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ICT Adoption, Innovation, and Labor Productivity in ASEAN: Evidence from Panel Data Analysis

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Abstract

Why do stark productivity disparities persist in ASEAN despite rapid digitalization? This study investigates the divergent drivers of labour productivity in the advanced ASEAN-6 and the catching-up ASEAN-10 from 2000–2023. Employing dynamic panel models, we demonstrate a fundamental dichotomy. In ASEAN-10, basic internet access and foreign direct investment (FDI) are the primary catalysts, enabling catch-up growth. Conversely, in the more developed ASEAN-6, productivity is driven by frontier innovation - specifically, patentable outputs and long-term R&D - while broad digital expansion yields diminishing returns. Critically, we identify an innovation - productivity paradox: composite innovation inputs show negative returns, whereas tangible patent applications consistently enhance productivity. The findings prescribe a bifurcated policy approach: ASEAN-10 must focus on technology diffusion and strengthening intellectual property, while ASEAN-6 should prioritize mission-oriented R&D and enhancing the commercialization ecosystem to escape the middle-income trap.

Keywords: ICT adoption, innovation, labor productivity, ASEAN economies, panel data analysis, JEL Code: O33, O47, F21, C23

Introduction

The Association of Southeast Asian Nations (ASEAN), established in 1967 to provide regional economic growth and integration, grew from its initial five founding members—Indonesia, Malaysia, the Philippines, Singapore, and Thailand - to Brunei, Vietnam, Laos, Myanmar, and Cambodia, which underscored a common desire for peace and economic progress (Rajaratnam, 1992).

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ASEAN productivity growth during the latest period has been partly driven by ICT investment and technology innovation, as the increased Solow growth model would put ICT at the forefront of productivity driving (Salim et al., 2024). Along with technology, human capital and innovation capacity remain a prerequisite for long-term growth; it is clear that countries that advance education and innovation-supportive environments - such as Indonesia and Thailand—experience superior economic performance (Muhamad et al., 2018; Fatimah et al., 2021). Nevertheless, prevailing imbalances in ICT infrastructure, quality education, and innovation capacity remain to constrain balanced regional development (ASEAN Secretariat, 2021).

Structural transformation and value chain integration have also driven productivity growth, as captured by Vietnam's experience with FDI and digitalization - defining "technology leapfrogging" benefits (Bairagi, 2024; OECD, 2019). On the other hand, richer economies like Singapore experience diminishing marginal returns with already high levels of productivity (Bloom et al., 2017), while middle-income countries like Malaysia experience the "productivity middle-income trap" since the initial gains from labor reallocation do not amount to lengthening overall productivity growth (World Bank, 2024, Guindo et al., 2023). The trends confirm Rodrik’s (2016) argument that "premature deindustrialization" can keep follower economies behind by preventing them from growing higher value-added output.

Investment in research and development (R&D) remains most important for sustained productivity, with higher R&D spending linked to higher quality products and competitiveness (World Bank, 2019). However, significant disparities remain: Singapore and Malaysia have well-established innovation systems (Wong, 2022), whereas other countries like Myanmar and Laos lack high R&D investment and weaker institutions (ASEAN Secretariat, 2021b). Singapore leads in the Global Innovation Index, while Cambodia, Myanmar, and Laos trail behind, indicating chronic disparity (WIPO, 2023).

Today's digital revolution—saturation of the internet, mobile technology, and cloud computing—has enormous productivity potential by closing information gaps and enhancing supply chains. ASEAN's Digital Masterplan 2025 looks forward to increased ICT adoption and a strong digital economy, but flaws such as uneven infrastructure and emerging cybersecurity vulnerabilities remain (Kaspersky, 2023). ASEAN's digital economy is expected to reach USD 1 trillion by 2030, driven by e-commerce and fintech (World Economic Forum, 2023). But slow adoption of emerging technologies like AI and ongoing digital skills gaps can exacerbate inequality. R&D expenditure is still uneven: Singapore spent 2.17% of GDP, Malaysia 1.33%, with Cambodia and Myanmar spending less than 0.2% in 2020 (UNESCO, 2021). Addressing these gaps is essential in realizing ASEAN's ambition to become an innovation center by 2030 (ASEAN, 2023).

While existing research typically examines these drivers separately or focuses on OECD economies, limited empirical studies examine how ICT adoption, innovation, human capital, infrastructure, and FDI combine to affect productivity in ASEAN, particularly between ASEAN-6 and ASEAN-10. The current study answers the essential question: What are the drivers that contribute most significantly to labor productivity growth in ASEAN economies, and how do their effects differ across ASEAN-6 and ASEAN-10? This is an important issue given the persistence of structural infrastructure deficits, education, and innovation systems (ASEAN Secretariat, 2021a). For example, R&D spending and patent applications remain high in Malaysia and Singapore (WIPO, 2023; UNESCO, 2021), while stagnation is threatened in Malaysia and lower-development members Cambodia and Myanmar are inhibited by institutional bottlenecks (World Bank, 2024; ASEAN Secretariat, 2021b). Structural transformation, GVC integration, and foreign capital inflows complicate productivity trajectories (OECD, 2019; Rodrik, 2016).

This study empirically investigates the combined effect of these drivers on labor productivity in 2000–2023 using dynamic panel estimation (Fixed Effects and System GMM) from endogenous growth theory and the Technology–Organization–Environment. The findings will be employed to inform policy actions aimed at enhancing innovation systems, upgrading digital infrastructure, and aligning human capital with the demands of the market to support more balanced and sustainable growth in productivity across ASEAN.

