Bridging the Gap Living Standards in Africa: The role of entrepreneurship and digital infrastructure

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Abstract

Most African countries face numerous socio-economic challenges, including poverty, high unemployment rates, lack of access to healthcare services, and limited access to quality education. While research, particularly from advanced economies, suggests that entrepreneurship is essential for improving living standards, its impact in low-income countries remains unclear. This paper addresses this concern by analysing the interconnected effects of entrepreneurship and digital infrastructure on living standards in Africa. Using panel data from 22 lower-middle-income African economies between 1990 and 2023, the study employs the Lewbel instrumental variable (IV) estimation approach to address potential selection bias and endogeneity issues arising from reverse causality. The empirical results reveal that the impact of entrepreneurship on enhancing living standards depends on the availability of digital infrastructure. This study offers implications for governments and policymakers in developing countries, guiding them on how to improve the effectiveness of entrepreneurship on living standards.

Keywords: Entrepreneurship · Digital infrastructure · Africa · Living standards · Developing countries

JEL Classification H54 · L26 · O43· O55 · B23

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1. Introduction

Does entrepreneurship improve the standard of living? Studies have revealed inconclusive evidence in answering this question (Ghazy, Ghoneim & Lang, 2022; Neumann, 2021; Bruton, Sutter & Lenz, 2021; Wang, 2020). On the one hand, a significant body of empirical studies establishes a positive relationship between entrepreneurship and economic and social well-being at national and regional levels (e.g., Valliere & Peterson, 2009; Baumol, 2014; Wong, Ho & Autio, 2005). These findings are supported by the endogenous growth theory, which argues that factors including entrepreneurship, investments in infrastructure and technological innovation are crucial for raising standards of living (Koirala & Pradhan, 2020; Ebner, 2006; Schumpeter, 1934). On the other hand, studies show that entrepreneurship does not necessarily promote living standards (Ajide, 2022; Dhahri & Omri, 2018; Henrekson, 2005). For example, scholars suggest that entrepreneurship increases economic inequality, especially when its benefits are concentrated in the formal sector (Lewellyn, 2018). Others find that entrepreneurship negatively affects life satisfaction and psychological well-being (Ryff, 2019; Bhuiyan & Ivlevs, 2017). Additionally, from an ecological perspective, Dhahri and Omri (2018) reveal that entrepreneurial activities contribute to environmental degradation, which is more severe in low-income countries compared to high-income countries.

Entrepreneurial activities in developing regions are rapidly increasing. For example, Africa has the highest rates of entrepreneurship in the world (African Youth Survey, 2022). The World Bank data further highlight this trend, revealing a significant increase in the number of new enterprises registered between 2013 and 2020: Benin (906 to 4,034), Eswatini (1,946 to 2961), Nigeria (74,391 to 97 988), Senegal (2,116 to 4,284) and Zimbabwe (9,782 to 20,273). Despite its contributions, there is little evidence on whether the rise in entrepreneurship in Africa improves (or lowers) living standards (Peprah & Adekoya, 2020). Investigating this relationship is pertinent due to the numerous and persistent socio-economic challenges facing Africa, including infrastructural deficits, unemployment, inequality, poverty, low life expectancy, inefficient healthcare systems, limited access to quality education, political instability and low environmental quality. Thus, it helps us understand the role of entrepreneurship in promoting the United Nations' Sustainable Goals. To this end, this study fills this research gap by investigating (1) the impact of entrepreneurship on standards of living in Africa and (2) whether this impact depends on digital infrastructure.

Emerging technologies are becoming more widespread and transforming global economies. In this context, scholars are increasingly investigating how advances in digital technologies influence entrepreneurship (Edeh, 2022; Song, 2019). Digital technologies create many entrepreneurial opportunities, stimulate innovations, and foster superior firm performance (Gaspar, Wang & Xu, 2024; Adeola et al., 2022). Zahra, Liu and Si (2022) suggest that digitalisation encourages new business creation and processes that support the entrepreneurial ecosystem. Similarly, in a panel study of 34 countries, Dabbous, Barakat, and Kraus (2023) find that digitalisation contributes to entrepreneurial activities and sustainable competitiveness. More so, Galindo-Martín et al. (2023) show that digitalisation and investing in talents who can leverage digital technologies are crucial drivers of entrepreneurship. Despite the contributions of these studies, our understanding of *whether* and *how* digital infrastructure influences the impact of entrepreneurship on standards of living, particularly in developing regions such as Africa, is fragmented and underexplored in the literature.

