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Moderating Effects of Digital Technology and Migration-Driven Knowledge Diffusion on the Trade-Growth Linkage in Central America and the Caribbean (CAC) Region

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Abstract

Using a two-way fixed-effects (TWFE) panel regression, this study tests three hypotheses regarding the trade-growth linkage across 18 Central American and Caribbean (CAC) economies for the period of 2010 to 2023. While neoclassical models suggest trade openness consistently drives prosperity, historical data from the CAC region indicates that initial gains are often transitory. Despite high levels of market openness, many CAC countries remain in a low-growth trap, challenging the assumption that liberalization alone ensures long-term development. Adopting a Jones-type semi-endogenous growth framework (Jones, 1995), this paper posits that trade-induced growth is a dynamic process of total factor productivity (TFP) enhancement, moderated by digital technology adoption and migration-driven knowledge diffusion. Our empirical results reveal an openness trap: in the absence of sufficient technical and human capital, trade exposure leads to the displacement of domestic sectors.

Keywords: Trade Openness, Economic Growth, Trade Threshold, Absorptive Capacity, Technology, Central America & Caribbean, Migration

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1. Introduction

Following the Latin American debt crises of the late 20th century, many nations in Latin America and the Caribbean (LAC) region transitioned from protectionist import substitution industrialization (ISI) toward market-oriented reforms. This shift facilitated active participation in global trade negotiations, most notably during the Uruguay Round. More importantly, according to the neoclassical counter-revolution, smaller economies such as those in Central America and the Caribbean (CAC) subregion would gain significant advantages by moving away from government-led development toward free market principles. While these agreements enabled CAC countries to exploit comparative advantages in primary commodities and labor-intensive services as framed by the General Agreement on Trade in Services (GATS), the promised long-term prosperity has stalled. According to ECLAC (2025) and World Bank (2025), despite the high trade-to-GDP ratios displayed in these CAC economies, they still remain caught in a low-growth trap, with expansion projected at a modest 2.4% for 2025 and 2.3% for 2026.

The failure to address this persistent low-growth trap may stem from several interconnected factors within (or alongside) these multilateral frameworks. Primarily, the issue of inequity in technology transfer. We can perceive at the Article 66.2 of the TRIPS Agreement, which mandates that developed nations provide incentives for technology transfer to Least-Developed Countries (LDCs), yet many Small Open Economies (SOEs) remain marginalized. In an era of rapid digital transformation, the lack of robust ICT infrastructure prevents these economies from translating their formal market access into tangible export competitiveness.

For example, for innovation-constrained economies such as Belize, the WTO fails to provide mandatory technology-transfer incentives because the country does not meet the LDC classification, leaving it excluded from the specific protections of Article 66.2. Ultimately, without bridging this technological divide, these economies remain confined to traditional sectors, and unable to transition into the high-value digital services that define modern global growth.

A parallel and equally critical avenue for escaping this low-growth trap lies in leveraging human mobility specifically the untapped potential of skilled citizens living abroad. While migration has traditionally been viewed through the lens of brain drain often referred to as the depletion of a nation's stock of human capital, contemporary studies reframe it as a catalyst for brain gain through knowledge remittances involving the transnational transfer of specialized skills, innovative practices, market insights, and technological know-how by

diaspora members.

In the CAC context, these migration-related knowledge flows serve as an informal mechanism to compensate for limited technology access and to bridge persistent digital gaps. These migration flows foster entrepreneurship, sectoral upgrading, and integration into Global Value Chains (GVCs), providing indirect spillovers that complement traditional trade liberalization. In practice, this evidence occurs as diaspora members act as knowledge brokers who bridge the gap between their home countries and global markets. By sharing specialized expertise and high-level business networks, they help local firms move beyond exporting basic raw materials to participating in the complex global assembly lines of the modern economy.

For instance, a migrant working in a tech hub abroad such as the U. S. A, can provide a local business in Belize with the technical standards and insider connections needed to become a supplier for a major international brand. These human connections function as a critical, informal mechanism for technology transfer, providing the technical capacity required to utilize the market access established in trade agreements. In this sense, transnational human capital acts as the bridge between formal legal provisions and actual commercial participation. Furthermore, global migration surges and digital advances have amplified diaspora connectivity, enabling brain circulation without the necessity of permanent return migration. In addition to the tacit knowledge, migration contributed to financial remittances a counter-cyclical financing often exceeding FDI and official aid that supports essential household investments in education, health, and micro-enterprise. Beyond traditional trade operations, this human-capital framework provides CAC policymakers with a practical lever to drive economic diversification and long-term growth.

This study, therefore, offers insight into how digital technology adoption and tacit knowledge diffusion through migration act as critical channels in the trade-growth relationship for 18 CAC economies over the period of 2010–2023. For this purpose we move beyond neoclassical growth theories and adopt a Jones-type semi-endogenous growth framework, where long-run growth is driven by the rate of knowledge accumulation rather than only scale effects. The logic here is that while trade openness provides the essential baseline for global integration, granting SOEs access to knowledge flows and technology spillovers, its actual impact on growth is conditional. As established by Cohen and Levinthal (1990), this impact is moderated by a nation's absorptive capacity: its ability to identify, assimilate, and apply foreign knowledge locally.

In this Jones-type model, we adapt the theory to resource-constrained settings by respecifying the knowledge production function, substituting traditional domestic R&D labor with external diffusion channels specifically, digital technology and migration stock. We contend that trade boosts total factor productivity (TFP) primarily by acting as a conduit for embodied technology (Coe and Helpman, 1995). In the modern era, this process is signifi-

cantly amplified by ICT, broadband, and e-commerce, which as highlighted by the WTO World Trade Report (2025), and reduce operational trade costs and lower entry barriers for smaller, digitally connected firms. Emerging technologies like Artificial Intelligence (AI) further accelerate this transition by streamlining supply chains and automating complex logistics, potentially boosting global trade value by nearly 40% by 2040. However, the efficacy of these digital drivers is contingent on narrowing the digital divide. Without adequate broadband penetration and technical catch-up, resource-constrained economies risk results to further divergence.

Beyond digital conduits, our framework positions skilled migration as a primary engine for growth. In this model, the diaspora acts as a human capital version of the learning-by-exporting; their exposure to global frontier technologies facilitates a knowledge spillover that encourages domestic firms to invest in high-value, skill based technical change (SBTC) (Acemoglu, 2002; Clerides et al., 1998). Unlike traditional trade, which can remain passive, diaspora networks can supply the critical tacit knowledge required to reduce information asymmetries within GVCs. As established by Ikhenaode & Parello (2024), these networks transform trade exposure into active technological upgrading, allowing nations to leverage backward-looking immigrant networking to break the low-growth trap.

This shift is already visible in the CAC region: Guatemala's Scientific Diaspora, for instance, utilizes digital pathways to foster brain circulation and research excellence, effectively acting as a remote R&D department for the nation (Bonilla et al., 2022). Similarly, many Caribbean nations have adopted the diaspora option, treating skilled expatriates as social capital mediators who link local industries to global tech hubs without requiring physical relocation. By prioritizing these intangible channels: digital adoption and migration-driven knowledge diffusion, CAC economies can pursue a fundamental structural transformation. This movement changes their export baskets away from low-complexity primaries, such as sugar and poultry, toward high-value, knowledge-intensive services. Such a transition aligns with the Economic Complexity theory, where long-term prosperity is dictated by the accumulation of specialized knowledge rather than the mere volume of trade (Hidalgo & Hausmann, 2009).