Review of the Literature

This study draws on four complementary theories to explain how ICT adoption and innovation affect labor productivity in ASEAN. First, the Endogenous Growth Theory (Romer, 1990) emphasizes that growth is fueled by domestic factors like innovation, R&D investment, and human capital accumulation. Knowledge spillovers from ICT adoption can increase industry-wide productivity (Brynjolfsson et al., 2014), but heterogeneous institutional quality and absorptive capacity in ASEAN may limit such benefits. Second, the Technology–Organization–Environment (TOE) Framework (Tornatzky et al., 1990) explains how technological readiness, organizational capacity, and external environments affect ICT integration. Thailand 4.0 and Singapore's Smart Nation illustrate how supportive policy and organizational capacity translate technological potential into productivity gains. Third, Diffusion of Innovations Theory (Rogers, 2003) explains how new technologies spread through societies. The rate of adoption depends on perceived benefits, compatibility, and visibility. This helps explain why advanced economies like Singapore lead in AI and 5G adoption, while infrastructural and cultural barriers slow uptake elsewhere.

Finally, Knowledge Spillover Theory (Audretsch et al., 2004) accounts for why some regions benefit more from pooled knowledge, highlighting the absorptive capacity of human capital (Cohen et al., 1990) for external innovations. Successful regional clusters such as Singapore's Block 71 and Malaysia's Penang ICT corridor illustrate these processes, while less human capital-endowed countries such as Myanmar witness less spillover. By combining these theories, the study covers macro-level drivers (R&D and innovation), policy and organizational context (TOE), technology diffusion processes, and the role of human capital in moderating productivity gains. Together, they suggest that technology alone is insufficient without complementary institutions, skilled workers, and effective diffusion.

There is extensive literature linking ICT adoption and innovation to increases in productivity in ASEAN. Vu (2017) and Salim et al. (2024) identify internet and mobile use to have a significant impact on labor productivity, and hence this study includes these as variables. Earlier studies mostly employed static models; this study uses dynamic panel GMM to account for endogeneity and lagged effects (Vu, 2013; Jing et al., 2020). With regards to innovation, (Idota et al., 2014) show organizational learning and ICT adoption support innovation among manufacturing firms. (Na & Kang, 2019) discover that product innovation boosts sales, but process innovation slows down initial growth. (J. Zhang & Islam, 2020) show R&D spending supports innovation in services, while (Calza et al., 2018) discover innovation is better for Vietnamese SMEs when they are on par with international standards.

Other studies consider moderating variables. (Ahmed, 2017) and (Ismail, 2018) stress education and human capital as the turning point in transforming ICT into productivity. (Nguyen-Van & Chang, 2024) show FDI drives innovation, supporting this study's examination of FDI flows. (Wongwuttiwat et al., 2024) document ASEAN's unbalanced digital readiness, and the need for fixed effects to account for differences in structures. Challenges are documented. (Quimba et al., 2024) find the Philippines falls behind in AI adoption despite proper infrastructure, due to barriers in regulation and skills. (Bunyi & Cua, 2013) show ICT impacts vary by type: hardware boosts productivity, yet web presence may not. Suphannachart (2017) illustrates Thai farming is capital and R&D intensive instead of demographic. Putra (2024) documents subnational variation in Indonesia's ICT impacts.

Modern research shows temporal dynamics. Vu & Nguyen (2022) illustrate prolonged ICT adoption improves SME performance in line with the dynamic context of this study. (Nakavachara, 2020) finds that broadband boosts Thai SME productivity, while (Tan & Aung, 2025) and (Vutha & Thangavelu, 2023) report post-pandemic productivity gains linked to digitalization in Brunei and Cambodia, respectively (Sorn et al., 2023) and (Vixathep & Phonvisay, 2019) find human capital importance, especially in Laos and Cambodia. Methodologically, studies vary from Malmquist TFP indices (Afzal et al., 2023) to structural equation and fixed effects modeling. (L. Zhang et al., 2025) note that governance quality and innovation capability combined enable the growth of digital trade. In conclusion, existing research indicates ICT and innovation have the greatest impact on productivity when accompanied by human capital, institutions, and FDI inflow. Country- and sector-level factors determine such impacts. This work contributes to existing literature by: (1) examining ICT and innovation together; (2) using dynamic GMM over 2000–2023 to account for cumulative effects; and (3) including, FDI, and human capital to investigate heterogeneity in ASEAN.

Method, Data and Analysis

- **Conceptual Framework and Theoretical Foundation**

This study's analytical approach is grounded in a synthesis of neoclassical and endogenous growth theories. The foundational Solow Growth Model (Solow, 1956) provides the basis for understanding capital accumulation and exogenous technological progress. This framework is extended by Endogenous Growth Theory (Romer, 1990; Lucas, 1988), which emphasizes the pivotal roles of intentional innovation, research and development (R&D), human capital accumulation, and knowledge spillovers as internal drivers of long-term productivity growth.

Guided by this theoretical foundation, we investigate a set of key drivers derived from the literature: ICT adoption, innovation outputs and inputs, human capital, physical infrastructure, and foreign direct investment (FDI). This integrated framework allows us to test whether the forces highlighted by endogenous growth theory are actively shaping productivity trajectories across ASEAN's diverse economies.

❖ Country Grouping and Justification

To account for the significant heterogeneity in development stages and institutional maturity within ASEAN, the empirical analysis is conducted on two distinct country groups:

ASEAN-6: This group comprises the six founding and earlier members with relatively more advanced and diversified economies: Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Brunei.