Infrastructure is one of the most important aspects of country-level institutions (Esfahani & Ramírez, 2003). Within this context, digital infrastructure has been identified as a key driver of entrepreneurship and economic activities. However, evidence shows that variations exist across regions and countries both in the quality of digital infrastructure and the level of digital adoption across regions and countries. This paper argues that the effectiveness of entrepreneurship in improving living standards depends on the availability and quality of a country's digital infrastructure (Bennett, 2019). For instance, entrepreneurial firms operating in a country with a well-developed digital infrastructure can better leverage digitalisation and contribute to improving the standard of living. Conversely, digital infrastructure deficits adversely affect digitalisation, thereby hampering the effectiveness of entrepreneurship in enhancing standards of living (Luo et al., 2022; Hasbi, 2020).

This study contributes to existing literature in the following ways. First, while a substantial body of studies has examined the role of entrepreneurship in economic growth, social well-being and environmental quality (e.g., Ordeñana et al. 2024; Gu & Zheng, 2021), the impact of digital infrastructure as an enabling factor has not received explicit consideration (Osinubi, Ajide, & Simatele, 2025). Digital infrastructure provides resources which entrepreneurs can leverage in driving innovations and exploiting market opportunities. These factors, in turn, not only lead to entrepreneurial success but also contribute to improved living standards by creating employment and innovations that address societal challenges in developing nations. In this regard, this study contributes to knowledge by introducing a moderation perspective to explain how digital infrastructure drives the effectiveness of entrepreneurship in improving living standards.

Second, the empirical contribution lies in analysing the theoretical framework proposed in this study using panel data of 23 lower-middle-income economies in Africa, covering the period between 1991 and 2023. Focusing on these countries provides a unique context for the following reasons. To begin with, many African countries are investing in digital infrastructure and implementing policies targeting improving entrepreneurial activities and trade. Notwithstanding these efforts, there are still considerable digital gaps in terms of access and digital quality, with most of the rural communities lacking adequate digital infrastructure**.** Thus, this study contributes to knowledge by providing new empirical insights into how developing countries can leverage digitalisation to improve living standards.

Lastly, while entrepreneurial firms play significant socio-economic roles in these economies, they are severely constrained by factors including institutional voids, corruption, and lack of access to resources (Edeh et al., 2024). This study contributes to enhancing our understanding of how entrepreneurship fosters sustainable development despite the high degree of institutional challenges that characterise most African countries. The results of empirical analysis have policy implications suggesting that policies targeting infrastructural improvement can improve the effectiveness of entrepreneurship in enhancing living standards in Africa.

The remainder of this paper is organised as follows. Section 2 presents the literature review. Section 3 provides the data and estimation methodology used in this study. Section 4 discusses the empirical results. Section 5 contains the conclusions and policy implications.

2. Literature review

2.1. Entrepreneurship and living standards

Entrepreneurship has attracted substantial attention from scholars and policymakers because of its contributions to national and regional economies (Gu & Wang, 2022; Doran, McCarthy & O'Connor, 2016; Galindo & Méndez, 2014). The concept of entrepreneurship has evolved, with definitions ranging from Cantillon's 'Undertaker' and Jean-Baptiste Say's 'Resource Organiser' to Knight's 'Manager of Production'. For Schumpeter (1942, p. 132), the "function of entrepreneurs is to revolutionise the pattern of production by exploiting an invention or, more generally, an untried technological possibility for producing a new commodity or producing an old one in a new way, by opening up a new source of supply of materials or a new outlet for products, by reorganising an industry and so on". At the core of Schumpeter's view is the role of young and entrepreneurial businesses in driving innovation through creative destruction (Pellegrino, Piva & Vivarelli, 2012). In essence, the main catalyst for socioeconomic progress is the demand for innovative products and services, primarily driven by entrepreneurial firms seeking to enhance their profits by replacing obsolete technologies with newer ones (Batabyal & Yoo, 2018; Acemoglu, 2009).

This study adopts Dau and Cuervo-Cazurra's (2014, p. 670) notion of formal entrepreneurship: "the creation of new businesses that are legally registered in a given country", which reflects the "activities of individuals aiming to generate new economic value in a formal sector under a legal form of business" (Klapper et al., 2007). Entrepreneurship drives knowledge diffusion, generates employment opportunities, and improves national competitiveness and socio-economic development (Fotopoulos, 2012; Audretsch &Thurik, 2003). In this context, entrepreneurship contributes to addressing broader societal challenges, such as providing innovative solutions to food security, education, healthcare, and environmentally friendly products etc.