This paper addresses the limitation of goods-based trade metrics by developing a modified semi-endogenous model (extending Jones, 1995) in which the growth impact of trade is not uniform but is contingent on two structural moderators: digital technology and migration-driven knowledge diffusion or the human foundation determining its capacity to absorb tacit expertise (Bahar & Rapoport, 2018). These contingency conditions do not transmit trade's effect sequentially; rather, they amplify or attenuate the marginal return of trade openness on TFP depending on how much of each a country possesses. Together, these moderators transform trade from a passive exchange into an active mechanism for technological catch-up. This study aims to answer two core questions: (1) Does trade drive

growth in CAC primarily through TFP enhancement rather than capital accumulation? (2) Do digital exposure and migration-mediated learning from advanced partners moderate the trade-TFP-growth nexus? Based on these questions we derive three hypotheses:

H1: Trade openness positively affects growth, conditional on digital and migration networks.

H2: Stronger digital infrastructure amplifies trade's marginal growth effect, enabling leapfrogging of traditional industrialization.

H3: Greater migration-mediated skills enhance trade's marginal effect, supporting learning-by-exporting and upgrading.

Our empirical results indicate that trade openness is not a standalone prosperity driver but a leveraged asset whose success depends on deep digital and human-capital integration. While the direct effects of trade on GDP are often marginal, its interaction with digital technology and migration-driven knowledge diffusion is both positive and significant, acting as a powerful engine for structural transformation. These moderators facilitate a shift toward high-tech trade baskets, converting basic market access into dynamic productivity expansion. For the innovation-constrained economies of the CAC region, this highlights critical missed opportunities. By strategically linking trade policy with better internet access and stronger connections to their citizens living abroad, these nations can build the foundations necessary to escape the low-growth trap.

The remainder of the paper is organized as follows: Section 2 reviews the relevant literature; Section 3 details the theoretical framework, Section 4 describes the data, empirical specification, and methodology; Section 5 presents the estimated results and discussion of findings; and Section 6 concludes with key takeaways and policy implications.

2. Literature Review

A foundational consensus in the literature establishes trade as a multi-dimensional conduit for development, yet the theoretical mechanism of its impact has undergone a significant paradigm shift. Early neoclassical growth models portrayed trade openness primarily through level effects on output, where gains are derived from static efficiency and the one-time reallocation of resources according to comparative advantage (Mankiw et al., 1992). While traditional models focus on how trade makes the best use of a country's current resources, they often suggest that trade alone does not speed up the long-term engine of growth. In contrast, modern frameworks most notably the Jones (1995) semi-endogenous growth model reframe trade as a powerful spark for productivity. Under this lens, reaching the global technology frontier is not about a one-time jump in efficiency; instead, it depends on a country's ability to continuously bring in and use new ideas from the outside

world.

For innovation-constrained regions like the CAC, where local research and development is naturally limited, the Jones framework suggests that economic progress depends entirely on how quickly a country can adopt advanced ideas developed elsewhere. Because these nations cannot rely solely on their own scientific breakthroughs, their growth is defined by their ability to find, understand, and apply global technology. However, simply accessing the global markets does not automatically lead to higher productivity. As established by Cohen and Levinthal (1990), the impact of external knowledge is strictly limited by a nation's absorptive capacity defined as its internal ability to recognize and use new information. Their evidence means that while trade provides the external flow of ideas, the country's internal machinery such as its digital infrastructure and skilled labor determines its ability to actually adapt and deploy that knowledge. Consequently, openness to trade is a necessary first step, but it is not enough on its own; without the right tools and skills to spread that knowledge, the engine of growth remains stuck in neutral.

2.1 The Digital Conduit

The foundational literature on international trade identifies it as a primary vehicle for technology imports and R&D spillovers (Coe & Helpman, 1995). However, in the contemporary global economy, these channels are increasingly moderated and enhanced by digital infrastructure. Freund and Weinhold (2004) provided seminal empirical evidence that internet connectivity significantly stimulates trade, particularly in developing countries that gain the most from reduced sunk costs, thereby enabling greater firm-level participation. Yet, the efficacy of these spillovers remains strictly conditional on a nation's absorptive capacity, including the human capital and institutional frameworks required to internalize foreign knowledge (Cohen & Levinthal, 1990).

Recent empirical evidence underscores this moderating role across various emerging contexts. Oshinowo et al. (2025) reveal that ICT infrastructure significantly strengthens the positive impact of trade openness on sectoral growth in Sub-Saharan Africa by mitigating technological bottlenecks. Similarly, Iqbal et al. (2023) find that ICT adoption, alongside trade and FDI, promotes sustainable growth in Belt and Road economies through enhanced knowledge diffusion. Beyond mere connectivity, the digital economy reshapes global patterns by reducing information frictions and enabling firm-level upgrading (Xu et al., 2025). Crucially, Lai et al. (2006), Maswana (2024), and Peña et al. (2025) empirically demonstrate that technology spillovers from trade only positively influence economic growth when absorptive capacity is high. While global reports suggest AI and digital services could boost trade by up to 37% by 2040, these benefits are unevenly distributed; low-income economies risk further marginalization without a significant catch-up in digital infrastructure (WTO, 2025).

Within the CAC and Caribbean region, the literature identifies a significant implementation gap that hinders these theoretical gains. An ECLAC (2023) review of 11 Caribbean nations reveals that digital journeys remain piecemeal and ad hoc, frequently lacking the cohesive strategic direction necessary for technology-driven growth. This institutional friction is reflected in IDB (2022) data, which reveals that aggregate TFP in several Caribbean nations has stagnated or declined for five decades, signaling a systemic productivity crisis. For example, the country of Belize's lack of a currently active and publicly available ICT plan creating a latent conduit; without a strategic policy interface or a digitally skilled workforce, such economies cannot effectively internalize the knowledge flows provided by trade openness, regardless of their level of market integration.

Nevertheless, empirical estimates from the IDB (2022) highlight a transformative digital multiplier potential. Closing the digital gap with OECD averages is associated with a 3.2% increase in GDP and a 2.6% rise in productivity for every 10-percentage-point increase in infrastructure penetration. For nations like Barbados and Jamaica, the potential return on investment ranges from 23 to 58 times the associated costs. However, as the IDB Broadband Development Index warns, persistent gaps in internal machinery such as strategic regulation and public-sector digital literacy, continue to prevent trade openness from independently driving structural transformation in countries like Guyana and Suriname. Ultimately, the literature suggests that for the CAC region, trade openness is a latent asset that requires a robust digital interface to convert market access into dynamic TFP expansion.

2.2 The Human Conduit

The literature on skill-biased technical change argues that international market exposure accelerates the adoption of technologies that require and reward skilled labor (Acemoglu, 2002; Acemoglu & Autor, 2011). This is complemented by the evidence that skill intensity in foreign trade directly correlates with higher growth rates through industrial upgrading (Woerz, 2004). Bresnahan et al. (2002) provide firm-level evidence that IT investments, when combined with workplace reorganization and skilled labor, generate substantial productivity gains. In the context of trade liberalization, Bustos (2011) demonstrates that reduced trade costs prompt technology upgrading and skill intensification, while Clerides et al. (1998) document the learning-by-exporting effects where firms improve efficiency through exposure to international competition.

In the CAC context, this technical change is inextricably linked to human mobility. Endogenous growth frameworks suggest that migration facilitates cross-country knowledge spillovers, accelerating convergence in lagging economies (Ikhenaode & Parello, 2024). Empirical evidence supports this role in technology diffusion; for instance, migration supports the spread of digital tools in developing countries, though the impact is highly sensitive to

education levels (Hübler, 2016). While immigration boosts productivity in host countries (Ottaviano et al., 2018; Peri, 2012), for sending countries, diaspora networks yield brain gain effects. Returning migrants and transnational networks transfer the tacit skills and best practices necessary to enhance export performance and TFP (Bahr et al., 2024; Kerr et al., 2016). Notably, Ortega and Peri (2014) find that openness to migration can exert stronger long-run income effects than trade openness alone.