ASEAN-10: This group expands the analysis to include all ten-member states, adding the four transitional economies that joined later: Cambodia, Laos, Myanmar, and Vietnam.

The analysis first focuses on the ASEAN-6 to isolate drivers in more mature economies and is subsequently extended to the ASEAN-10 to provide a comprehensive regional overview and capture the distinct catch-up dynamics present in the less developed members. This split allows for a nuanced comparison of how productivity drivers differ across the development spectrum.

Table 1. Country Groupings for Panel Data Analysis

Group	Countries	Rationale
ASEAN-6	Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei	Founding and earlier members with more established, diversified economies.
ASEAN-10	ASEAN-6 + Cambodia, Laos, Myanmar, Vietnam	The full ASEAN membership, capturing a wider spectrum of development levels.

The chosen time frame, 2000–2023, is strategically selected as it captures three pivotal technological epochs: the pre-digital era of the early 2000s; the smartphone and mobile broadband revolution of the 2010s; and the post-pandemic acceleration in digitalization (2020–2023).

- **Data Sources and Variable Construction**

The study employs a balanced panel dataset spanning 23 years (2000-2023) for the ASEAN countries. All data are sourced from reputable international databases to ensure reliability, consistency, and cross-country comparability. The construction and justification of variables are as follows:

- **Dependent Variable**
  - **Labor Productivity (LP):** Measured as GDP per person employed (constant 2021 PPP dollars). *Source: World Bank.*
- **Core Explanatory Variables**
  - **ICT Adoption**: Proxied by (1) Individuals using the Internet (% of population) and (2) Mobile cellular subscriptions (per 100 people). *Source: International Telecommunication Union (ITU) and World Development Indicators (WDI).*
  - **Innovation**: Captured through three measures: (1) R&D expenditure (% of GDP) (input), (2) Patent applications (per million people) (tangible output), and (3) the Global Innovation Index (composite measure). *Sources: UNESCO, World Intellectual Property Organization (WIPO), and the Global Innovation Index.*
- **Complementary and Control Variables**
  - **Human Capital**: Proxied by average years of schooling of the population aged 15 and above. Source: Barro-Lee Dataset. We acknowledge this variable's limitation as a measure of educational quantity rather than quality. Our findings related to this variable should be interpreted with this in mind, echoing the literature (e.g., Hanushek & Woessmann, 2008, 2012) that emphasizes cognitive skills as the true driver of growth.
  - **Infrastructure:** Measured by (1) Electricity access (% of population) and (2) Road density (km per 1,000 people). Source: World Development Indicators (WDI). While road density is a standard proxy, it captures the quantity of infrastructure. Our interpretation of its frequent insignificance is supported by literature (e.g., Calderón & Servén, 2010; World Bank, 1994) which finds that the quality and efficiency of infrastructure are far more critical for productivity.

- **Foreign Direct Investment (FDI):** Measured as Net FDI inflows (% of GDP). Source: UNCTAD and World Bank.

❖ **Empirical Strategy and Model Specification**

The analysis is guided by two central hypotheses:

- H1: ICT adoption exerts a significant positive impact on labor productivity in ASEAN countries.
- H2: Human capital, infrastructure, and FDI significantly enhance labor productivity.

To test these hypotheses robustly, we employ a two-stage econometric approach.

❖ **General Empirical Model The baseline model is specified as follows:**

$$LP_{it} = \beta_0 + \beta_1 ICT_{it} + \beta_2 Innovation_{it} + \gamma X_{it} + \alpha_i + \lambda_t + \varepsilon_{it}$$

where:

- LP_{it} is labor productivity in country i at time t.
- ICT_{it} and $Innovation_{it}$ represent the main vectors of explanatory variables.
- X_{it} is a vector of control variables (FDI, human capital, infrastructure)
- α_i captures unobserved country-specific fixed effects.
- λ_t represents year-fixed effects to control for common temporal shocks.
- ε_{it} is the idiosyncratic error term

❖ **Estimation Techniques**

Fixed Effects (FE) Regression: We first employ the FE estimator (using Stata's xtreg command) to control for all time-invariant, country-specific heterogeneity (α_i). The model includes year-fixed effects and uses robust standard errors clustered at the country level to account for heteroscedasticity and serial correlation. A Hausman test is used to formally validate the FE model over the Random Effects (RE) alternative.

System Generalized Method of Moments (System GMM): To address potential endogeneity (e.g., reverse causality where higher productivity might attract more FDI or enable higher R&D spending) and to capture the dynamic nature of productivity (where past productivity influences current productivity), we employ the System GMM estimator (Blundell & Bond, 1998) via Stata's xtabond2 command.

- This estimator uses internal instruments (lagged levels and differences of the variables) to control for endogeneity.
- We use the "collapsed" instrument option to prevent instrument proliferation and maintain the reliability of specification tests.
- The consistency of the GMM estimator is verified using several diagnostic tests: the Arellano-Bond test for autocorrelation [AR (1) and AR (2)] and the Hansen test for the validity of the overidentifying restrictions.

❖ **Diagnostic and Validation Procedures**

The analysis follows a rigorous sequence:

Descriptive Statistics: Summarizing all variables to understand data distribution and heterogeneity.

Stationarity Testing: Fisher-type Augmented Dickey-Fuller (ADF) tests are applied to check for unit roots and mitigate spurious regression risks.

Model Estimation and Comparison: Both FE and System GMM results are estimated and compared to assess the robustness and consistency of the findings across different model assumptions.