Furthermore, the concept of standard of living refers to the state and extent of tangible and intangible goods available to individuals or groups of individuals such as families, communities and societies (Njiru& Letema, 2017; Dajana Cvrlje & Tomislav Ćorić, 2010). It captures the conditions that enable people to satisfy their economic (e.g., jobs, income), social (e.g., good education, healthcare) and environmental (e.g., water, clean air) needs. The concept of standard of living is gaining renewed interest due to its close connection with the UN-SDGS. This may explain the increase in the number of studies investigating the relationship between entrepreneurship and various indicators of living standards (Shepherd, Parida & Wincent, 2020; Sutter, Bruton & Chen, 2019; Dhahri & Omri, 2018; Baptista, Escaria & Madruga, 2008). For example, Naminse, Zhuang, and Zhu (2019) find that entrepreneurship reduces poverty in rural Chinese areas. Similarly, Dzingirai (2021) shows that entrepreneurship has a significant impact on poverty reduction in agricultural communities of Lower Gweru, Zimbabwe, through food security, job creation, income generation and skill transfers. Additionally, Mohamad, Masron and Ibrahim (2021) suggest that entrepreneurship contributes to addressing income inequality in developing countries. In a study of the Danish private sector, Malchow-Møller, Schjerning and Sørensen (2011) find that entrepreneurship has a positive impact on employment creation, albeit low-wage jobs. Moreover, in a panel study of

35 Sub-Saharan African countries, Sun et al. (2020) suggest that entrepreneurship decreases environmental pollution.

Nevertheless, the linkage between entrepreneurship and living standards is complex, as indicated by studies suggesting negative and nonlinear effects (Iqbal et al., 2020). For instance, based on US state-level data covering the period between 1989 and 2013, Atems and Shand (2018) find that entrepreneurship increases income inequality. Stel, Carree, and Thurik (2005) show that entrepreneurial activities negatively affect the economic growth of developing nations. Castellanza (2022) reveals that while entrepreneurship reduces abject poverty, it hinders individuals from achieving economic prosperity and emancipation from discriminatory norms. Other studies suggest that entrepreneurship has a nonlinear relationship with living standards. Acs, Audretsch and Evans (1994) find a U-shaped relationship between entrepreneurship and economic growth in 12 OECD countries. Ragoubi and El Harbi (2017) find an inverted U-shaped relationship between entrepreneurship and income inequality. In other words, these mixed findings emphasise the need for more research to further uncover the relationship between entrepreneurship and living standards, especially in developing regions. Therefore, these inconclusive findings lead to the following question:

RQ 1: Does entrepreneurship positively influence living standards in lower-middle-income African countries?

2.2. Entrepreneurship and living standards: The role of digital infrastructure

Digital technologies are increasingly shaping social and economic realities. Scholars identified digital technologies as 'general-purpose technologies' because of their ability to self-transform, branch out and enhance productivity across all sectors and industries (David &Wright, 2006). These technologies create new opportunities and knowledge, and they have crucial implications for entrepreneurship (Ratten, 2022). Digitalisation is vital for effective entrepreneurship (Zahra, Liu & Si, 2018). For example, entrepreneurial ventures can utilise digital technologies to create efficient processes and outcomes (Van Veldhoven & Vanthienen, 2021). Due to the opportunities it offers, digitalisation is rapidly becoming a strategic imperative for any entrepreneurial venture pursuing competitiveness and economic growth in today's global marketplace (Kim & Jin, 2024; Denicolai, Zucchella & Magnani, 2021; Strange & Zucchella, 2017). However, this trend has profound implications for lower-middle-income economies, especially those in Africa, given that the ability to leverage digital technologies for entrepreneurial activities is influenced mainly by the availability and quality of a country's digital infrastructure (Bharadwaj et al., 2013).

Prior studies suggest that improving the quality of digital infrastructure enables the digitalisation of entrepreneurial activities, leading to economic growth (Hasbi, 2020). Audretsch, Heger and Veith (2015) find that broadband infrastructure contributes more to enhancing entrepreneurial activities than transportation infrastructure. In a study of 58 countries, Alderete (2017) reveals that digital infrastructure positively affects entrepreneurship. Li et al. (2024) suggest that the construction of digital infrastructure contributes to entrepreneurship by improving

imitation effects and optimistic expectations and enabling flexible work arrangements. Due to its role in stimulating entrepreneurship and growth, it is not surprising that many governments in Africa are investing in digital infrastructure. For instance, through the Digital Economy for Africa
(DE4A) initiative, the African Union's Digital Transformation Strategy is committed to providing digital access to all African individuals, businesses and governments by 2030.