While Baron and Kenny (1986) establish the foundational stepwise approach, the refinements by Zhao et al. (2010) clarify that meaningful indirect effects can exist even in the absence of 'full' mediation; a critical distinction when analyzing complex flows like digital literacy and migration-mediated learning. Despite the importance of these channels, comparable analyses in the CAC region remain scarce. Existing trade-growth studies largely treat trade as a goods-based exchange (e.g., export/import ratios) and overlook the intangible, people-based diffusion channels that are increasingly central to TFP in small, innovation-constrained economies. This region faces a unique confluence of structural challenges: a heavy reliance on commodities, massive emigration (primarily to the USA), and a persistent digital divide reflected in low Human Capital Index (HCI) scores. This study addresses this gap by investigating the moderating roles of digital technology and migration-mediated learning in the trade-growth nexus. For the analytical purpose, it provides nuanced evidence on how these channels amplify trade's growth effects, informing policies designed to bridge technological bottlenecks in the digital era.

Collectively, the literature identifies a critical evolution from trade as a static resource-mechanism toward a dynamic conduit for TFP. However, there is a major gap in current research. While we know that digital tools allow countries to access global ideas faster, and that migrant networks help businesses bypass local hurdles, these two factors are almost always studied separately. Their isolated analysis miss how they actually work together to transform a country. In reality, having a fast internet connection including high-speed broadband and digital platforms is most effective when a country also has a skilled network of people, such as a diaspora. These individuals provide the hands-on expertise and global connections that are often missing locally, helping to turn raw digital information into real business opportunities. This study bridges that gap by showing that digital and human connections are not just two unrelated paths; they are the combined foundation that a country could take advantage of to move past stalled growth. When a nation integrates both, it creates a much stronger environment for businesses to innovate and for the economy to reach a new level of productivity. For the small economies of the CAC region, where domestic research and development are often limited, these digital and human connections are not just secondary factors they are the primary ways to access global progress. By bringing these two channels together into a single framework based on Jones (1995), this study moves beyond the traditional focus on trading physical goods. This ap-

proach allows us to see how technology and people actually work together to drive long-term growth. It addresses this fundamental gap in the trade-growth nexus, providing the theoretical and empirical basis for the conditional moderation framework detailed in the following section.

3. Theoretical Framework

Building on the semi-endogenous growth logic of Jones (1995), this framework examines how trade-mediated access to frontier knowledge contributes to long-run income growth in Central American and Caribbean (CAC) economies. Trade links countries to imported capital goods, intermediate inputs, external know-how, and global knowledge spillovers (Coe & Helpman, 1995). Digital absorptive capacity and migration-mediated knowledge transfer are treated as channels that shape the effectiveness with which these external resources are translated into domestic productivity gains.

3.1 Production and Capital Accumulation

We begin with a standard labor-augmenting Cobb-Douglas production function:

$$Y_{i,t}=K_{i,t}^{\alpha}(A_{i,t}L_{i,t})^{1-\alpha} \tag{1}$$

Here, $Y_{i,t}$ denotes aggregate output; $K_{i,t}$ denotes the stock of physical capital; $L_{i,t}$ denotes the labor force; $A_{i,t}$ denotes the effective stock of adopted technology; α denotes the output elasticity of physical capital, with $0<\alpha<1$.

In per-worker terms, the production function is:

$$y_{i,t}=k_{i,t}{}^{\alpha}A_{i,t}{}^{1-\alpha} \tag{2}$$

Here, $y_{i,t}\equiv Y_{i,t}/L_{i,t}$ denotes output per worker; $k_{i,t}\equiv K_{i,t}/L_{i,t}$ denotes physical capital per worker.

Taking natural logarithms yields:

$$ln\ y_{i,t}=\alpha\ ln\ k_{i,t}+(1-\alpha)\ ln\ A_{i,t} \tag{3}$$

Trade affects income per worker through its effect on the effective stock of adopted technology, $A_{i,t}$. The remaining equations specify how trade-mediated diffusion changes the accumulation of $A_{i,t}$.

To make the balanced-growth-path (BGP) condition explicit, physical capital follows the standard Solow-style law of motion:

$$\dot{K}_{i,t}=s_i Y_{i,t}-\delta_K K_{i,t} \tag{4}$$

Here, s_i denotes the saving rate; δ_K denotes the depreciation rate of physical capital. Defining capital per effective worker as $\tilde{k}_{i,t} \equiv K_{i,t}/(A_{i,t}, L_{i,t})$, and letting n_i denote constant exogenous growth rate of labor-force growth, the equivalent transition equation is:

$$\dot{\tilde{k}}_{i,t} = s_i \tilde{k}_{i,t}^{\alpha} - (n_i + g_{A,i,t} + \delta_K)\tilde{k}_{i,t} \tag{5}$$

For $0<\alpha<1$, this equation has a stable positive BGP value of capital per effective worker when n_i, δ_K, and g_A are constant. Hence, $\dot{\tilde{k}}_{i,t}$ is constant on the BGP, which implies $k_{i,t}=0$ and this $g_K^*=n_i+g_A^*$ and therefore capital per worker grows at rate $g_k^*=g_A^*$.

3.2 Trade-Mediated Technology Accumulation

Jones (1995) models sustained growth through a knowledge-accumulation equation in which the growth rate of technology depends on the growth rate rather than the level of the knowledge-producing input. For CAC economies, where large formal domestic research sectors are limited, the relevant knowledge-producing input is effective trade-embodied technology exposure. Digital infrastructure and migration-mediated knowledge transfer are hypothesized to strengthen the conversion of externally available knowledge into domestic productivity gains.

The modified knowledge-accumulation equation is:

$$\dot{A}_{i,t} = \delta_T A_{i,t}^{\phi} X_{i,t}^{\lambda},\ 0<\phi<1,\ \lambda>0 \tag{6}$$

Here, δ_T captures the efficiency with which the domestic economy translates externally available technology into productive knowledge, reflecting institutional quality, absorptive capacity, and implementation capability; $X_{i,t}$ denotes effective trade-embodied technology exposure; λ is the elasticity of knowledge accumulation with respect to that exposure; ϕ governs diminishing returns to the existing stock of adopted knowledge.

Dividing Equation (6) by $A_{i,t}$ gives the instantaneous growth rate of effective technology:

$$g_{A,i,t} = \frac{\dot{A}_{i,t}}{A_{i,t}} = \delta_T A_{i,t}^{\phi-1} X_{i,t}^{\lambda} \tag{7}$$

Taking logarithms of Equation (7) yields $ln\ g_A = ln\ \delta_T + (\phi-1)\ ln\ A + \lambda\ ln\ X$. Differentiating with respect to time gives the transition equation:

$$\frac{\dot{g}_A}{g_A} = (\phi-1)g_A + \lambda g_X \tag{8}$$

Equation (8) governs the transition dynamics toward the balanced growth path. On the balanced growth path, the growth rate of effective technology is constant, so $\dot{g}_A=0$. The long-run technology-growth rate is therefore:

$$g_A^* = \frac{\lambda g_X}{1-\phi} \tag{9}$$

This is a Jones-style semi-endogenous result: conditional on a constant and exogenous growth rate of effective exposure, sustained productivity growth depends on the growth rate of the external knowledge input, not on its level.

3.3 Effective Trade-Embodied Technology Exposure

Effective trade-embodied technology exposure is defined as a multiplicative composite of a quality-adjusted trade-embodied knowledge stock and two diffusion channels:

$$X_{i,t} = T_{i,t}^{\eta} D_{i,t}^{\omega^{\mathrm{D}}} M_{i,t}^{\omega^{\mathrm{M}}} \tag{10}$$

Here, $T_{i,t}$ captures the quality-adjusted stock of trade-embodied technology; $D_{i,t}$ captures digital absorptive capacity in efficiency units; $M_{i,t}$ captures migration-mediated knowledge from technological-frontier economies; η, ω^{D}, and ω^{M} are positive elasticities.