This comprehensive methodological approach allows us to provide credible and nuanced insights into how technological adoption, innovation, and complementary factors shape labor productivity across ASEAN's diverse economic landscape.

Result and Discussion

❖ **ASEAN-10 Results**

Empirical data for ASEAN-10 partially supports Hypothesis 1 concerning the effects of ICT adoption and innovation on labor productivity. Descriptive statistics appear in Table 4.1: average GDP per employed individual is USD 42,450 (constant 2021 PPP dollars) and has a high standard deviation (52.52), indicating extreme cross-country variation. Internet penetration is at 38.4%, mobile subscriptions 83.4 per 100 people, and patent applications have wide range variations, indicating structural variations across member nations.

❖ **Descriptive Statistics (ASEAN-10, 2000–2023)**

Table1 presents descriptive statistics of key variables in the ASEAN-10 sample for the period 2000–2023. Labour productivity, defined as GDP per capita employed, has a mean of approximately USD 42,450 (constant 2021 PPP dollars) with a high standard deviation of 52.52, reflecting a high level of heterogeneity across nations. Internet penetration is 38.4% of the population on average with extreme range (from 0% to 98%), while mobile subscriptions are fairly high, being 83.4 per 100 people. Innovation-related variables also exhibit extreme range; patent applications per million population have an average of 146 and a range of over 2,200, which reveals extreme cross-country variation in innovative capacity. Similarly, R&D expenditure as a percentage of GDP is also very small (mean = 0.91%) but extremely heterogeneous over the panel. Generally, these descriptive statistics make evident both structural heterogeneity over ASEAN economies and panel econometric methods to tackle country-specific heterogeneity.

Table 1. Descriptive Statistics of Key Variables (ASEAN-10, 2000–2023)
(N=240)

Variable	Mean	Std. Dev.	Min	Max
GDP per person employed (constant 2021 PPP $)	42.45	52.52	2.15	223.90
Individuals using the Internet (% population)	38.36	30.55	0.00	98.00
Mobile cellular subscriptions (per 100)	83.44	46.30	0.30	172.80
R&D expenditure (% of GDP)	0.91	1.04	0.00	4.10
Patent applications (per million people)	145.82	361.70	0.00	2235.00
Innovation Index	33.79	15.28	11.40	85.60
Average years of schooling	8.23	2.74	3.20	14.70
Net FDI inflows (% of GDP)	4.01	4.39	0.10	26.30
Electricity access (% population)	85.09	24.48	13.30	100.00
Road density (km per 1,000 people)	5.01	3.69	1.20	16.20

Source: Author's calculations. Data highlight wide cross-country heterogeneity.

❖ Stationarity Test Results (ASEAN-10)

To ensure the robustness of the regression analysis and rule out spurious correlations, Fisher-type Augmented Dickey–Fuller (ADF) tests were applied to examine the stationarity of all variables. Results show that three variables—Internet use, mobile subscriptions, and electricity access—are stationary at the 5% significance level, while most others, including the dependent variable (GDP per person employed), are non-stationary. Such non-stationarity risks introducing biased estimates by capturing shared trends rather than true causal effects. To address this, the study employs Fixed Effects regression with year-fixed effects (i.Year) to absorb time-specific shocks and trends, alongside the System GMM estimator, which corrects for dynamic persistence and endogeneity through lagged dependent variables and internal instruments.

Table 2. Stationarity Test Results (Fisher-type ADF) – ASEAN-10

Variable	Stationary?	Pm-stat
GDP per person employed	No	0.9695
Internet usage	Yes	0.0000
Mobile subscriptions	Yes	0.0000
R&D (% of GDP)	No	0.9982
Patent applications	No	0.8929
Innovation Index	No	0.8947
Average years of schooling	No	0.9983
FDI (% of GDP)	No	0.9170
Electricity access (%)	Yes	0.0000
Road density	No	0.9982

Note: Significant at 5% level means stationary in levels.

❖ Fixed Effects Regression (ASEAN-10)

Hausman test was used to choose between Fixed Effects (FE) and Random Effects (RE) specifications and yielded a chi-square value of 109.98 ($p < 0.01$), which rejected the null hypothesis in favor of FE. The preferred FE specification, estimated using year dummies and country-clustered robust standard errors, has strong within-country explanatory power ($R^2 = 0.955$). Patent filings per million people (coef. =

0.042, $p < 0.01$) and net FDI inflows (% GDP) (coef. = 0.905, $p < 0.01$) are crucial drivers of labor productivity. Use of the internet is also positively significant (coef. = 0.117, $p < 0.05$). All other variables, including R&D expenditures, mobile phone subscriptions, years of schooling, and infrastructure proxies, lack a statistically significant effect, meaning they have conflicting effects. The high contribution of FDI and physical innovation outputs (patents) shows these are the key sources of productivity growth in ASEAN-10 economies.

Table 3. Fixed Effects Regression Results on Labor Productivity (ASEAN-10, 2000–2023)

Variable	Coef.	Robust SE	t	p-value
Internet use (%)	0.117	0.045	2.60	0.029**
Mobile subscriptions	−0.019	0.017	−1.14	0.285
R&D (% of GDP)	−0.537	1.339	−0.40	0.698
Patent applications	0.042	0.002	20.50	0.000***
Innovation Index	0.313	0.154	2.04	0.072*
Average schooling years	−0.398	1.071	−0.37	0.719
FDI inflows (% GDP)	0.905	0.115	7.88	0.000***
Electricity access	−0.025	0.029	−0.86	0.412
Road density	−2.660	1.658	−1.60	0.143

R^2 (within): 0.955; N=240; 10 countries; clustered SE.