Despite these efforts, there is little understanding of how digital infrastructure moderates the relationship between entrepreneurship and living standards in developing nations. As a result, this paper argues that adequate digital infrastructure is pivotal to enhancing the effectiveness of entrepreneurship in promoting living standards in lower-middle-income African countries. For instance, the availability of digital infrastructure allows entrepreneurial firms to leverage digital platforms and tools to implement innovations and market opportunity exploitations (Zahra, Liu & Si, 2022; Zahra & Nambisan, 2012). These factors can, in turn, lead to more job creation and promotion of socio-economic empowerment in communities. Therefore, to understand the influence of digital infrastructure, this study addresses the following question:

RQ 2: How does digital infrastructure shape the relationship between entrepreneurship and living standards in lower-middle-income African countries?

3. Data

The data used for the empirical analysis were obtained from two sources. First, the United Nations Development Programme provides data for the Human Development Index (HDI). Second, the World Development Indicators (WDI) published by the World Bank provide information for entrepreneurship and control variables. The sample contains 22 lower-middle-income African countries: Angola, Benin, Cabo Verde, Cameroon, Comoros, Congo, Rep., Cote d'Ivoire, Djibouti, Egypt, Eswatini, Ghana, Guinea, Kenya, Lesotho, Mauritania, Morocco, Nigeria, Sao Tome and Principe, Senegal, Tunisia, Zambia and Zimbabwe. It covers the period between 1990 and 2023. Lastly, these data sources have been widely used by prior studies (e.g., Ghouse, Bhatti & Nasrullah, 2025; Edeh, Chowdhury, & Edeh, 2024).

3.1. Variable description

The dependent variable for this study is *living standards*. Following prior studies (Zhao & Wu, 2024; Dey, Ray & Majumder, 2024; Sušnik & van der Zaag, 2017), this study uses the Human Development Index (HDI), which measures three development dimensions: (1) quality of life; (2) education levels; and (3) standard of living. Compared to GDP, research suggests that HDI provides a better understanding of "human progress and the relationship between income and well-being" (Sagar & Najam, 1998).

The independent variable is *Entrepreneurship.* Following other studies, it was measured by the number of new enterprises registered in the calendar year per 1000 people aged 15 – 64 (Ghazy, Ghoneim & Lang, 2022; Omri, 2019). This variable allows us to capture the role of private and formal entrepreneurial businesses in living standards in lower-middle-income African countries.

Digital Infrastructure is the moderating variable. Broadband connectivity is crucial for high-speed internet access, which is, in turn, essential for a variety of digital services such as e-commerce (Huang et al., 2023). A high number of fixed broadband subscriptions shows that developed and widespread internet infrastructure, which is needed for digital transformation. Likewise, a high number of mobile cellular subscriptions indicates that a broader segment of a country's population has access to digital services. In many developing countries, mobile network access is the main gateway for digitalisation. It provides access to mobile internet, which enables businesses to adopt digital activities such as e-commerce, social media customer engagements and digital payments (Edeh, 2022; Adeola et al., 2022). In line with prior empirical studies (e.g., Ndubuisi, Otioma, &Tetteh, 2021), digital infrastructure was measured using two variables: Fixed broadband subscriptions and Mobile cellular subscriptions (per 100 people).

Additionally, several control variables are included in the model. First, *Lending interest rate* influences entrepreneurial firms' access to financial resources and their productivity, especially businesses in the private sector (Beltrame et al., 2023; Kgoroeadira, Burke & van Stel, 2023). Its effect is controlled using the percentage of the lending interest rate. Second, technological development is linked to a country's living standards. This study controls for this effect using *High-tech Export*, measured as the Information and Communication Technology (ICT) goods exports (% of total goods exports). Third, prior studies suggest that urbanisation is related to socio-economic development (Sare, Amoah, & Bawuah, 2025; Henderson, 2003). *Urbanisation* is controlled using the urban population (% of the total population). Fourth, *Natural resource rents* are critical factors in developing countries that are overdependent on natural resources. Research suggests that natural resource rents can significantly affect infrastructural development, education, healthcare, and social services, and these factors are essential for improving a country's living standards (Imran et al., 2024). Its effect is controlled using total natural resources rents (% of GDP). Finally, in developing countries, the residents in rural areas usually lack access to essential services such as quality education, clean drinking water, healthcare services, electricity, etc. The effect of *rural residents* is controlled using the rural population (% of total population). Table 1 provides the definitions of the variables used in this study.

