is of interest because it shows the equilibrium relationship between y_{it} and X_{it}, from which Model Eq. 2 can be inferred.

3.2. Empirical approach

A comprehensive empirical approach is used to examine the time-series characteristics of panel data, followed by an estimation of long-run coefficients and Granger causality analyses. All panel series are first checked for unit root presence by utilizing both first-generation and second-generation tests. Based on the results, cointegration tests are applied using methods by Kao (1999), Pedroni (1999, 2004), and Westerlund (2007). If cointegrated, long-run elasticities are gauged via the Pooled Mean Group (PMG) estimator from Pesaran *et al.* (1999). Comparisons are made with outcomes from Fully Modified OLS (FMOLS) and Panel Dynamic OLS (DOLS) regression techniques. Finally, Granger pairwise tests for heterogeneous panel data (Dumitrescu & Hurlin, 2012) discern causality directions within the considering variables.

3.3. Data and descriptive statistics

We sourced data from publicly reputable databases. Real GDP (*Y*), public capital (*KG*), and private capital (*KP*), expressed in 2017 international dollars, were retrieved from the novel IMF Infrastructure database.[1] Energy consumption data, both fossil-based (*FEC*) and renewable (*REC*), came from Ritchie *et al.* (2022) and is measured in megawatt-hours. Labor (*EM*) series, represented in thousands, were obtained from the Conference Board's cross-sectional time series. We confined our dataset to 1981-2019, including countries with at least 35 years of renewable energy data. This filtering resulted in 1872 country-year observations from 48 countries.[2]

4. Empirics and discussions

4.1. Unit Root and Cointegration Tests

As outlined in the preceding subsection, a comprehensive examination of the first-order integration was undertaken for all series in the cross-sectional time data, which is elaborated upon in Table 1 below. Panel unit root tests can be broadly categorized into two groups: first-generation tests and second-generation tests. The first-generation tests operate under the assumption of cross-sectional independence, while the second-generation tests, such as those proposed by Pesaran (2007), are designed to be robust to heterogeneous panels that exhibit cross-sectional dependence. The test results suggest that six series—*LY, LKG, LKP, LEM, LFEC, and LREC*—are integrated of order one, I(1), implying that their first differences exhibit stationarity.

Upon establishing the requisite conditions for conducting a cointegration analysis, Table 2 presents the results of three prominent tests developed by Kao (1999), Pedroni (1999, 2004), and Westerlund (2007). It should be noted that while the first two tests are not designed to be robust against cross-sectional dependence, the latter is. The findings indicate that the system under study is statistically cointegrated, thereby implying a long-term equilibrium relationship

[1] Only the years prior to 2020 are covered by the IMF Infrastructure Database.
[2] See Figure A1 and Table A1 in the Appendix for descriptive statistics and list of countries.

among the series *LY, LKG, LKP, LEM, LFEC, and LREC*. Consequently, the panel model can be further analyzed using mean group estimators.

Table 1. Panel unit root tests

Prob.	LY	LKG	LKP	LEM	LFEC	LREC	DY	DKG	DKP	DEM	DFEC	DREC
1st Generation Unit Root Tests												
- H_0: Common unit root												
Levin, Lin & Chu	0.951	0.264	0.631	0.069	1.000	0.668	<0.001	0.003	0.166	<0.001	<0.001	<0.001
Breitung	1.000	1.000	1.000	0.999	0.999	1.000	<0.001	-	-	-	-	-
- H_0: Individual unit root												
Im, Pesaran and Shin	1.000	0.999	1.000	0.944	1.000	0.310	<0.001	0.003	<0.001	<0.001	<0.001	<0.001
Fisher – ADF	0.999	0.258	0.999	0.888	1.000	0.047	<0.001	0.007	<0.017	<0.001	<0.001	<0.001
2nd Generation Unit Root Tests												
Pesaran (2007)	0.997	1.000	0.915	0.999	0.937	0.711	<0.001	0.006	0.001	<0.001	<0.001	<0.001

Source: own elaboration.
Note: p-values are reported. The AIC lag is used for all panel unit root tests, except for capital variables. The prefixes "L" and "D" are used to indicate logarithmic and log-difference variables, respectively. Trend specifications are used for log-level variables, while log-differenced variables are tested without trend specifications.