- **System GMM Regression (ASEAN-10)**

To address endogeneity and dynamic effects, the analysis employs System GMM estimation... The lagged dependent variable is highly significant (coef. = 1.0095, $p < 0.01$), indicating strong persistence in productivity.

This finding is critically important. A coefficient on the lagged productivity variable so close to unity suggests that the labor productivity process in the broader ASEAN-10 is highly persistent, closely resembling a random walk. This implies that past productivity levels are an almost perfect predictor of future levels, leaving little short-term variation for the included explanatory variables to explain. This high persistence points to the dominance of deep-seated structural and institutional factors—such as the quality of institutions, the robustness of the financial system, and deeply embedded technological capabilities—that evolve slowly over time and are not fully captured by our model's variables (Acemoglu & Robinson, 2012). It underscores that while policy can influence variables like FDI and internet access, fundamentally shifting the productivity trajectory of these economies requires long-term, structural reforms that alter these underlying institutional fundamentals.

FDI remains a positive and significant determinant (coef. = 0.0818, $p < 0.01$) even in this highly persistent model, confirming its unique role as a potent external force capable of disrupting path dependency. Other explanatory variables, including ICT and innovation indicators, are insignificant in this dynamic specification, likely because their effects are either overshadowed by this strong persistence or are themselves mediated through these slow-moving structural factors.

Table 4. System GMM Estimation Results (ASEAN-10, 2000–2023)

Variable	Coef.	Robust SE	z	p-value
L.GDP per person employed	1.0095	0.0079	128.16	0.000***
Internet use	0.0027	0.0072	0.37	0.712
Mobile subscriptions	−0.0012	0.0044	−0.26	0.792
R&D (% of GDP)	0.2179	0.1529	1.42	0.154
Patent applications	−0.0002	0.0003	−0.52	0.604
Innovation Index	0.0099	0.0072	1.38	0.166
FDI inflows	0.0818	0.0251	3.25	0.001***
Average schooling years	-0.0272	0.0373	-0.73	0.466
Electricity access	0.0043	0.0026	1.65	0.098***
Road Density	-0.0692	0.0540	-1.28	0.200

One-step GMM; N=230; instruments=32.

Table 5. Diagnostic Tests – ASEAN-10

Test	Statistic	p-value	Interpretation
AR(1)	−1.13	0.260	No serial corr.
AR(2)	−1.02	0.308	No serial corr.
Hansen	1.34	1.000	Instruments valid

❖ **Fixed Effects and System GMM Regression Results (ASEAN-10)**

The combined regression results for ASEAN-10 (Table 6) reveal distinct patterns between short-term associations and long-term dynamic effects, offering a nuanced view of productivity drivers in the broader region. The static Fixed Effects model indicates that internet adoption is a significant catalyst for productivity, a finding consistent with the Diffusion of Innovations Theory. This suggests that in less advanced ASEAN economies, basic digital inclusion delivers immediate benefits by transforming business practices and improving information flows. However, this positive effect vanishes in the dynamic System GMM specification, implying that without sustained parallel investments in digital skills and organizational restructuring - a key tenet of the TOE Framework—the initial productivity boost from connectivity may not be sustained over the long run.

A similar pattern emerges for innovation. Patent applications show a strong, positive association with productivity in the static model, directly supporting the Knowledge Spillover Theory by highlighting how tangible innovation outputs create immediate, economy-wide benefits. Yet, this relationship turns insignificant in the dynamic model, pointing to significant commercialization lags. This indicates that while patenting is a powerful signal of innovative capacity, the full productivity payoffs from these knowledge spillovers materialize only after a considerable delay.

In contrast, FDI inflows stand out as the most robust driver, demonstrating a significant and positive impact in both the static and dynamic models. This underscores the role of foreign investment as a persistent channel for technology transfer and managerial expertise, aligning with the predictions of Endogenous Growth Theory.

Meanwhile, several other variables - including mobile subscriptions, R&D expenditure, human capital, and infrastructure proxies - consistently show no statistically significant relationship with productivity in this context. This reinforces the conclusion that the mere expansion of these inputs is insufficient to boost productivity without complementary improvements in institutional quality, efficiency, and relevance to the economic structure. In summary, for ASEAN-10, the analysis distinguishes between short-level catalysts and long-term engines of growth. While internet access and patenting help explain cross-sectional productivity differences, the dynamic trajectory of the region is most strongly influenced by foreign direct investment. The findings caution that the benefits of innovation inputs are not instantaneous, emphasizing the need for policies that support the lengthy process of commercialization and capacity-building.

Table 6. Fixed Effects and System GMM regression results (ASEAN-10)

Variable	Fixed Effects Coef.	Robust SE	t	p-value	System GMM Coef.	Robust SE	z	p-value
Internet use (%)	0.117	0.045	2.60	0.029 **	0.0027	0.0072	0.37	0.712
Mobile subscriptions	−0.019	0.017	−1.14	0.285	−0.0012	0.0044	−0.26	0.792
R&D (% of GDP)	−0.537	1.339	−0.40	0.698	0.2179	0.1529	1.42	0.154
Patent applications	0.042	0.002	20.50	0.000 ***	−0.0002	0.0003	−0.52	0.604
Innovation Index	0.313	0.154	2.04	0.072 *	0.0099	0.0072	1.38	0.166
Average schooling years	−0.398	1.071	−0.37	0.719	-0.0272	0.0373	-0.73	0.466
FDI inflows (% GDP)	0.905	0.115	7.88	0.000 ***	0.0818	0.0251	3.25	0.001 ***
Electricity access	−0.025	0.029	−0.86	0.412	0.0043	0.0026	1.65	0.098***
Road density	−2.660	1.658	−1.60	0.143	-0.0692	0.0540	-1.28	0.200
Lagged GDP per person employed	–	–	–	–	1.0095	0.0079	128.16	0.000 ***