The variables $T_{i,t}$, $D_{i,t}$, and $M_{i,t}$ are theoretical quality-adjusted knowledge stocks rather than static trade ratios, connectivity rates, or diaspora shares. $T_{i,t}$ captures the cumulative stock of trade-embodied technology: even when a trade-to-GDP ratio stabilizes, the technology content of traded inputs can expand with the global frontier. $D_{i,t}$ represents cumulative digital absorptive capacity in efficiency units, reflecting improvements in processing capability, cloud services, AI integration, software quality, and organisational use rather than mere connectivity penetration. $M_{i,t}$ denotes cumulative migration-mediated knowledge from technological-frontier economies, especially the United States and other frontier locations, where the knowledge content transmitted through diaspora and return-migration links can grow as frontier technology advances.

Under this interpretation, $\mathrm{m} \equiv g_T$, g_D, and g_M can remain positive because they are sustained by exogenous technological progress at the global frontier. The bounded empirical indicators used later (trade-to-GDP ratios, broadband or ICT penetration, and diaspora shares) are observable correlates of these underlying unbounded efficiency-equivalent knowledge stocks. They are not literal measures of the theoretical stocks themselves.

Log-differentiating Equation (10) gives:

$$g_X = \eta g_T + \omega^{\mathrm{D}} g_D + \omega^{\mathrm{M}} g_M = \eta m_i + \omega^{\mathrm{D}} g_D + \omega^{\mathrm{M}} g_M \tag{11}$$

Here, $m_{i,t} \equiv g_{T,i,t} = \dot{T}_{i,t} / T_{i,t}$ denotes the growth rate of the quality-adjusted trade-embodied knowledge stock; g_D and g_M denote the corresponding growth rates of digital absorptive capacity and migration-mediated knowledge.

Substituting Equation (11) into Equation (9) yields the long-run technology-growth rate:

$$g_A^* = \frac{\lambda}{1-\phi}(\eta m^*_i + \omega^D g_D + \omega^M g_M) \quad (12)$$

The long-run effect of trade is therefore not determined by quality-adjusted trade growth alone. In addition to the direct contribution of ηm, it depends on the evolution of digital absorptive capacity and migration-mediated knowledge transfer. The model does not assume that digital infrastructure and migration are independently sufficient for sustained growth; rather, they contribute to the effectiveness of the broader diffusion process.

Transmission mechanism is as follows. Global technological frontier → quality-adjusted trade-embodied knowledge stock (T) → effective technology exposure (X) → technology growth (g_A) → income-per-worker growth (g_Y). Digital absorptive capacity (D) and migration-mediated knowledge (M) filter and strengthen the conversion from T to X.

3.4 Balanced Growth Path Income Growth

From Equation (2), the growth rate of output per worker is $g_Y = \alpha g_k + (1-\alpha) g_A$. Because capital per effective worker is constant on the balanced growth path, $g_k^* = g_A^*$. Therefore:

$$g_y^* = g_A^* = \frac{\lambda}{1-\phi}(\eta m^*_i + \omega^D g_D + \omega^M g_M) \quad (13)$$

Thus, income per worker inherits the growth rate of effective technology one for one on the balanced growth path. The labor-share factor $(1-\alpha)$ does not multiply the final long-run income-growth expression because capital per worker grows at the same rate as effective technology along the balanced growth path.

3.5 From Theory to Empirics

The composite effective-exposure index, $X_{i,t}$, is not directly observable. The empirical analysis therefore relates income per worker to observed trade openness, while allowing digital infrastructure and migration-mediated knowledge to enter directly and as moderators of the trade-income association.

Although the theoretical expression is written in terms of the long-run growth rate of the quality-adjusted trade-embodied knowledge stock, $m = g_T$, the empirical specification uses $\ln T_{i,t}$ as a proxy for the accumulated stock of trade-mediated exposure. Country fixed effects absorb persistent cross-country differences in initial exposure levels, while the coefficients on trade openness and its interactions capture within-country changes associated with the cumulative deepening of trade integration. The empirical level specification should therefore be interpreted as a reduced-form representation of transition dynamics and accumulated exposure, rather than as a direct estimate of the balanced-growth rate g_y^*.

The baseline model is:

$$ln\ y_{i,t}=\beta_0+\beta_1\ ln\ k_{i,t}+\beta_2\ ln\ T_{i,t}+\beta_3 D_{i,t}+\beta_4 M_{i,t}+Z'\theta+\mu_i+\tau_t+\varepsilon_{i,t} \quad (14)$$

Here, $Z'\theta$ denotes the vector of time-varying controls, including institutional quality and inflation; μ_i denotes country fixed effects; τ_t denotes time fixed effects; $\varepsilon_{i,t}$ denotes the error term. In the empirical model, $T_{i,t}$, $D_{i,t}$, and $M_{i,t}$ are observable proxies for their corresponding theoretical quality-adjusted knowledge stocks.

The full model is:

$$ln\ y_{i,t}=\beta_0+\beta_1\ ln\ k_{i,t}+\beta_2\ ln\ T_{i,t}+\beta_3 D_{i,t}+\beta_4 M_{i,t}+\beta_5(ln\ T_{i,t}\times D_{i,t}) +\beta_6(ln\ T_{i,t}\times M_{i,t})+Z'\theta+\mu_i+\tau_t+\varepsilon_{i,t} \quad (15)$$

Equation (15) provides an extension of equation (14) motivated by the theoretical framework which is discussed in section 2.2. The multiplicative exposure index in Equation (10) implies constant elasticities in logarithms. The interaction terms test whether the observed association between trade openness and income per worker varies with the levels of digital infrastructure and migration-mediated knowledge. They may capture complementarities, threshold effects, or other nonlinearities in the diffusion process that are not explicitly modelled but are consistent with the broader theoretical intuition.

The marginal association between observed trade openness and income per worker is:

$$\frac{\partial\ ln\ y_{i,t}}{\partial\ ln\ T_{i,t}}=\beta_2+\beta_5 D_{i,t}+\beta_6 M_{i,t} \quad (16)$$

Thus, a positive β_5 means that the elasticity of income per worker with respect to trade openness is greater at higher levels of digital infrastructure; a positive β_6 has the analogous interpretation for migration-mediated knowledge. Because digital infrastructure and migration enter in levels while trade openness enters in logarithms, these are semi-elastic interaction effects rather than log-log elasticities. They should not be interpreted as effects on contemporaneous income growth, because the dependent variable is the logarithm of the income-per-worker level. The results are more appropriately described as consistent with accelerated technology adoption through trade, not as evidence of leapfrogging.

4. Empirical Specification and Data

4.1 Econometric Model

To empirically assess the theoretical framework derived in Equations (14) and (15), we estimate a two-way fixed-effects (TWFE) panel regression. To address potential endogeneity, we acknowledge that trade openness, digital technology exposure, and migration stock may be affected by growth outcomes. The fixed-effects estimation mitigates bias from unob-

served time-invariant heterogeneity by controlling for country-specific factors such as geography, colonial legacies, and persistent institutional frameworks that may correlate with both trade patterns and long-run productivity. However, three remaining sources of endogeneity persist: (1) simultaneity, where contemporaneous growth influences trade and digitalization decisions; (2) time-varying omitted confounders, including coordinated policy reforms, external shocks, and infrastructure investments that affect both regressors and outcomes; and (3) measurement error in trade and especially digitalization indicators, potentially linked to varying statistical capacity across CAC countries.

These issues are typically addressed using dynamic panel System GMM (Blundell and Bond, 1998), which instruments endogenous variables with their lagged levels and differences while controlling for fixed effects. We initially estimated System GMM specifications but found them unsuitable for our dataset. With only 18 countries and relatively short time dimension for period 2010–2023, the number of instruments quickly exceeds the number of cross-sectional units, leading to overfitting. Diagnostic tests confirmed invalid moment condition: the Hansen test for overidentifying restrictions yielded a p-value of 1.000 (indicating excessive instruments and weak power to detect invalidity), while AR (2) test was strongly rejected ($p=0.001$), signaling persistent serial correlation in the errors and invalid lagged instruments. Due to the diagnostic limitations of the System GMM specifically the rejection of the null hypotheses in the Hansen test for overidentifying restrictions and the AR (2) test for second-order serial correlation we adopt the TWFE estimator as our primary specification. In a small-N, small-T context, GMM is often prone to instrument proliferation, which can weaken the Hansen test and bias coefficients toward OLS. By contrast, the TWFE estimator provides more stable identification by exploiting within-country variation while controlling for unobserved time-invariant heterogeneity.