Table 2. Panel Cointegration Tests

Panel A: Pedroni					
Statistics	Value	Prob.	Statistics	Value	Prob.
Panel v-Statistic	2.7407	0.0031	Group rho-Statistic	4.7833	1.0000
Panel rho-Statistic	3.3893	0.9996	Group PP-Statistic	-1.7072	0.0439
Panel PP-Statistic	-1.5209	0.0641	Group ADF-Statistic	-3.1837	0.0007
Panel ADF-Statistic	-1.7647	0.0388			
Panel B: Kao					
ADF	-2.494	0.006			
Panel C: Westerlund					
Ha: all panels are cointegrated			Ha: some panels are cointegrated		
Variance ratio	-2.0172	0.0218	Variance ratio	-3.4058	0.0003

Source: own elaboration.
Note: Panel cointegration tests are exercised at an AIC(BIC)-selected lag with trend specification.

4.2. Long-run analysis

The Mean Group (MG) type estimators, as proposed by Pesaran & Smith (1995) and Pesaran *et al.* (1999), necessitate a Hausman test to assess the assumption of long-run homogeneity.

Under the null hypothesis, the PMG estimator is both consistent and efficient, while the MG estimator could be inefficient.[3] The bottom line of Table 3 reveals that we fail to reject the Hausman null hypothesis (p-value = 0.6373), indicating that the PMG estimates are preferable. The same conclusion is drawn with respect to the Dynamic Fixed Effects (DFE) model (p-value = 0.1639). Notice that despite slight differences in magnitude, all elasticities remain consistent in terms of positive signs across PMG, DOLS, and FMOLS methods. This means that an increase in any independent variable will result in an income amelioration in the long run.[4]

Table 3 shows that a 1% rise in public capital (e.g., transportation infrastructure) leads to a 0.34% increase in GDP, holding all other variables equal. Also, a 1% change in private capital corresponds to a 0.12% change in GDP, while a 1% change in employment and fossil-based energy use leads to 0.408% and 0.416% changes in GDP, respectively. The influence of renewable energy usage is, however, statistically modest, with an elasticity coefficient of 0.018. Since all elasticity coefficients are strongly significant at $\alpha = 1\%$, our first hypothesis (H1) is statistically proven.

Regarding the short-term effects, the coefficient of the error correction term (ECT) is negative and statistically significant, indicating that the cointegrated system is mean-reverting. The magnitude of ECT is 0.078, suggesting that 7.8% of the disequilibrium will be corrected annually. It will take around 13 years to completely rectify any divergence from equilibrium. Moreover, there are notable immediate effects of employment and fossil fuel energy use on income, with values of 0.643 and 0.228, respectively.

It is important to analyze the long-term effects of public infrastructure on energy usage to confirm our second hypothesis. Table 4 presents the findings, which reveal that the elasticities of public capital on both types of energy use—renewable and fossil-based—are statistically significant. Specifically, a 1% increase in KG is associated with a 0.46% rise in REC and a 0.23% increase in FEC. Also, a 1% increase in REC is linked to a 0.39% reduction in FEC. The more pronounced effect on renewable energy implies that investment in public capital appears to facilitate a transition toward a low-carbon economy.

The estimates in Table 4 also validate the relationship between economic growth and energy consumption, indicating that a 1% increase in income leads to a 0.95% increase in the use of renewable energy sources and a 0.52% increase in the use of fossil-based options. This implies a growing demand for sustainable energy sources as people's income levels rise.

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[3] Evidence suggests that the panel data exhibits weak cross-sectional dependence (Pesaran, 2015; Juodis & Reese, 2022); however, the detailed results are not presented here but are available upon request. Consequently, the PMG (Pooled Mean Group) estimates remain valid.

[4] The PMG estimates are also consistent when considering a set of static regressors, namely, geopolitical risk, economic uncertainty and FDI inflows. Table A.3 reports the robustness outcome.