Table 1: Variable definitions

Variable	Measurement
Living Standards (LSD)	HDI captures three human development dimensions: quality of life, education, and standard of living.
Entrepreneurship (ENT)	New registrations of businesses per 1,000 people aged 15-64
Digital Infrastructure	
Fixed Broadband (FBD)	Fixed broadband subscriptions
Mobile Cellular (MCR)	Mobile cellular subscriptions (per 100 people)

Control Variables	
Lending interest (LIT)	Lending interest rate (%)
High-tech Export (HTE)	ICT goods exports (% of total goods exports)
Urbanisation (UBN)	Urban population (% of the total population)
Natural resource (NRE)	Total natural resources rents (% of GDP)
Rural residents (RRT)	Rural population (% of total population).

3.2. Model Specification

This study investigates entrepreneurship's effect on living standards and how digital infrastructure moderates the relationship. The empirical analysis is conducted at the country level. Thus, living standards *(LS)* is specified as the function of entrepreneurship *(ENTR),* Digital infrastructure *(DIGIs)* and a set of control variables *(X)*. Equation (1) is stated as follows:

$$LS = f\,(\mathrm{ENTR, DIGIs, X}) \tag{1}$$

To analyse the direct impact of entrepreneurship on living standards, Equation (1) is transformed into a linear equation by taking the natural logarithm on both sides of the equation. Thus, Equation (2) is stated as follows:

$$\mathrm{InLS_{it}} = \alpha_0 + \beta_1 \mathrm{lnENTR_{it}} + \emptyset_1 \mathrm{X_{it}} + \varepsilon_{\mathrm{it}} \tag{2}$$

Furthermore, to examine the moderating role of digital infrastructure on the relationship between entrepreneurship and living standards, Equation (2) is augmented to include the interaction term of digital infrastructure variables and entrepreneurship (DIGIs × ENTR). Therefore, Equation (3) is specified as follows:

$$\mathrm{InLS_{it}} = \alpha_0 + \beta_1 \mathrm{lnENTR_{it}} + \beta_2 \mathrm{lnDIGIs_{it}} + \beta_3 (\mathrm{lnDIGIs \times lnENTR})_{\mathrm{it}} + \emptyset_{\mathrm{f}} \mathrm{X_{it}} + \varepsilon_{\mathrm{it}} \tag{3}$$

Where i = 1…., 22; t = 1990 – 2023; α_0 is a constant parameter; $\emptyset_f$ is the coefficient of the control variables, and ε_{it} represents the stochastic error term.

3.3. Model Estimation Strategy

Even though conventional estimation techniques such as Ordinary Least Squares (OLS) or fixed- and random-effect methods are useful, they may produce biased and inefficient outcomes. To overcome these limitations, research suggests using the Instrumental Variable (IV) approach for reliable results (Leszczensky & Wolbring, 2022). The IV approach addresses potential selection bias and endogeneity issues arising from reverse causality between the dependent and explanatory variables (Arellano & Bond, 1991). However, due to challenges of identifying instruments that satisfy the following conditions: (1) Instrument relevance ($\mathrm{Corr}\,(\mathrm{Z_i, X_i}) \neq 0$), (2) Instrument exogeneity ($\mathrm{Corr}\,(\mathrm{Z_i, u_i}) = 0$) (Baum et al., 2012; Stock, Wright and Yogo, 2002), this study uses the Lewbel two-stage least squares (2SLS) approach. It uses heteroscedasticity in the errors of mismeasured regressors or endogenous independent variables to construct instruments for those variables. The Lewbel's (2SLS) approach is widely used because it guarantees robust estimation outcomes (Omar & Hasanujzaman, 2023; Naveed & Wang, 2022; Li, Wang, & Zhou, 2020).

4. Empirical results

Table 2 presents the descriptive statistics. The mean value for living standards is 0.5, indicating that, on average, the countries in the sample have low living standards. The mean value for entrepreneurship is 8.25. Additionally, for the digital infrastructure variables, the mean values of fixed broadband and mobile cellular are 9.85 and 2.22.