Notes:

- *Fixed Effects: R^2 (within) = 0.955; N=240; 10 countries; clustered SE.*
- *System GMM: One-step GMM; N=230; instruments=32.*

*Significance levels: *** p<0.01; ** p<0.05; * p<0.1.*

❖ ASEAN-6 Results

For ASEAN-6 (Singapore, Malaysia, Thailand, Indonesia, Philippines, Brunei), descriptive statistics in Table 4.6 reveal higher mean GDP per person employed (USD 52,850) and greater average internet penetration (43.3%), with patent applications also more concentrated.

❖ Descriptive Statistics (ASEAN-6, 2000–2023)

Table 7 summarizes the ASEAN-6 sample. GDP per person employed averages USD 52,850, with large dispersion. Innovation capacity, measured by patent applications, also varies widely (mean = 242). Internet penetration is higher (mean = 43.3%)

compared to ASEAN-10, and electricity access is almost universal (mean = 96.3%). These figures provide more advanced digital and infrastructure conditions relative to ASEAN-10.

Table 7. Descriptive Statistics of Key Variables (ASEAN-6, 2000–2023)
(N=144)

Variable	Mean	Std. Dev.	Min	Max
GDP per person employed (constant 2021 PPP $)	52.85	58.64	8.80	223.90
Internet use (% population)	43.33	29.63	0.00	98.00
Mobile subscriptions (per 100)	94.52	44.77	1.20	172.80
R&D expenditure (% of GDP)	1.48	0.99	0.10	4.10
Patent applications (per million)	242.10	441.95	1.00	2235.00
Innovation Index	40.20	15.91	11.40	85.60
Average years of schooling	9.80	1.99	5.80	14.70
Net FDI inflows (% of GDP)	4.37	5.49	0.10	26.30
Electricity access (% population)	96.25	6.14	75.00	100.00
Road density (km per 1,000 people)	4.63	2.15	1.50	9.50

Source: Author's calculations.

- **Stationarity Tests (ASEAN-6)**

Fisher-type ADF tests show that only two variables—mobile subscriptions and electricity access—are stationary in levels. Non-stationarity in other variables necessitates using time-fixed effects in FE models and dynamic GMM estimators to address common trends and ensure robust inference.

Table 8. Stationarity Test Results (Fisher-type ADF) – ASEAN-6

Variable	Stationary?	Pm-stat
GDP per person employed	No	0.9735
Internet usage	No	0.9539
Mobile subscriptions	Yes	0.0000
R&D (% of GDP)	No	0.9873
Patent applications	No	0.4885
Innovation Index	No	0.6980
Average years of schooling	No	0.9907
FDI (% of GDP)	No	0.9504
Electricity access	Yes	0.0000

Variable	Stationary?	Pm-stat
Road density	No	0.9886

Note: Only mobile subscriptions & electricity access are stationary in levels.

❖ Fixed Effects Regression (ASEAN-6)

The Hausman test again favors the FE model ($\chi^2 = 121.91$, $p < 0.001$). Patent applications (coef. = 0.046, $p < 0.01$), net FDI inflows (coef. = 1.147, $p < 0.01$), and average years of schooling (coef. = 1.453, $p < 0.05$) positively affect productivity. Conversely, mobile subscriptions (coef. = −0.078, $p < 0.05$) and electricity access (coef. = −0.450, $p < 0.05$) show significant negative effects, suggesting saturation or structural inefficiencies.

Table 9. Fixed Effects Regression Results on Labor Productivity (ASEAN-6, 2000–2023)

Variable	Coef.	Std. Err.	t	p-value
Internet use (%)	0.130	0.077	1.68	0.153
Mobile subscriptions	−0.078	0.033	−2.36	0.065**
R&D (% of GDP)	0.855	1.156	0.74	0.493
Patent applications	0.046	0.003	14.42	0.000***
Innovation Index	−0.222	0.202	−1.10	0.323
Average years of schooling	1.453	0.581	2.50	0.054**
FDI inflows (% GDP)	1.147	0.128	8.94	0.000***
Electricity access	−0.450	0.142	−3.17	0.025**
Road density	2.257	1.937	1.17	0.297

R^2 (within): 0.966; N=144; clustered SE by country.

❖ System GMM Regression (ASEAN-6)

Dynamic GMM estimation confirms the significant positive effects of R&D expenditure (coef. = 0.367, $p < 0.05$), patent applications (coef. = 0.006, $p < 0.01$), and FDI (coef. = 0.349, $p < 0.01$). The lagged dependent variable remains highly significant (coef. = 0.931, $p < 0.01$). Diagnostics validate model specification: no autocorrelation (AR(1) $p = 0.245$; AR(2) $p = 0.308$) and valid instruments per Hansen test ($p = 1.000$). These results highlight that in more institutionally mature ASEAN-

6 economies, sustained R&D investment and patent-driven innovation significantly enhance productivity.