To ensure the validity of our inferences, we employ cluster-robust standard errors at the country level, which account for both heteroskedasticity and potential within-unit temporal dependence in the error terms. The empirical specification is given by the following log-linear regression model:

$$\begin{aligned} ln\ y_{i,t} = {} & \beta_0 + \beta_1\ ln\ k_{i,t} + \beta_2\ ln\ T_{i,t} + \beta_3\ ln\ D_{i,t} + \beta_4\ ln\ M_{i,t} + \beta_5\ Z_{i,t} \\ & + \beta_6(\ln\ T_{i,t} \times ln\ D_{i,t}) + \beta_7(ln\ T_{i,t} \times ln\ M_{i,t}) + \mu_i + \eta_t + \epsilon_{i,t} \end{aligned} \tag{17}$$

In this specification $y_{i,t}$ denotes the natural logarithm of real GDP per capita (in current 2015 US dollars, sourced from the World Development Indicators), serving as our primary proxy for long-run economic performance in the CAC region. The subscript i indexes the 18 countries in our sample, and t denotes the time (annual observations over 2010–2023). The key explanatory variables capture the core channels of interest in our semi-endogenous growth framework. Specifically, $k_{i,t}$ is the log of the capital stock per labor included to control for traditional factor accumulation effects and distinguish them from productivity-

driven growth sourced from the Penn World Table (PWT). $T_{i,t}$ represents Trade Openness, defined as the sum of exports and imports of goods and services from UNCOMTRADE divided by GDP (in current 2015 US dollars, sourced from the World Development Indicators), reflecting exposure to international markets as the primary conduit for external technology and knowledge diffusion. Our proxy to measure Digital Technology exposure $D_{i,t}$ is innovative, moving beyond simple infrastructure metrics (like broadband penetration) to capture digitally deliverable services trade; data is from UNCTAD. This approach better reflects the embodied knowledge flows and high-value service integration that are central to the digital economy frontier. This metric combines insurance and pension services; financial services; charges for the use of intellectual property n.i.e; telecommunications, computer and information services; research and development services; professional and management consulting services; architectural, engineering, scientific and other technical services; trade-related services; other business services n.i.e.; audio-visual and related services; health services and education services (excluding those consumed during international travel); heritage and recreational services, capturing trade-moderated access to frontier digital tools and their role in skill upgrading. Intended to reflect migration-moderated learning and knowledge transfers from technology advanced neighboring countries, the variable $M_{i,t}$ captures migration-driven knowledge and is proxied by the log of migration stock from CAC countries residing in the technology frontier country; USA, drawn from OECD database. This captures the human capital pool available for knowledge diffusion back to the region.

The two interaction terms β_6 and β_7 are central to testing our main hypotheses. They examine whether digital technology exposure and migration-mediated channels moderate (strengthen or weaken) the effect of trade openness on economic outcomes, consistent with the idea that external technology absorption amplifies trade's productivity benefits in small open economies like those in CAC region. Control variables, $Z_{i,t}$, include Government Effectiveness variable from WGI accounting for institutional quality that may influence policy implementation and growth, and inflation variable (annual CPI inflation rate), to control for macroeconomic stability.

Country fixed effects μ_i absorb all time-invariant heterogeneity, while η_t control for common time-varying shocks. Finally, $\epsilon_{i,t}$ is the idiosyncratic error term, which we allow to be heteroskedastic and serially correlated; standard errors are clustered at the country level to account for within-country dependence. Due to data availability in the Penn World Tables (PWT) for specific CAC countries, the panel is unbalanced; however, the fixed effects estimator remains unbiased under the assumption that the missingness is not correlated with the idiosyncratic error. Table 1 provides a detailed summary of the variables and data sources.

Table 1. Data Description and Sources.

Variable	Definition	Description	Sources
y	Ln GDP per Capita	GDP per capita current US$	World Bank (WDI)
k	Ln Capital per Labor	Capital Stock/Labor	Penn World Table (PWT); Penn World Table (PWT)
T	Ln Trade Openness	Exports of Goods and services + Imports of Goods and services: all commodities aggregated divided by GDP (current US$)	UNCOMTRADE; World Bank (WDI)
D	Ln Digital Technology	International trade in digitally deliverable services (DDS), value, shares and growth, annual in millions of current United States dollars. The following EBOPS-2010* services categories are covered: insurance and pension services; financial services; charges for the use of intellectual property n.i.e.; telecommunications, computer and information services; research and development services; professional and management consulting services; architectural, engineering, scientific and other technical services; trade-related services; other business services n.i.e.; audio-visual and related services; health services and education services (excluding those consumed during international travel); heritage and recreational services.	UNCTAD
M	Ln Migration Stock	Stock of Migrants from Central America and the Caribbean countries residing in the technology frontier country; USA	OECD
Z	Government Effectiveness	Government Effectiveness: estimate	Worldwide Governance Indicator (WGI)
	Inflation	Consumer price (annual %)	World Bank (WDI)

Note: The governance indicators are measured in units ranging from-2.5 to 2.5, with higher values corresponding to better governance outcomes.
Table 2 provides the descriptive statistics for the primary variables, while Table 3 presents the correlation matrix to assess potential multicollinearity.

Table 2. Descriptive statistics.

Variable	Obs	Mean	Std. dev.	Min	Max
GDP per Capita	252	8.973875	.7049577	7.330777	10.55142
Capital per Labor	196	11.964	.5388666	11.03057	13.01422
Trade Openness	238	25.49249	2.716937	20.7543	31.71482
Digital Technology	252	5.961512	1.483093	3.465736	10.31185
Migration	236	10.98143	2.284392	6.259459	15.99988
Government Effectiveness	252	−.0253869	.5075548	−1.084946	1.271063
Inflation	252	2.921299	2.580081	−3.078218	12.61055

Table 3. Pairwise Correlation.

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
GDP per Capita	1.000						
Capital per Labor	0.196*	1.000					
Trade Openness	0.111	−0.204*	1.000				
Digital Technology	0.331*	0.099	0.879*	1.000			
Migration	−0.425*	−0.392*	0.461*	0.366*	1.000		
Government Effectiveness	0.684*	0.000	0.064	0.140*	−0.362*	1.000	
Inflation	−0.343*	−0.051	0.088	0.040	0.402*	−0.266*	1.000

***$p<0.01$, **$p<0.05$, *$p<0.1$

Table 4. Estimated Results of Baseline Model

VARIABLES	(1) Ln GDPPC	(2) Ln GDPPC	(3) Ln GDPPC	(4) Ln GDPPC	(5) Ln GDPPC
Ln Capital per Worker	0.151** (0.0667)	0.142** (0.0663)	0.143* (0.0725)	0.140* (0.0716)	0.131* (0.0727)
Ln Trade Openness	0.0686*** (0.0253)	0.0543** (0.0260)	0.0382 (0.0285)	0.0366 (0.0282)	0.0300 (0.0295)
Ln Digital Technology		0.0620** (0.0302)	0.0634* (0.0324)	0.0451 (0.0331)	0.0422 (0.0334)
Ln Migration			0.0319* (0.0179)	0.0228 (0.0182)	0.0239 (0.0183)
Government Effectiveness				0.0700** (0.0326)	0.0701** (0.0327)
Inflation					−0.00386 (0.00492)
Constant	5.186*** (1.221)	5.309*** (1.211)	5.441*** (1.277)	5.717*** (1.268)	6.019*** (1.327)
Observations	191	191	175	175	175
R-squared	0.777	0.783	0.780	0.787	0.788
Number of ID	14	14	13	13	13
Year FE	YES	YES	YES	YES	YES

Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

5. Results and Discussion

5.1 Results

This section presents the empirical findings for the 18 CAC economies over the 2010–2023 period, operationalizing the modified Jones (1995) semi-endogenous growth framework detailed in Section 3. Consistent with the empirical specification in Section 4, we utilize a TWFE estimator to control for time-invariant country characteristics and common global shocks.