Table 3. Cointegrating Equation Estimations

Estimator	DOLS	FMOLS	PMG	MG	DFE
Dependent Var:	LY	LY	LY	LY	LY
	(1)	(2)	(3)	(4)	(5)
Long-run coefficients:					
LKG	0.1532**	0.1501**	0.3367**	0.2271	-0.0602
	[8.195]	[7.959]	[9.984]	[0.909]	[-0.271]
LKP	0.3674**	0.3201**	0.1221**	-0.1715	0.2012
	[21.365]	[16.583]	[4.017]	[-0.512]	[1.099]
LEM	0.5301**	0.4806**	0.4076**	0.1168	-0.1806
	[19.983]	[21.441]	[10.789]	[0.367]	[-0.455]
LFEC	0.1065**	0.1548**	0.4164**	0.6331*	0.7869**
	[6.413]	[10.121]	[15.5327]	[2.068]	[2.592]
LREC	0.0353**	0.0651**	0.0181*	0.1145	0.2141*
	[8.347]	[15.029]	[2.5465]	[1.417]	[2.551]
Short-run coefficients:					
ECT			-0.0777**	-0.3042**	-0.0194**
			[-4.6927]	[-9.8377]	[-2.6942]
DEM			0.6434**	0.5279**	0.5782**
			[-1.987]	[5.1283]	[19.6334]
DFEC			0.2276**	0.1278**	0.110**
			[7.1456]	[5.0249]	[19.1194]
Countries	48	48	48	48	48
Observations	1804	1844	1843	1843	1843
Hausman test, p-value			-	0.6373	0.1639

Source: own elaboration.

Note: ** p<0.01, * p<0.05, + p<0.1. t-statistics are in the squared brackets. DOLS (Dynamic OLS), FMOLS (Fully Modified OLS), PMG (Pooled Mean Group), MG (Mean Group), DFE (Dynamic Fixed Effects). The Hausman test is in favor of the PMG model over the MG and DFE models at p-value = 0.6373 and p-value=0.1639. The BIC criterion is applied to PMG lag-selection.

Overall, our findings align with recent literature on energy economics. The estimated disequilibrium adjustment is twice as long as reported in Binh & Nguyen (2024). The marginal effect of public capital on GDP substantially exceeds that of public investment found by Binh & Nguyen (2024). Nonetheless, both studies report a similar elasticity of state investment on energy consumption. Finally, the observed positive, bidirectional relationship between economic growth and both fossil-based and renewable energy use is consistent with the findings of Chen *et al.* (2020) and Asafu-Adjaye *et al.* (2016).

Table 4. More Pooled Mean Group Estimations

Estimator	PMG	PMG
Dependent Var:	LFEC	LREC
	(1)	(2)
Long-run coefficients:		
LY	0.5149**	0.9548**
	[7.4428]	[9.6658]
LKG	0.2262**	0.4550**
	[3.8826]	[6.0802]
LKP	0.1313**	-0.2274**
	[2.3677]	[-2.8327]
LEM	0.1483+	-0.4252**
	[1.9435]	[-3.8949]
LFEC		-0.1604*
		[-2.1866]
LREC	-0.3922**	
	[-18.3905]	
Short-run coefficients:		
ECT	-0.0766**	-0.1954**
	[-4.789]	[-5.8136]
DFEC		-0.4309**
		[-2.6556]
DLY	0.6478**	
	[11.8582]	
Countries	48	48
Observations	1804	1844

Source: own elaboration.
Note: ** p<0.01, * p<0.05, + p<0.1. t-statistics are in the squared brackets. The BIC criterion is applied to PMG lag-selection.

4.3. Granger causality analysis

In the final step, we employed the Dumitrescu & Hurlin (2012) method for heterogeneous panels to assess the pairwise Granger causality directions. The outcomes (see Table A.2 in the Appendix) show bidirectional causality between output, public capital, private capital, and employment. While real income appears to influence both fossil-based and renewable energy consumption, the inverse appears to be statistically insignificant. Two energy forms, in particular, have strong bidirectional Granger causality relationships with public and private capital, as well as employment. These results, together with previously highlighted positive effects of public capital on output and renewable energy, provide strong support for our second hypothesis (H2).

5. Conclusions

The relationship between public capital, economic growth, and energy use has been an ongoing debate among researchers. Our initial finding aligns with the neoclassical framework, which posits that investments in public infrastructure enhance economic activity. For instance, public financing transportation networks, power grids, and communication infrastructure can reduce production costs, improve market accessibility, and facilitate labor mobility and productivity, thereby boosting economic growth. Moreover, investment in renewable energy infrastructure is crucial for shifting energy consumption towards sustainable sources, offering an alternative to fossil fuels and promoting a sustainable energy mix.

The role of public capital extends beyond its direct impact on economic growth. By addressing risks and uncertainties associated with infrastructure deficiencies, public investments can draw in private capital. This synergy can further stimulate economic growth and spur innovations in energy efficiency and renewable energy technologies.