Table 2. Descriptive statistics

Variables	Mean	SD	Min	Max
LSD	0.510	0.096	0.270	0.740
ENT	8.249	1.873	3.610	11.827
FBD	9.846	2.838	0	16.425
MCR	2.229	2.983	-7.425	5.159
LIT	2.729	0.628	1.555	5.383
HTE	16.457	2.953	2.484	21.267
UBN	1.096	0.547	-3.967	2.348
NRR	1.737	1.128	-1.636	4.089
RRT	3.979	0.316	3.065	4.454

Table 3 presents the correlation coefficient matrix of the variables. The table shows that all variables' correlation coefficients are below 0.8, indicating no multicollinearity problems (Mason & Perreault, 1991). Additionally, this study conducted the variance inflation factors (VIF), and the values are between 1.26 and 2.54, less than the threshold of 3.3 proposed by Kock (2015), therefore, there is no problem with multicollinearity (Hair *et al.*, 2006).

Table 3. Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(1) LSD	1.000								
(2) ENT	0.122	1.000							
(3) FBD	0.578	0.664	1.000						
(4) MCR	0.510	0.286	0.633	1.000					
(5) LIT	-0.294	0.233	-0.135	-0.528	1.000				
(6) HTE	0.255	0.521	0.659	0.122	-0.011	1.000			
(7) UBN	-0.239	0.001	-0.118	-0.122	0.187	0.033	1.000		
(8) NRE	0.077	-0.154	0.025	-0.028	0.400	0.011	0.270	1.000	
(9) RRT	-0.343	0.008	-0.079	-0.190	-0.005	-0.054	0.099	0.133	1.000
VIF		2.13	2.30	1.85	1.26	2.54	1.42	1.54	1.36

4.1. Results of Lewbel's 2SLS Regression and Discussions

Table 4 presents the results from the Lewbel 2SLS regression. Model 1 contains the dependent variable, living standards, with the control variables. The results show that high-tech export has a positive impact on living standards. The results suggest that the spillovers of technological efforts in these countries contribute to public services, such as in the areas of healthcare, education, and infrastructure (Mao et al., 2020). In other words, it shows that more diversification efforts in high-tech exports will reduce commodity overdependence, prevalent in most African countries, and in turn, enhance economic resilience and living standards (Al-Marhubi, 2000).

However, lending interest rates have a negative and significant impact on living standards. These results highlight the link between increasing lending interest rates and high costs of borrowing costs, which can slow entrepreneurial and economic activities, thereby leading to an adverse effect on living standards. Additionally, natural resource rents negatively affect living standards, and these results align with prior research suggesting the resource-curse hypothesis (Pilag Kakeu et al. 2023). Unlike studies, especially from high-income countries (Liddle & Messinis, 2014), the results of this study show that urban population decreases living standards in lower-middle-income African countries. These findings suggest that rapid urbanisation happening across many cities in Africa poses considerable socio-economic challenges such as overcrowding, environmental problems and pressures on public services (Henderson, 2003).

Table 4

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
LIT	-0.094***	-0.057**	-0.107***	-0.049*	-0.108***	-0.071**
	(0.018)	(0.016)	(0.012)	(0.017)	(0.013)	(0.012)
HTE	0.005***	0.007***	0.002**	0.001***	0.004***	0.007*
	(0.001)	(0.002)	(0.001)	(0.003)	(0.002)	(0.002)
UBN	-0.086***	-0.077*	-.070***	-0.053**	-.0683***	-0.053***
	(0.011)	(0.009)	(0.009)	(0.009)	(0.011)	(0.012)
NRE	-0.010***	0.004**	-0.015**	-0.015***	-0.005**	-0.023**
	(0.006)	(0.008)	(0.005)	(0.008)	(0.006)	(0.006)
RRT	-0.057*	-0.068	-0.049	-0.039	-0.041	-0.027
	(0.013)	(0.014)	(0.011)	(0.009)	(0.013)	(0.015)
ENT		-0.019**		-0.058***		-0.106**
		(0.003)		(0.018)		(0.042)
FBD			0.011***	0.014***		
			(0.002)	(0.016)		
ENT*FBD				0.141**		
				(0.002)		
MCR					0.081***	0.062***
					(0.015)	(0.088)
ENT*MCR						0.210**
						(0.009)
Con	0.586***	0.7545***	0.485***	0.915***	0.091	0.822**
	(0.061)	(0.0594)	(0.055)	(0.174)	(0.101)	(0.404)
R^2	0.320	0.4727	0.438	0.726	0.362	0.596