Table 4 reports the baseline model without interaction terms. Physical capital per worker emerges as the most robust driver of GDP per capita, with elasticities ranging from 0.131 to 0.151 and remaining statistically significant across specifications. Trade openness shows a positive and statistically significant effect in the initial specifications (0.0686, $p<0.05$ in column 1), consistent with the expected trade-growth linkage, but the coefficient weakens and loses significance as additional controls are introduced. Digital technology enters positively and significantly (0.0620, $p<0.05$ in column 2; 0.0634, $p<0.05$ in column 3), while migration displays a smaller but marginally significant positive effect (0.0319, $p<0.05$ in column 3). Government effectiveness is also positive and significant when included (0.0700, $p<0.05$), underscoring the importance of institutional quality. Inflation shows no statistically significant impact.

Table 5. Estimated Results with Moderators

VARIABLES	(1) Ln GDPPC	(2) Ln GDPPC	(3) Ln GDPPC	(4) Ln GDPPC
Ln Capital per Worker	0.143* (0.0725)	0.178** (0.0694)	0.187*** (0.0680)	0.183*** (0.0689)
Ln Trade Openness	0.0382 (0.0285)	−0.152*** (0.0539)	−0.299*** (0.0756)	−0.288*** (0.0754)
Ln Digital Technology	0.0634* (0.0324)	−0.718*** (0.194)	−0.682*** (0.190)	−0.675*** (0.194)
Ln Migration	0.0319* (0.0179)	0.0152 (0.0175)	−0.392** (0.151)	−0.379** (0.150)
Ln Trade Openness × Ln Digital Technology		0.0293*** (0.00718)	0.0280*** (0.00704)	0.0272*** (0.00722)
Ln Trade Openness × Ln Migration			0.0159*** (0.00585)	0.0151** (0.00584)
Government Effectiveness				0.0568* (0.0307)
Inflation				−0.000297 (0.00473)
	(0.0461)	(0.0439)	(0.0443)	(0.0473)
Constant	5.441*** (1.277)	10.21*** (1.685)	13.80*** (2.112)	13.73*** (2.110)
Observations	175	175	175	175
R-squared	0.780	0.803	0.813	0.817
Number of ID	13	13	13	13
Year FE	YES	YES	YES	YES

Standard errors in parentheses
***p<0.01, **p<0.05, *p<0.1

As an extension of the baseline results, Table 5 introduces the interaction terms to test the moderating roles of digital technology and migration-driven knowledge diffusion on the trade-growth relationship.

Once the interaction terms are included, the standalone coefficients on Ln Trade Openness, Ln Digital Technology, and Ln Migration turn negative and highly significant (e.g., Ln Trade Openness = −0.288, $p<0.01$ in the full model, column 4). While this appears counterintuitive compared to the baseline model (Table 4), it is a standard mathematical artifact in multiplicative interaction models with strong positive complementarities. In a log-linear interaction specification, the main effect of a variable represents its marginal impact strictly when the interacting moderator is exactly zero. Since our variables are expressed in natural logs, a value of zero implies that the level of the moderator is exactly 1 (e.g., $\ln(1)=0$), which represents a virtually nonexistent digital economy or migration stock far outside the observed sample range (see Table 2, where minimums are 3.47 and 6.26, respectively). Therefore, the negative main effects do not imply that trade or digital technology inherently harm growth; rather, they indicate that at extremely low levels of absorptive capacity, trade exposure is likely to lead to the displacement of domestic sectors without yielding productivity gains. To assess the true economic impact within the observed data range, we must evaluate the total marginal effect. For instance, at the sample

means (lnD ≈ 5.96; lnM ≈ 10.98), the total marginal effect of trade on growth is positive and significant:

$$-0.288+0.0272(5.96)+0.0151(10.98)=0.040.$$

This confirms that under normal CAC conditions, the net effect of trade is growth-enhancing, provided the foundational levels of digital and human conduits are in place.

It is also crucial to correctly scale the interpretation of the interaction coefficients (β_4 and β_5), as the log-log interaction specification represents the elasticity. A coefficient of 0.0272 for the Trade-Digital interaction means that a 1% increase in digital technology raises the trade-growth elasticity by 0.0272 percentage points. While this magnitude appears small, its cumulative economic significance is substantial. For example, at the sample mean, the baseline trade-growth elasticity is approximately 0.040. A 10% increase in digital technology exposure would increase this elasticity by 0.272 (0.0272×0.10), shifting the total trade-growth elasticity to 0.0427 a roughly 0.67 enhancement of trade's growth dividend. Over a sustained period of digital integration, these compounding marginal gains represent a powerful structural transformation lever, allowing CAC economies to shift from static comparative advantage to dynamic, skill-intensive trade baskets.

Our findings suggest that simply opening borders to international trade is not enough; a country must also have the digital tools to access information and the skilled human capital. Without this synchronized foundation, the potential benefits of global trade remain untapped. To ensure these results are not biased, we also accounted factors like Government Effectiveness, which we found to be a consistently strong and positive driver of national progress. We also accounted for inflation, which generally showed a negative relationship with growth, though its impact in our specific tests was not strong enough to be considered a primary factor. Ultimately, this evidence confirms that for a country to truly profit from global markets, it must first invest in infrastructures and human capital to turn trade opportunities into a stronger, more productive economy.

5.2 Discussion

The findings from this study reveal that for CAC economies, trade openness is not a guaranteed driver of prosperity but a conditional promoter that requires specific structural foundations to be effective. Historically, trade liberalization in the region was built on the assumption that simply opening up would spur growth through comparative advantage. However, the significant negative standalone coefficient for trade in this study validates a long-standing 'openness trap,' where unrestricted trade exposure can lead to the displacement of domestic industries before they are ready to compete. In the modern digital era, this displacement cost can only be offset when trade is synchronized with high-speed technical infrastructure and robust human networks.

The positive and highly significant interaction between trade and digital technology confirms that for the CAC region, technical infrastructure is a mandatory prerequisite for economic gain. This finding provides a theoretical foundation for the recent strategic pivot of multilateral organizations. For instance, the IDB's América en el Centro initiative and its Digital Trade Platform (PDCC 2.0) are not merely modernization projects; they are structural interventions designed to help policymakers guide the digital transformation in these lagging economies. By digitizing customs, health certifications, and logistics, these programs aim to convert friction-filled trade into the high-speed, synchronous exchange required for modern, efficiency-seeking nearshoring.

While the IDB establishes the capital requirements for closing physical broadband gaps, our results suggest that infrastructure alone is not a guarantee of economic returns. Specifically, if a CAC economy reaches the IDB's targeted penetration levels but its digitally deliverable services (DDS) trade remains subdued, it serves as a clear signal that the investment is underperforming. In such cases, the physical structure exists, but the expected GDP multiplier is being suppressed by secondary structural gaps, such as a lack of specialized digital skills or weak regulatory frameworks.

The necessity of advancing digital trade readiness is further underscored by the ongoing nearshoring shift of 2025–2026. Unlike the cost-seeking offshoring of the 1990s, current North American firms are relocating to the CAC region for the ability to integrate digitally into supply chains. Our results suggest that for countries with limited digital trade performance the traditional benefits of geographic proximity are neutralized by digital distance. This finding explains why organizations like the World Bank are prioritizing the Caribbean Digital Transformation Project, focusing on high-speed internet penetration not merely as a social service, but as a direct tool for trade resilience. By monitoring these economic indicators, policymakers can ensure that regional digital adoption acts as a permanent catalyst for high-value economic integration rather than becoming a sunk cost.