Our second empirical finding indicates that income and public capital have a greater impact on renewable energy consumption than fossil-based energy. It is suggestive of a significant shift towards a lower-carbon economy, where higher income levels and government infrastructure investments are more likely to increase consumption of renewable energy sources compared to fossil fuels.

In sum, these results highlight the potential for government policy to support sustainable energy transitions by fostering infrastructure development in areas like renewable energy generation and transmission. This approach can accelerate the achievement of Sustainable Development Goals (SDGs) focused on energy (SDG 7), economic growth (SDG 8), infrastructure (SDG 9), and climate action (SDG 13).

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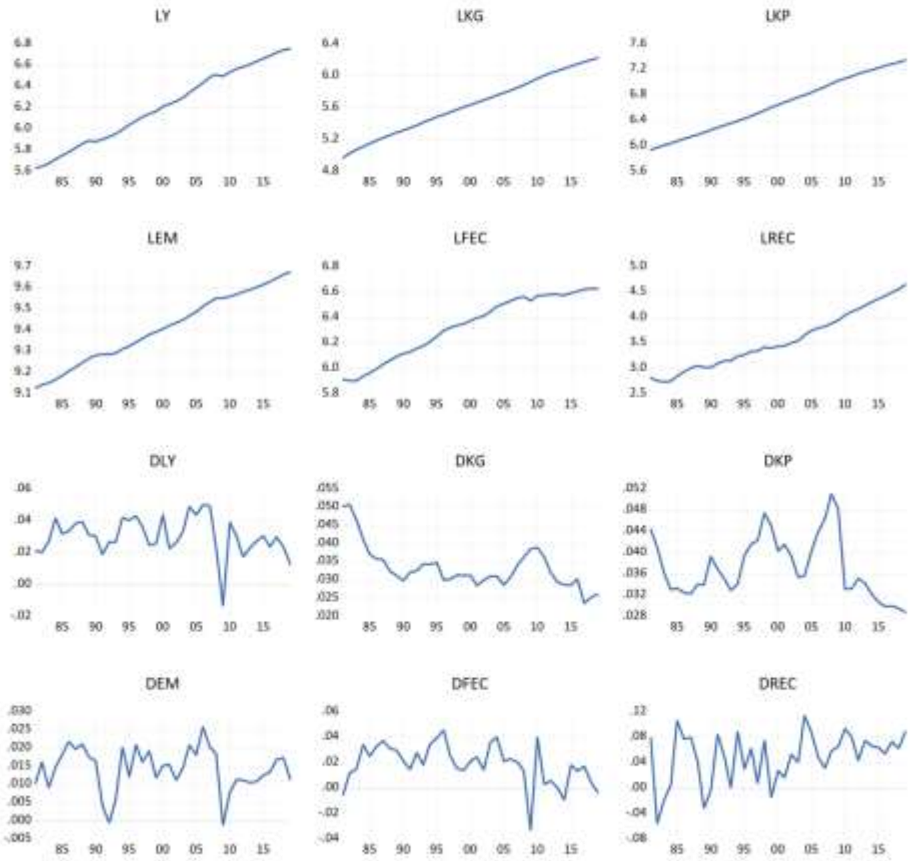
Appendix

Figure A1. Dynamics of LY, LKG, LKP, LEM, LFEC and LREC



Source: own elaboration.

Table A1. Descriptive Statistics

	LY	LKG	LKP	LEM	LFEC	LREC	DY	DKG	DKP	DEM	DFEC	DREC
Mean	6.214	5.635	6.649	9.409	6.333	3.552	0.031	0.033	0.037	0.014	0.019	0.049
Median	6.099	5.473	6.531	9.377	6.229	3.923	0.032	0.030	0.032	0.014	0.019	0.040
Maximum	9.931	10.315	10.472	13.544	10.432	8.595	0.226	0.243	0.263	0.206	0.253	3.267
Minimum	1.898	2.050	2.504	5.074	3.364	-5.809	-0.431	-0.022	-0.053	-0.175	-0.241	-2.614
Std. Dev.	1.342	1.471	1.428	1.454	1.328	2.116	0.038	0.028	0.032	0.025	0.052	0.248
Obs.	1854	1872	1872	1872	1868	1872	1852	1872	1872	1872	1863	1871

Source: own elaboration.
The prefixes "L" and "D" indicate logarithmic and log-difference variables, respectively.
List of countries: Algeria, Argentina, Australia, Austria, Bangladesh, Belgium, Brazil, Bulgaria, Canada, Chile, China, Colombia, Czechia, Denmark, Egypt, Finland, France, Germany, Greece, Hungary, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Luxembourg, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Norway, Pakistan, Peru, Poland, Slovakia, South Africa, Spain, Switzerland, Taiwan (China), Thailand, Turkey, United Kingdom, United States, Venezuela, Vietnam.