Table 10. System GMM Estimation Results (ASEAN-6, 2000–2023)

Variable	Coef.	Std. Err.	z	p-value
L.GDP per person employed	0.931	0.031	29.75	0.000***
Internet use (%)	0.023	0.017	1.34	0.181
Mobile subscriptions	−0.008	0.009	−0.89	0.376
R&D (% of GDP)	0.367	0.156	2.35	0.019**
Patent applications	0.006	0.002	2.72	0.006**
Innovation Index	−0.096	0.043	−2.25	0.025**
Average years of schooling	0.204	0.222	0.92	0.359
FDI inflows (% GDP)	0.349	0.084	4.18	0.000***
Electricity access	0.071	0.067	1.06	0.289
Road density	0.533	0.494	1.08	0.280
Average years of schooling	0.204	0.222	0.92	0.359

N=138; instruments=32; one-step GMM.

Table 11. Diagnostic Tests – ASEAN-6

Test	Statistic	p-value	Interpretation
Wald Chi^2 (10)	49.67	0.000	Joint significance confirmed
AR(1)	−1.16	0.245	No serial correlation
AR(2)	−1.02	0.308	No serial correlation
Hansen	0.00	1.000	Instruments valid

❖ Combined Regression Results (ASEAN-6)

The analysis of the more advanced ASEAN-6 economies reveals a distinct set of drivers, where the dynamic, long-term model uncovers nuances not apparent in the static analysis. A clear divergence between innovation inputs and outputs is evident. While R&D expenditure shows no immediate effect in the static model, it emerges as a significant positive driver in the dynamic specification. This turnaround strongly supports the core tenet of Endogenous Growth Theory, confirming that in institutionally mature economies, the returns to research investment are realized with a considerable lag as ideas transition from the lab to the marketplace.

Conversely, the results for innovation outputs are unequivocal. Patent applications demonstrate a robust and statistically significant positive impact on productivity in both the static and dynamic models. This consistent finding powerfully validates the Knowledge Spillover Theory, underscoring that it is the tangible output of the innovation process - rather than the input - that serves as the most reliable vehicle for knowledge diffusion and productivity enhancement in these economies.

A striking and theoretically significant result is the significant negative relationship between the Innovation Index and productivity in the long-run model. This counterintuitive finding can be effectively interpreted through the Technology-Organization-Environment (TOE) Framework. It suggests a critical misalignment: the broad "Environment" of national innovation policy may be channeling resources into sectors or initiatives that do not yield widespread productivity gains, while firms ("Organization") may lack the absorptive capacity to convert these policy-driven inputs into commercial outcomes. This indicates that composite measures of innovation input can be misleading if they mask inefficiencies in the ecosystem.

Mirroring the regional trend, FDI inflows confirm their status as a fundamental and robust driver, showing a strong positive association with productivity across both model specifications. This reaffirms the vital role of global capital in facilitating technology transfer and integration into international value chains.

Finally, the analysis suggests that ICT access has reached a point of saturation, with variables like internet and mobile penetration showing no significant dynamic effects. This is consistent with the later stages of the Diffusion of Innovations curve, where mere access yields diminishing returns and the focus must shift to the depth and sophistication of technology use.

In summary, for the ASEAN-6, sustainable productivity growth is not driven by more connectivity or generalized innovation spending, but by a focused ecosystem that effectively translates R&D into concrete outputs like patents, efficiently absorbs foreign technology and investment, and ensures that national innovation strategies are aligned with firm-level capabilities and market realities.

Table 12. Fixed Effects and System GMM regression results (ASEAN-6)

Variable	Fixed Effects Coef.	Robust SE	t-Statistic	p-Value	System GMM Coef.	Robust SE	z-Statistic	p-Value
Internet use (%)	0.130	0.077	1.68	0.153	0.023	0.017	1.34	0.181
Mobile subscriptions	−0.078	0.033	−2.36	0.065**	−0.008	0.009	−0.89	0.376
R&D (% of GDP)	0.855	1.156	0.74	0.493	0.367	0.156	2.35	0.019**
Patent applications	0.046	0.003	14.42	0.000***	0.006	0.002	2.72	0.006 **
Innovation Index	−0.222	0.202	−1.10	0.323	−0.096	0.043	−2.25	0.025 **
Average years of schooling	1.453	0.581	2.50	0.054**	0.204	0.222	0.92	0.359
FDI inflows (% of GDP)	1.147	0.128	8.94	0.000***	0.349	0.084	4.18	0.000 ***
Electricity access (%)	−0.450	0.142	−3.17	0.025**	0.071	0.067	1.06	0.289
Road density (km per 1000)	2.257	1.937	1.17	0.297	0.533	0.494	1.08	0.280
Lagged GDP per worker	–	–	–	–	0.931	0.031	29.75	0.000 ***

Model statistics:

- *Fixed Effects: R^2 (within) = 0.966; N = 144; 6 countries; robust standard errors clustered by country.*
- *System GMM: one-step estimator; N = 138; instruments = 32.*

*Significance codes: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$.*

- **ASEAN-10 vs ASEAN-6**

The empirical results offer a nuanced picture of productivity drivers, revealing distinct patterns between the less developed ASEAN-10 and the more advanced ASEAN-6, with important theoretical implications.

The impact of ICT adoption is strongly contingent on the level of development. For ASEAN-10, the static model shows a significant positive effect of internet adoption, aligning with the Diffusion of Innovations Theory. This underscores the transformative power of basic digital connectivity in catching-up economies, where it bridges critical information gaps. However, this effect dissipates in the dynamic model, suggesting that without sustained investment in complementary digital skills and business process upgrades - a key concern of the TOE Framework - the initial productivity surge may not be sustainable.