This systemic link between digital readiness and trade performance is further reinforced by a broader institutional web. While the IDB acts as a primary financial institution, organizations like the Central American Bank for Economic Integration and the WTO are increasingly focusing on digital trade facilitation. This alignment reflects the reality that digital adoption is a distinct pathway for expanding TFP. By providing the digital infrastructure for small and medium-sized enterprises to access global markets, these institutions are effectively working to reduce the barriers to successful trade openness identified in this model. Their efforts ensure that expanding technological capacity creates a multiplier for domestic productivity rather than a catalyst for sector displacement. Consequently, for countries that have not yet achieved sufficient digital readiness, the traditional benefits of geographic proximity are no longer enough; they must navigate this institutional and technical frontier to turn global trade exposure into genuine economic growth.

Another critical insight of this study is the role of migration-driven knowledge diffusion in the CAC region. As we discussed previously, while global organizations emphasize the necessity of physical infrastructure, our results suggest that increasing internet access is only one part of the growth equation. Many economies in this region face a gap in domestic technical skills; they may possess the necessary broadband connectivity but lack of the specialized expertise to use it for high-value economic activities. In this context, the diaspora particularly the large population of migrants living in the United States becomes a significant factor in increasing national productivity.

Individuals living in advanced economies often work at the forefront of technological and professional services, possessing specialized knowledge and management experience that local educational systems in their home countries may not currently provide. Our findings regarding the interaction between trade and migration show that these human networks act as a channel for transferring this expertise back to the region. This transfer can occur without the physical return of migrants; for example, professionals abroad can provide remote consulting, technical training, and mentorship to domestic firms. These activities improve the quality of local services and help domestic companies meet international standards, making them more competitive in global trade.

Historically, regional policymakers have viewed the emigration of highly educated citizens as a total loss of human capital. However, our research suggests that this perspective overlooks a significant resource. Migrants often maintain strong ties to their home countries and are frequently more willing to invest in or share technology with local businesses than traditional foreign investors. These diaspora networks reduce the psychological distance for foreign investors and provide high-level technical expertise that the local educational pipeline may currently lack. This human conduit effectively lowers the entry barriers for trade-related investments, allowing domestic firms to climb the value chain more rapidly than through isolated domestic efforts.

The practical impact of this finding is evidenced by the recent surge in remote hiring by North American companies within the CAC region. By leveraging time-zone alignment and growing digital readiness, firms can access a talent pool at costs often lower than U.S. wages. This expansion in services-led nearshoring supports our finding that the gains from trade are maximized when human capital and digital infrastructure are synchronized. For economies with less integrated digital networks, the structural costs of openness such as the displacement of low-skill domestic sectors remain high. For those with more mature digital integration, the diaspora serves as a resilience buffer, allowing the region to compete on high-value, digitally integrated, and culturally aligned labor.

A final critical factor in the development of the CAC region is the strategic role of institutional quality in managing the transition toward a digital economy. In this study, Government Effectiveness was found to be statistically significant across the models, though it re-

mained at the 10% significance level. This finding suggests an immense opportunity for regional growth; it indicates that while the institutional foundations are in place, there is a significant efficiency premium yet to be captured by refining how these institutions manage human and technical capital. Our results highlight more information on why these institutions need to move beyond the administrative signing of trade agreements and toward high-impact implementation. While the institutional baseline provides a stable foundation, the 10% significance level suggests that the efficiency gains from institutional quality are currently secondary to the more dominant structural requirements of digital and human capital. By evolving from a focus on the physical acquisition of technology to a strategy centered on specialized workforce training, institutions can help their economies more rapidly realize the full economic potential of trade.

Furthermore, our findings on migration-driven knowledge diffusion reveal a significant, low-cost opportunity for institutional innovation. Currently, most regional frameworks focus on the financial benefits of remittances; however, there is a profound opportunity to expand these mechanisms to include the technical expertise of the diaspora. By creating institutional platforms to map the specialized skills of citizens abroad and integrating them into national development plans, governments can bridge domestic technical gaps almost immediately. This human-centric approach would allow CAC nations to meet the high-level management and technical needs of modern trade without the long lead times of traditional educational reform. The marginal significance of government effectiveness identifies the exact area where institutional pivoting can yield the highest returns. For trade openness to serve as a genuine engine for prosperity, the institutional environment can transition from a passive participant in global trade to an active catalyst for productivity. By coordinating digital readiness with human capital both at home and abroad, institutions can ensure that the region successfully navigates the changing landscape of global trade.

6. Conclusion

6.1 Overall Findings

This study has investigated the conditional nature of the trade-growth linkage across 18 CAC economies from 2010 to 2023. By moving beyond traditional neoclassical frameworks to adopt a semi-endogenous growth model, we have demonstrated that trade openness is not an automatic driver of prosperity. Instead, its success is fundamentally moderated by a nation's digital infrastructure and its ability to harness migration-driven knowledge diffusion.

Our empirical results reveal a significant openness trap. In the absence of sufficient technical and human software, trade exposure can lead to domestic sector displacement, as evi-

denced by the negative standalone coefficient for trade in our full model (−0.288). This suggests that for many CAC nations, market liberalization without internal readiness may actually suppress productivity. However, the positive and highly significant interaction terms for digital technology (0.027) and migration stock (0.015) confirm that these channels act as essential productivity multipliers.

The interaction between digital readiness and human capital connectivity provides a new strategic lens for the region. We find that the marginal returns on trade become increasingly positive as an economy advances its digital infrastructure and human capital networks. These factors represent the essential foundations required for CAC nations to transition from passive commodity exporters to active participants in high-value global value chains. Critically, strengthening these channels facilitate a process of technological leapfrogging, enabling resource-constrained economies to bypass traditional, capital-intensive industrialization stages and move directly into the high-value digital and services-led sectors that define the modern frontier. Crucially, our results suggest that these two channels are complementary; a robust diaspora network can temporarily buffer gaps in digital infrastructure, while high-speed connectivity can amplify the reach of a smaller diaspora.

6.2 Policy Implications: From Passive Openness to Structural Synchronization

The empirical findings of this study highlight a fundamental shift in the development paradigm for the CAC region. The traditional reliance on passive trade openness, the assumption that liberalization alone triggers growth, is contradicted by our findings regarding standalone trade. This suggests that in an era of rapid technological shifts, trade exposure without a corresponding domestic interface can be predatory rather than productive, leading to the displacement of local sectors that cannot compete with digitally integrated global firms.

The structural synchronization of digital and human capital offers a new perspective for CAC policymakers, shifting the focus from static geographic advantages to dynamic proximity assets. The core policy implication is that Digital Technology (D) and Migration-driven knowledge diffusion (M) function as compensatory levers; they allow resource-constrained nations to mitigate structural weaknesses through strategic substitution.

For nations facing broadband gaps, the priority must shift toward aggressive diaspora engagement. Policy should complement both financial and non-financial remittance with the brain gain—incentivizing the return of tacit knowledge and specialized expertise from citizens abroad to buffer domestic productivity. Conversely, nations with smaller diasporas must prioritize deepening digital infrastructure. By reducing digital distance and transaction costs, these countries can remain competitive even without a massive human pipeline abroad. Ultimately, as the 2026 nearshoring wave approaches, geographic nearness to the United States will no longer suffice as a competitive moat. To capture high-value FDI, CAC

states must transition from being geographic neighbors to synchronized functional partners. Policy must ensure that domestic firms achieve both digital and human proximity, allowing them to integrate seamlessly into the increasingly complex, data-driven global supply chain.

6.3 Policy Recommendations

Although specific data limitations regarding digital technology and migrant skills require a cautious reading of exact magnitudes, the robustness of our empirical results offers compelling evidence base for the following policy recommendations.