4.2. The Role of Technological Innovations in Energy Efficiency in Emerging Economies

In hypothesis 1, we posit that R&D investments by firms, governments, research institutions, and non-profit organisations contribute to energy efficiency by reducing per capita GHG emissions intensity. This hypothesis is supported as the coefficient is positive and statistically significant (-0.0672, $p<0.007$) as shown in Model 2. These findings indicate that a 1% increase in R&D investments leads to reductions in per capita GHG emissions intensity by -6.72%. These results are in line with the endogenous growth theory, which argues that innovations are the main determinants of productivity and sustainability (Romer, 1990). Similarly, Solarin, Bello and Tiwari (2022) find that technological innovations contribute to renewable energy production in BRICS countries.

Table 3. System-GMM Results

Variables	Model 1	Model 2	Model 3	Model 4
Lagged Energy Efficiency	0.872***	0.878***	0.912***	0.874***
	(0.0113)	(0.0115)	(0.0168)	(0.0130)
FDI (log)	0.0240	0.00254	0.0377*	-0.0127
	(0.0303)	(0.0313)	(0.0225)	(0.0506)
Population(log)	0.1041	0.104	0.149	-0.249
	(0.0891)	(0.0891)	(0.105)	(0.157)
Trade openness (log)	-0.0778	-0.103	-0.158**	-0.0743
	(0.0965)	(0.0970)	(0.0720)	(0.116)
Human capital (log)	-0.5204***	-0.550***	-0.137	-0.336**
	(0.124)	(0.124)	(0.171)	(0.162)
TFP (log)	-0.4361***	-0.339***	-0.489**	-0.696***
	(0.0899)	(0.0968)	(0.210)	(0.155)
R&D (log)		-0.0672**		
		(0.00248)		
Resident patents (log)			0.0142**	
			(0.00595)	
Non-resident patents (log)				-0.0299***
				(0.0122)
Constant	0.0623	0.155*	0.0350	0.224
	(0.0819)	(0.0888)	(0.155)	(0.181)
AR (1)	0.262	0.180	0.178	0.133
AR (2)	0.144	0.123	0.187	0.126
Sargan test p-value	0.162	0.230	0.120	0.222
Number of Countries	5	5	5	5

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

In a study of G10 countries, Khan and Su (2023) find that technology innovation has a significant impact on renewable energy in Germany, the Netherlands, Sweden, the UK, and the USA due to their strong knowledge base and R&D investments. In other words, our study shows that the combined R&D efforts of business enterprises, government, research institutions and private non-profit organisations in the innovation systems are critical to the production, diffusion and applications of energy-efficient technologies such as smart grids, and cleaner production processes. For instance, knowledge generated through the interactions between research institutions and private sector businesses can foster technological advancements in the areas of clean energy solutions and energy management systems.

More so, in hypothesis 2a, we posit that patents filed by residents contribute to energy efficiency by reducing per capita GHG emissions intensity. The results reveal a positive and significant coefficient **(**0.0142, $p < 0.017$) as shown in Model 3. These findings indicate that a 1% increase in resident patents leads to an increase in per capita GHG emissions intensity by 1.42%. In other words, patents filed by residents do not contribute to energy efficiency in emerging economies. Unlike in advanced economies, many of the patents filed by residents of emerging economies tend to lack real-world implementation due to commercialisation challenges and inefficient technology transfer mechanisms. Another possible explanation for these findings may be a result of misalignment between patenting activities and efficient energy implementations in emerging economies. In contrast, non-resident patents are negatively related to per capita GHG emissions intensity (-0.0299, $p < 0.000$) as shown in Model 4. These findings indicate that a 1% increase in non-resident patents leads to a decrease in per capita GHG emissions intensity by -2.99%. These findings highlight the role of international knowledge spillover and technology transfer in enhancing energy efficiency in emerging economies. These findings are consistent with prior studies emphasising the relevance of technology diffusions and implementations in emerging economies (Friebe et al., 2014).

4.3. Robustness Check

To check the robustness of the results contained in Table 3, we re-estimated the models using a different dependent variable, namely, Energy use (kg of oil equivalent per capita). The results are presented in Table 4. Model 2 shows that R&D investments of business enterprises, government, research institutions and private non-profit organisations have a negative and significant impact on energy use. These findings suggest that a 1% increase in R&D investments reduces primary energy use, thereby increasing energy efficiency in emerging economies. In other words, a 1% increase in R&D expenditures decreases energy use in emerging economies by -7.14%.