In contrast, for ASEAN-6, both internet and mobile penetration show insignificant or even marginally negative effects, signaling a classic case of diminishing returns. In these digitally saturated economies, mere access is no longer a differentiator; productivity gains now depend on the sophistication of technology use rather than its availability.

A clear dichotomy between innovation inputs and outputs also emerges. Patent applications, a tangible output, consistently boost productivity in both groups, providing robust support for the Knowledge Spillover Theory. However, the dynamic models reveal a critical lag, particularly in ASEAN-10, where the benefits of patenting are not instantaneous due to commercialization delays.

The behavior of innovation inputs is more complex. R&D expenditure only reveals its significant, positive impact in the long-run dynamic model for ASEAN-6, a finding that perfectly encapsulates the lagged returns emphasized by Endogenous Growth Theory. Conversely, the Innovation Index exhibits a counterintuitive negative dynamic relationship in ASEAN-6. This can be interpreted through the TOE Framework as a symptom of misalignment: the "Environment" (national policy) may be prioritizing capital-intensive sectors with limited short-term employment benefits, while the "Organization" (firms) may lack the absorptive capacity to convert broad innovation inputs into commercial outcomes.

FDI inflows stand out as the most robust and consistent driver across all models and country groups. This reaffirms its pivotal role in facilitating technology transfer and integrating economies into global value chains, acting as a powerful engine for productivity growth irrespective of a country's development stage.

In contrast, the foundational factors of human capital (proxied by years of schooling) and physical infrastructure (road density) show persistently weak or insignificant effects. This reinforces the argument that the quantity of schooling or roads is insufficient; the quality, relevance to the labor market, and operational efficiency of these assets are what ultimately matter for productivity, a point well-established in the literature (Hanushek & Woessmann, 2008; Calderón & Servén, 2010).

In summary, the drivers of productivity are fundamentally different across the ASEAN development spectrum. ASEAN-10 benefits most from catch-up growth fueled by basic digital inclusion and foreign investment. For these economies, policy should focus on extending digital and physical infrastructure while building the absorptive capacity to leverage FDI and eventually commercialize innovation.

Conversely, ASEAN-6 has entered a stage where growth is driven by frontier expansion. Here, the priority shifts from basic access to enhancing the productivity of advanced inputs. Sustainable growth hinges on a focused ecosystem that effectively commercializes R&D into patents, ensures national innovation strategy is aligned with economic realities, and prioritizes the quality of human capital and infrastructure over mere expansion.

Conclusion and Suggestions

This study has empirically analyzed the drivers of labor productivity across ASEAN-10 and ASEAN-6 from 2000–2023, employing robust panel data techniques to account for endogeneity and dynamic persistence. The core finding is that the effectiveness of standard productivity levers—ICT, innovation, human capital, and infrastructure—is highly contingent on a country's level of development and institutional maturity. While foreign direct investment (FDI) stands out as a universally potent driver, and patentable innovations consistently show positive effects, the impacts of digital access, R&D spending, and foundational investments vary dramatically between the more and less advanced ASEAN economies.

Based on these nuanced findings, we propose the following targeted policy suggestions:

For ASEAN-10 Economies (Cambodia, Laos, Myanmar, Vietnam):

Digital and Technological Catch-up: Policy should prioritize technology adoption and diffusion rather than frontier R&D. This includes expanding affordable internet access and promoting digital literacy and e-commerce platforms to maximize the productivity benefits of basic connectivity.

Innovation System Foundations: Focus on strengthening intellectual property rights and legal systems to encourage patentable, incremental innovations and adaptations that are immediately relevant to local industries.

Strategic FDI Leverage: Actively attract FDI in sectors with high technology transfer potential and implement programs to foster backward linkages between foreign firms and local small and medium-sized enterprises (SMEs) to enhance knowledge spillovers.

For ASEAN-6 Economies (Indonesia, Malaysia, Philippines, Singapore, Thailand, Brunei):

Advanced Innovation Focus: Move beyond general R&D spending to prioritize mission-oriented R&D in high-potential sectors (e.g., digital economy, advanced manufacturing, green technology). Crucially, policy must improve the ecosystem for commercializing university and corporate research to bridge the gap between patent creation and market application.

FDI Quality and Depth: Design targeted policies to attract FDI in knowledge-intensive services and high-tech manufacturing. The goal should be to move up the global value chain, requiring a parallel focus on developing a domestic workforce and supplier base capable of engaging in complex, high-value activities.

Quality over Quantity: Shift the policy focus from expanding educational enrollment and infrastructure stock to enhancing their quality. This means aligning higher education curricula with the skills demanded by a modern, innovation-driven economy and investing in the reliability, efficiency, and strategic connectivity of infrastructure networks.

Limitations and Avenues for Future Research

This study, while comprehensive, is subject to several limitations inherent in macro-level analysis. The reliance on country-level data may obscure significant sectoral or firm-level heterogeneities. Furthermore, the proxy for human capital (average years of schooling) does not capture crucial variations in education quality, and our model may not fully account for all dimensions of institutional quality. Future research would benefit greatly from utilizing firm-level panel data to uncover micro-foundations of these productivity relationships. Additionally, incorporating direct measures of institutional quality, such as the World Governance Indicators, or education quality, such as standardized test scores, could more precisely quantify the role of these fundamental but hard-to-measure factors in conditioning productivity outcomes. In conclusion, a one-size-fits-all policy approach is ill-suited for the diverse ASEAN region. Sustaining productivity growth requires a differentiated strategy that recognizes the distinct developmental stages of its member states, focusing on foundational catch-up for the less advanced and quality-intensive frontier innovation for the more developed economies.

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