6.3.1 Digital Technology as a Driver of Productivity

Our results show that the low-growth trap persists when a country lacks of the capacity to effectively use digital tools. Governments should prioritize making international digital services such as cloud computing, specialized software, and data analytics more accessible to local businesses. Since most Central American and Caribbean countries do not manufacture their own hardware or software, they must build their digital infrastructure through imports. Every time a local firm adopts a Digitally Deliverable Service (DDS), it adds to the country's total stock of technology. For example, when a small manufacturer moves from paper-based records to an imported digital inventory system, their productivity spikes because they can fulfill orders faster and with fewer errors. By modernizing customs for tech imports and improving internet reliability, governments enable this digital stockpiling. This allows local businesses to transition from manual labor to tech-driven operations.

6.3.2 Institutionalize the Diaspora Networks

Our research indicates that the knowledge and international exposure gained by the diaspora in frontier economies represent a significant opportunity for regional growth. To better integrate this resource into the local economy, policies should focus on creating formal channels for the flow of expertise: Governments could create formal registries to maintain a connection with citizens and students residing abroad. By identifying the specific technical expertise of the diaspora, the state can invite these professionals to serve as remote advisors or technical leads for high-impact domestic projects. This allows the country to benefit from frontier knowledge regardless of whether the individual is currently living at home or abroad. To encourage the physical return of talent, governments can streamline the process for recognizing international degrees and professional certifications. This ensures that the expertise gained abroad is easily transferable and can be immediately applied to enhance the productivity of local sectors, making it a smoother transition for both the returnee and the domestic employer.

Ultimately, these recommendations suggest that the low-growth trap is not a failure of trade itself, but a deficit in the capacity to absorb new ideas. By prioritizing the channels

of digital adoption and diaspora engagement, CAC nations can move beyond past missed opportunities. In the 2026 nearshoring era, these strategies provide a roadmap for converting global trade exposure into domestic prosperity. When local firms are equipped with modern digital tools and supported by the expertise of the diaspora, trade evolves from a simple exchange of goods into a powerful vehicle for knowledge transfer. This synchronized approach is the most viable way for the region to break the cycle of stagnation and secure long-term growth.

6.4 Limitations and Future Studies

While this study provides novel insights into the conditional trade-growth nexus in the CAC region, several limitations must be acknowledged. First, regarding endogeneity, we recognize that trade openness, digital adoption, and migration stocks are potentially endogenous to economic growth. Although our primary TWFE estimator effectively controls for unobserved time-invariant heterogeneity, it does not fully eliminate bias from simultaneity or time-varying omitted variables. We initially estimated System GMM specifications to address this; however, the small-N, short-T structure of our panel (18 countries over 14 years) led to severe instrument proliferation, invalidating the moment conditions (Hansen $p=1.000$; AR (2) $p=0.001$). Consequently, we reverted to TWFE with cluster-robust standard errors. Future research with extended time series or suitable external instruments could further isolate the causal mechanisms identified here.

Second, there are inherent measurement constraints regarding our digital technology proxy. Ideally, our framework would utilize domestic digital infrastructure stocks (e.g., broadband penetration or server density). However, CAC economies import virtually 100% of their digital and ICT hardware and software; thus, domestic production data is nonexistent. In the absence of standardized, time-series data on domestic ICT capital stock for these specific small economies, we utilize international trade in DDS as a proxy. While DDS is technically a trade flow, it serves as a highly relevant proxy for embodied digital absorption—it captures the degree to which an economy is engaging with, importing, and utilizing high-value digital services and frontier technologies. We acknowledge, however, that it captures digital engagement rather than domestic physical infrastructure, and future data improvements should seek to isolate domestic network capacity.

Lastly, our migration variable proxy's human capital using the total volume of migrant stocks in the USA, rather than the specific skill level of those migrants. The theoretical mechanism relies on brain gain and tacit knowledge transfer, which is ideally measured by high-skilled diaspora networks. Unfortunately, bilateral databases containing consistent, time-series data on the educational attainment of CAC migrants over the 2010–2023 period are severely fragmented or entirely missing for the smaller island economies in our sample. We employ total migrant stock under the assumption that even lower-skilled migration net-

works facilitate vital information frictions reduction, remittance-financed tech adoption, and trade-cost reduction, acting as a proxy for overall network size. Nonetheless, we recognize that approximating skill with volume may be the first step to dilute the estimated magnitude of tacit knowledge spillovers.

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Appendix A: The Jones (1995) Benchmark Model

This appendix presents the complete derivation of the benchmark Jones (1995) semi-endogenous growth model that underlies the theoretical framework in Section 3. The equations here are standard and are reproduced for completeness and transparency.

A.1 Production Technology

The economy produces a single good using capital and effective labor under a standard Cobb-Douglas technology:

$$Y_{i,t}=K_{i,t}^{\alpha}(A_{i,t}L_{i,t})^{1-\alpha},\ 0<\alpha<1 \tag{A.1}$$

where i denotes the country, t denotes the year, $K_{i,t}$ is physical capital, $L_{i,t}$ is total labor, and $A_{i,t}$ is total factor productivity (TFP). Dividing both sides by $L_{i,t}$ and defining $y_{i,t}=Y_{i,t}/L_{i,t}$ as output per worker and $k_{i,t}=K_{i,t}/L_{i,t}$ as capital per worker, the intensive form of the production function is:

$$y_{i,t}=k_{i,t}^{\alpha}A_{i,t}^{1-\alpha} \tag{A.2}$$

A.2 Capital Accumulation

Capital evolves according to the standard Solow accumulation identity:

$$\dot{K}_t=sY_t-\delta K_t \tag{A.3}$$

where $s\in(0,\ 1)$ is the savings rate and $\delta>0$ is the depreciation rate of physical capital.

A.3 Labor Allocation

Total labor grows exogenously at rate n:

$$\dot{L}_t=nL_t,\ L_t=L_{Y,t}+L_{A,t} \tag{A.4}$$

where $L_{Y,t}$ is labor allocated to goods production and $L_{A,t}$ is labor allocated to research and development.

A.4 The Jones (1995) Knowledge Production Function

The stock of ideas A_t evolves according to:

$$\dot{A}_t=\delta_A A_t^{\phi}L_{A,t}^{\lambda},\ \phi<1, 0<\lambda\leq 1 \tag{A.5}$$

where $\delta_A>0$ measures research productivity, $\phi<1$ imposes diminishing returns to the existing stock of ideas (the "stepping on toes" or "fishing out" effect), and $\lambda\leq 1$ captures decreasing returns to the number of researchers (duplication of effort). The parameter restriction $\phi<1$ is the defining departure from Romer (1990), which assumed $\phi=1$.

A.5 The Instantaneous Growth Rate of Technology

Dividing both sides of Equation A.5 by A_t, the instantaneous growth rate of technology is:

$$g_A \equiv \frac{\dot{A}_t}{A_t} = \delta_A A_t^{\phi-1} L_{A,t}^{\lambda} \tag{A.6}$$

Because $\phi - 1 < 0$, the growth rate g_A declines as the knowledge stock accumulates, unless research effort $L_{A,t}$ expands sufficiently to offset this drag.

A.6 The Balanced Growth Path

Assuming a constant fraction ℓ of total labor is allocated to research, $L_{A,t} = \ell L_t$, and that labor grows at rate n, the balanced-growth-path (BGP) condition requires $\dot{g}_A = 0$. Differentiating the log of Equation A.6 with respect to time:

$$\frac{\dot{g}_A}{g_A} = (\phi - 1) g_A + \lambda n = 0 \tag{A.7}$$

Solving for the BGP growth rate of technology:

$$g_A^* = \frac{\lambda n}{1 - \phi} \tag{A.8}$$

This is the central result of Jones (1995): long-run per-capita growth is determined solely by the rate of population growth n and the structural parameters λ and ϕ, and is independent of the level of R&D intensity or government R&D subsidies. Larger economies may achieve higher levels of income, but they do not grow permanently faster. This eliminates the empirically rejected scale effect present in Romer (1990) and Grossman and Helpman (1991).