Table A2. Panel Granger Causality Tests

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.
KG does not homogeneously cause Y	3.765	4.937	0.000
Y does not homogeneously cause KG	13.468	34.342	0.000
KP does not homogeneously cause Y	3.597	4.428	0.000
Y does not homogeneously cause KP	64.061	187.662	0.000
EM does not homogeneously cause Y	4.536	7.275	0.000
Y does not homogeneously cause EM	7.859	17.345	0.000
FEC does not homogeneously cause Y	2.648	1.552	0.121
Y does not homogeneously cause FEC	4.703	7.777	0.000
REC does not homogeneously cause Y	2.006	-0.392	0.695
Y does not homogeneously cause REC	6.654	13.694	0.000
KP does not homogeneously cause KG	10.450	25.266	0.000
KG does not homogeneously cause KP	6.938	14.595	0.000
EM does not homogeneously cause KG	11.224	27.615	0.000
KG does not homogeneously cause EM	5.148	9.157	0.000
FEC does not homogeneously cause KG	6.650	13.715	0.000
KG does not homogeneously cause FEC	4.920	8.461	0.000
REC does not homogeneously cause KG	3.889	5.333	0.000
KG does not homogeneously cause REC	7.536	16.411	0.000
EM does not homogeneously cause KP	25.367	70.581	0.000
KP does not homogeneously cause EM	6.515	13.310	0.000
FEC does not homogeneously cause KP	12.080	30.204	0.000
KP does not homogeneously cause FEC	3.587	4.413	0.000
REC does not homogeneously cause KP	3.791	5.035	0.000
KP does not homogeneously cause REC	7.570	16.517	0.000
FEC does not homogeneously cause EM	3.158	3.111	0.002
EM does not homogeneously cause FEC	4.117	6.022	0.000
REC does not homogeneously cause EM	3.180	3.179	0.001
EM does not homogeneously cause REC	5.679	10.770	0.000
REC does not homogeneously cause FEC	4.389	6.850	0.000
FEC does not homogeneously cause REC	4.984	8.657	0.000

Source: own elaboration.
Note: All tests are conducted with a 2-lag specification but also consistent with other lags. All series are first-differenced before entering the test.

Table A3. Pooled Mean Group Estimations with Static Regressors

Estimator	PMG	PMG	PMG	PMG	PMG
Dependent Var:	LY	LY	LY	LY	LY
	(1)	(2)	(3)	(4)	(5)
Static regressions	FDII	WUI	GRPC	WUI + FDII	GRPC + FDII
Long-run coefficients:					
LKG	0.2733***	0.2499***	0.2785***	0.2549***	0.2529***
	[7.3298]	[10.1183]	[5.4958]	[6.9462]	[6.3352]
LKP	0.1802***	0.1958***	0.1631***	0.2069***	0.1429***
	[4.7154]	[8.7324]	[2.8994]	[5.0889]	[2.4696]
LFEC	0.3870***	0.2872***	0.2504***	0.3792***	0.2887***
	[13.1837]	[9.1991]	[6.281]	[12.1754]	[7.7069]
LREC	0.0335***	0.0236***	0.0117	0.0320***	0.0242***
	[6.3125]	[4.8697]	[1.1615]	[6.2579]	[3.7198]
LEM	0.4319***	0.5366***	0.5585***	0.4333***	0.6120***
	[9.3723]	[12.6052]	[9.3615]	[8.5995]	[8.9014]
Short-run coefficients:					
ECT	-0.0914***	-0.0955***	-0.0647***	-0.0956***	-0.0907***
	[-5.031]	[-5.8748]	[-3.5431]	[-5.0073]	[-3.7793]
Countries	45	47	35	45	33
Observations	1682	1800	1225	1682	1134

Source: own elaboration.
Note: ** p<0.01, * p<0.05, + p<0.1. t-statistics are in the squared brackets. The BIC criterion is applied to PMG lag-selection. WUI is the World Uncertainty Index, GPR is the Geopolitical Risk Index, and FDII is the FDI inflows expressed as % of GDP.