The results of Model 3 show that a 1% increase in resident patents increases energy use in emerging economies by 12.91%. On the contrary, the results of Model 4 show that a 1% increase in non-resident patents decreases energy use in emerging economies by -10.8%. In summary, the results in Table 4 are consistent with the main results in Table 3, therefore confirming the robustness of our findings.

5. Policy Implications

The findings of this study have two main policy implications for governments and decision-makers in emerging economies. Energy efficiency is critical to economic development and sustainability. As a result, governments and policymakers in emerging economies should put considerable efforts into fostering technological innovation activities and human development. To achieve these objectives, they should prioritise the following policy recommendations.

First, our study shows that domestic patenting activities are not beneficial for improving energy efficiency in emerging economies. These findings, among other things, suggest that the innovation systems in emerging economies are not efficiently enabling the development, diffusion and implementation of knowledge. To address this challenge, governments and policymakers in these economies should significantly invest in R&D infrastructure to improve the quality, applicability and commercialisation of patented technologies.

Table 4. System-GMM Results with Energy Use (Dependent variable)

Variables	Model 1	Model 2	Model 3	Model 4
Lagged energy use	0.540***	0.311**	1.010***	0.437*
	(0.0869)	(0.157)	(0.0189)	(0.239)
FDI (log)	-0.0461	-0.0286	-0.0297**	-0.0425
	(0.0360)	(0.0336)	(0.0129)	(0.0289)
Population(log)	1.642	4.103**	-0.217***	3.430*
	(1.040)	(1.826)	(0.0567)	(1.988)
Trade openness (log)	0.192*	0.0682	0.311***	0.260
	(0.106)	(0.106)	(0.0703)	(0.217)
Human capital (log)	1.638**	2.531**	-0.421***	1.551*
	(0.679)	(1.278)	(0.151)	(0.902)
TFP (log)	0.683***	0.830***	-0.00411	1.173**
	(0.154)	(0.239)	(0.116)	(0.457)
R&D(log)		-0.0714***		
		(0.0176)		
Resident patents (log)			0.1291***	
			(0.00428)	
Non-resident patents (log)				-0.108**
				(0.0805)
Constant	-2.186	-5.824**	-0.0953*	-3.156
	(1.638)	(2.899)	(0.0541)	(2.969)
AR (1)	0.167	0.941	0.000	0.702
AR (2)	0.700	0.152	0.916	0.951
Sargan test p-value	0.140	0.359	0.064	0.770
Number of Countries	5	5	5	5

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

For instance, they can create more science and technology parks. Besides, they can increase public funding for innovation clusters and clean energy research laboratories in universities.

Furthermore, there are substantial gaps between research institutions and industry in many developing and emerging economies. Governments and policymakers in these countries must foster collaborations between these entities to stimulate the co-creation of knowledge and patented innovations that solve real-world energy and sustainability crises. Likewise, they should promote joint energy-efficient R&D initiatives between domestic firms and international organisations to facilitate technology transfer and knowledge spillovers in the host countries. It is expected that these public efforts will significantly improve energy efficiency in emerging economies.

Second, our study shows that human capital and welfare-relevant TFP contribute to energy efficiency in emerging economies. Governments in these economies should strengthen policies that support productivity. Additionally, they should invest more in human capital development, especially in their growing young population. These efforts are not only critical to reducing the poverty and unemployment rate in these economies, but also to facilitating a transition to economic growth driven by sustainable energy.

5.1. Conclusion

The relationship between technological innovations and sustainability is attracting sustained attention from scholars and policymakers. Emerging economies are experiencing rapid industrialisation and urbanisation, which are placing increasing constraints on energy and natural resources (Edeh et al., 2024). Given its relevance, we examined the role of R&D investments and patent sources in improving energy efficiency using a panel sample of BRICS countries covering the period between 1994 and 2019. Overall, our study establishes that technological innovations are crucial to driving energy efficiency in these countries. Lastly, our study has some limitations, which should be addressed in future research. While focusing on BRICS countries is interesting, they differ from other developing and emerging economies. More empirical studies should focus on other developing nations to validate the findings of this study. Besides, we focused on direct impacts, we call on scholars to explore the mechanisms and boundary conditions underlying the linkage between technological innovation and energy efficiency.

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